THE USE OF NARRATIVES AND CONCEPT CARTOONS IN THE PROFESSIONAL
DEVELOPMENT OF TEACHERS TO ACHIEVE HIGHER – ORDER THINKING SKILLS AND
DEEP LEARNING ABOUT THE EVOLUTION OF LIFE AND GEOLOGICAL TIME

by

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THESIS

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CO–SUPERVISOR: Dr F Durand

NOVEMBER 2011
DECLARATION

I declare that the work contained in this thesis is my own and all the sources I have used or quoted have been indicated and acknowledged by means of references.

I also declare that I have not previously submitted this thesis or any part of it to any university in order to obtain a degree.

Signature: ______________________________________
(Maria van der Mark)

Johannesburg
November 2011
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SYNOPSIS

Evolution of life as a scientific theory was introduced officially into the South African life sciences grade twelve curriculum in 2008. This presented an opportunity to investigate how teachers could incorporate teaching strategies, involving the use of narratives and concept cartoons, into their pedagogical content knowledge to encourage the use of higher-order thinking skills and deep learning about evolution, a new topic in the curriculum. Little research has been done on how narratives and concept cartoons contribute to the development of higher-order thinking skills in teachers and their ability to use these teaching strategies to effect a better conceptualization of evolution.

A mixed methods research design was adopted to establish generalizations about the teachers’ higher-order thinking skills as well as to explore their individual worldviews about evolution as a scientific theory and their perceptions about the controversy between science and religion. The quantitative and main part of the study involved a (quasi)experimental format based on interventions focusing on workshop presentations using either narratives or concept cartoons. A pre-test and post-test format was used to measure the effect of the treatments. A rubric, based on the Piagetian levels of concept development, was designed to transform qualitative responses into quantitative data. The responses to five open-ended questions of a questionnaire were analyzed using the Wilcoxon Signed Rank test and the Mann-Whitney U test. The smaller and supportive phase of the study involved categorizing and then analyzing qualitative data, derived from different artifacts and responses to the questionnaire, in order to establish how the teachers’ worldviews influenced their perceptions of the evolution of life, the nature of science and religion.

An embedded concurrent mixed methods design allowed for the simultaneous generation and collection of quantitative and qualitative data. The findings were integrated and mixed to give a clearer and more global picture not only of the teachers’ ability to use higher-order thinking skills but also to reflect their conceptual ecologies of evolution.

The statistical analyses indicated a significant improvement in the teachers’ abilities to use higher-order thinking skills in answering the questionnaire. These findings applied to both groups (those
who attended the workshop on narratives and on concept cartoons). To account for the improvement shown as a consequence of both interventions, the two control variables common to both workshop interventions were considered, namely the availability of information about evolution in the workshop materials and a focus on group work, discussion and designing their own narratives and concept cartoons. The qualitative part of the study showed that some teachers had identified barriers to the understanding of evolution being the influence of religious and cultural perceptions, parents and interest. The concept cartoons designed by the teachers showed conflict between religious and cultural beliefs and a lack of understanding of the nature of science. This could also be interpreted to indicate a conflict between epistemological beliefs involving knowledge seen as absolute and unchanging and the tentative and evolving interpretation of knowledge associated with the nature of science.

The pre-test responses indicated that teachers preferred to operate at lower levels of conceptualization and hence were inclined to adopt a descriptive approach to the teaching of evolution. The post-test results, however, showed that most teachers were capable of using higher-order thinking skills in order to make sense of evolution of life. They also had the ability to incorporate the use of higher-order thinking skills into their professional content knowledge and thus become more effective in teaching evolution at a conceptual level.

It is recommended that the teachers of life sciences be challenged to incorporate teaching strategies, such as the use of narratives and concept cartoons, into their professional content knowledge. Such professional development of teachers could enhance the quality of conceptualization and understanding of evolution and the nature of science. It is also important that the epistemology of knowledge, and in particular that of science, be addressed so that teachers become more familiar with the nature of science and can apply these ideas to their teaching. The focus should be on active involvement in the construction of conceptual knowledge with opportunities for discussion and the development of well crafted and scientifically valid arguments. It is also recommended that role models be used who have demonstrated that the barriers between science and the religious and cultural perceptions can be crossed successfully. For this to happen, it is vital that a required commitment on the part of the teachers as well as from their learners is necessary to achieve such success.
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CHAPTER 1

AN OVERVIEW OF THE STUDY

1.1 BACKGROUND

Evolution as a scientific theory was officially introduced for the first time in 2008 into the South African life sciences grade twelve curriculum. This was in line with the worldwide view of biologists and science educationists that the evolution of life is a theme which serves as an important cornerstone in understanding the biological and life sciences (Dobzhansky, 1973; Matthews, 2001; Dempster and Hugo, 2006). Without an evolutionary underpinning many aspects of biology and the life sciences cannot be interpreted and explained scientifically.

Teaching evolution of life effectively in the life sciences classroom is a challenge. A good knowledge about the substantive nature of biology and the life sciences in terms of principles and laws is required. It is also important that a clear understanding of the syntactical nature of science and its related processes is necessary. With the very recent introduction of evolution of life into the curriculum, it offers the researcher an ideal opportunity to investigate how teachers have coped with the challenge of dealing with a topic, generally little known to them, and the controversies that have arisen as a consequence of this addition to the content of the curriculum. Furthermore, by examining aspects of the teachers’ pedagogical content knowledge an attempt can be made to establish how their worldviews about science and evolution have impacted on the teaching of evolution in the classroom.

Science educationists in South Africa such as Dempster and Hugo (2006) and also university lecturers such as Chinsamy and Plagányi (2007) have raised concerns about the teaching of the life sciences which occurs mainly at a descriptive level and does not require much higher-order thinking. By adopting a more superficial factual and descriptive approach to biology and the life sciences, teachers can avoid using the theory of evolution as a scientific explanation of how structural developments have occurred in organisms and why life has diversified on Earth the way it has done so over a very long period of time.
The title of the study indicates various related areas of interest. This involves the use of innovative teaching strategies such as incorporating concept cartoons and narratives into lessons to encourage higher-order thinking skills and deep learning. Concept cartoons and narratives are seldom, if at all, used in the teaching of the life sciences. It would thus require further professional development of teachers to encourage them to incorporate these innovations into their teaching.

Linked to such professional development of teachers will also be a scientific knowledge about the evolution of life and the geological history of the Earth. Not mentioned in the title, but nevertheless always implied in the teaching of evolution, is the requirement of a good understanding of the nature of science which underpins such knowledge as Rutledge and Warden (1999); Trani (2004); Rutledge and Sadler (2007) and Deniz, Donnelly and Yilmaz (2008) have indicated in their research.

1.2 STUDY MOTIVATION
The central issue of this study concerned the effective teaching of evolution of life by life sciences teachers. This involved examining the teachers’ pedagogical content knowledge and also how, by introducing teaching strategies, such as the use of concept cartoons and the construction of narratives about the evolution of certain organisms, a contribution could be made to the introduction of higher-order thinking skills into the teachers’ pedagogy. As a consequence, this could also enhance the teaching of the life sciences and increase the skills that learners acquired in the classroom. The problem statement of the study linked these ideas in the following question:

What strategies can be used in the professional development of teachers to encourage them to further their knowledge about the evolution of life and the nature of science and to use higher-order thinking skills in addressing issues relating to the teaching of evolution of life?

A special area of interest in this study involved challenging teachers to use, firstly, their own higher-order thinking skills in preparing lessons that were both interesting and challenging to their learners and secondly, to encourage their learners also to develop such thinking skills. Teaching evolution of life as a scientific theory and linking this to the geological history of the Earth offered an ideal
opportunity to develop the teachers’ pedagogical content knowledge and also to further their professional development in the life sciences.

1.3 IDENTIFYING A GAP IN SCIENCE EDUCATION RESEARCH

Many studies quoted in the science education literature highlight the relationship of knowledge about evolution, acceptance of evolution and the understanding of the nature of science (Cooper, 2004; Ingram and Nelson, 2006; Rutledge and Sadler, 2007; and Cavallo and McCall, 2008). Fewer studies have explored the levels of understanding of evolution as mentioned by Dempster and Hugo (2006).

Little or no research has been done on the use of teaching strategies such as the use of concept cartoons and narratives in the life sciences. In particular, how these strategies could be incorporated into lessons to develop higher-order thinking skills to encourage a better conceptualization of the evolution of life. With the very recent introduction of the topic of evolution into the life sciences curriculum, opportunities have arisen to encourage teachers to further their knowledge about evolution and to explore ways to address problems which occur when they are faced with the differences between religion and the nature of science.

1.4 RESEARCH QUESTIONS

The research questions concerned how teachers could incorporate teaching strategies into their pedagogy to encourage higher-order thinking skills and achieve deep learning about evolution of life. Two teaching strategies, involving the use of concept cartoons and narratives, were developed to explore whether this was achievable in the classroom. The evolution of life on Earth served as the conceptual underpinning of these two teaching strategies. The research was based on seven research questions of which the first two focus on teaching strategies and higher-order thinking skills.

- **Research Question 1**
  How will the design of a narrative, about how scientists construct the evolution of organisms on Earth, encourage teachers to display higher-order thinking skills?
• **Research Question 2**
How will the use of concept cartoons generate discussion about issues relating to evolution of life, and, of science and religion, encourage teachers to display higher-order thinking skills?

A questionnaire consisting of five open-ended questions was constructed to probe the teachers’ ability to use higher-order thinking skills. A rubric, based on the Piagetian levels of concept development, was designed to transform the teachers’ responses, from a qualitative form into quantitative data. The results were then subjected to statistical analyses in order to determine any possible trends in and patterns of thinking. The third research question given below, addressed the problem of transforming data.

• **Research Question 3**
How will the achievement of higher-order thinking skills be measured?

Probing the context in which teachers operate when they teach evolution of life in the classroom, could help to understand how individual teachers coped with the controversy between science and religion. It was important to consider what worldviews they held and how these worldviews might influence their teaching of evolution. The sixth question of the questionnaire was designed to investigate these considerations. Furthermore, the teachers were also required to design concept cartoons which they could use in the classroom to encourage discussion of issues relating to the science and religion controversy. An analysis of these concept cartoons would also shed light on how teachers approached the teaching of evolution and why some viewed this as being problematic. Research question 4 and research question 5 were used to examine issues relating to the worldviews of teachers, their understanding of evolution as a scientific theory and their acceptance of evolution.

• **Research Question 4**
How can concept cartoons be used as a tool to analyze teachers’ worldviews about evolution of life, and, of science and religion?

• **Research Question 5**
What barriers can be identified that affect teachers’ understanding of evolution of life and the nature of science and why do these barriers arise?
A mixed methods research design was chosen because the study dealt with both generalizations about the teachers’ higher-order thinking skills and their individual worldviews about evolution as a scientific theory and their own religious perceptions. According to Creswell (2009) research questions underpinning a mixed methods research design need to reflect both the quantitative and qualitative aspects of the study. Hence the five research questions given above were rephrased to reflect a mixed methods research design.

- **Research Question 6**
  To what extent will the use of narratives and concept cartoons affect teachers’ ability to achieve higher-order thinking skills and deep learning about the evolution of life, the geological history of the Earth and the nature of science?

Furthermore, research question 7 examined how the teachers’ worldviews could affect their ability to teach the topic of evolution of life effectively.

- **Research Question 7**
  In what ways will the worldviews of teachers affect their ability to achieve higher-order thinking skills and deep learning about, and deal with, issues relating to the evolution of life, the geological history of the Earth and the nature of science?

## 1.5 RESEARCH DESIGN

A multi-faceted approach to the study was adopted and the use of a mixed methods design was suitable to allow for the generation of both quantitative and qualitative data. An ultimate mixing of results would give a more comprehensive, holistic and integrated view about the various aspects of the problem investigated.

The formation of conceptual knowledge structures about evolution of life could be affected by a variety of influences, or factors, which form part of a teacher’s ‘conceptual ecology of evolution’. The ‘conceptual ecologies of evolution’ held by the participants involved observations which could be measured both qualitatively and quantitatively. An embedded concurrent mixed methods design allowed for the simultaneous generation and collection of such qualitative and quantitative data (Creswell, 2009). All the data originated from the two different workshops which focused either on the use of concept cartoons or on the construction of narratives about the evolution of life.
1.5.1 A concurrent embedded mixed methods approach based on a (quasi)experimental design

In a (quasi)experimental design comparisons could be made about the effectiveness of the two teaching strategies, the use of concept cartoons and the design of narratives about the evolution of life on Earth. Teachers volunteering to attend these interventions, on different Saturday mornings, joined either of the two experimental groups: those attending the workshop on concept cartoons or those attending the workshop on narratives. This depended on which workshop was presented on a particular Saturday. Thus the participants were not assigned randomly to either of the experimental groups because their attendance was based on their ability to attend the workshops on specific dates. The reasons why a (quasi)experimental design was used instead of an experimental format, were based on the fact that the participants were not randomly assigned to the experimental groups and that no control group was initiated by the researcher (for ethical reasons that will be discussed later).

Thus in this (quasi)experimental format, the two teaching strategies constituted the independent variable of the investigation. The ability of the teachers to use higher-order thinking skills to answer questions dealing with the evolution of life, formed the dependent variable of the investigation.

1.5.2 Data collection

The workshops afforded the researcher the only opportunity to interact with all the participants. It was crucial to design the interventions in such a way to ensure that as much data as possible could be collected during this contact time. The main part of the study concerned the collection of data about the participants’ abilities to use higher-order thinking skills in response to open-ended questions of a questionnaire, administered before (pre-test) and at the end of each intervention (post-test).

The embedded part of the investigation happened concurrently with the main part of the study. This allowed opportunities to probe the teachers’ views about evolution of life at the same time as they were involved with activities that focused on the development of higher-order thinking skills. This phase concerned the collection of data about the individual perceptions and worldviews of the
Participants. Data could also be derived from their responses to the final (or sixth) question of the questionnaire, given as part of the pre-test and post-test procedures. Further data could also be obtained from the designs of the concept cartoons and narratives prepared by the teachers.

1.5.3 Data analysis

Initially the data collected from the main part of the study were in the form of qualitative responses to the open-ended questions of the questionnaire. This was why research question 3 was important because it addressed the problem of transforming qualitative data into quantitative data. In response to research question 3, a rubric was designed based on Piagetian levels of concept development. The rubric categorized, in a hierarchical order, the type of understanding (whether the interpretation was at a concrete or at an abstract level) and hence the ability to use higher-order thinking skills in constructing responses to the questions of the questionnaire.

Once the responses were transformed into a quantitative form, statistical analyses were performed to ascertain whether the two teaching strategies had been effective in promoting the use of higher-order thinking skills by the participants. Two non-parametric statistical procedures were used to compare the pre-test and post-test responses as well as comparing the effectiveness of the two different teaching strategies used in the interventions.

The Wilcoxon Signed Rank test (or the Wilcoxon Matched Pairs Signed Ranks test) is a non-parametric procedure designed to measure the difference between the action of the same participants, measured on two occasions, such as by a pre-test and a post-test. The Mann-Whitney U test is used to analyze ‘between groups’ responses and compares the medians of these two groups, rather than the means of two groups as used in parametric procedures.

The qualitative data generated from the last question of the questionnaire were grouped into categories which helped to probe the individual teachers’ perceptions about the teaching of evolution. This also helped to ascertain whether the interventions had effected a change in their perspectives and worldviews about the controversies linked to the teaching of evolution of life.
Furthermore, the information contained in the concept cartoons designed by the teachers about controversies associated with the teaching of evolution, was used to construct a composite picture of the worldviews held by them. Additional information was also gained by examining other artifacts generated by the participants during the workshops, such as the design of the narratives prepared by the teachers, who attended the workshop on narratives.

1.5.4 Results and conclusions

The purpose for using a mixed methods approach was to establish different perspectives on how teachers could become be more effective in teaching evolution of life by using higher-order thinking skills and deep learning. To achieve this, the findings were integrated and mixed in order to provide a clearer and more global picture of a multi-faceted and complex area of research involving the conceptual ecologies of evolution that teachers have.

1.5.5 Criteria of measurement quality

In discussing 'measuring anything that exists,' Babbie (2007, p. 142) pointed out that the criteria of measurement quality were ‘the yardsticks against which we judge our relative success or failure in measuring things’. In this study, both its validity and reliability were important considerations in determining whether what had been measured was indeed what should have been measured, and whether the design of the rubric to transform data could give consistent results.

Owing to the nature of mixed methods studies, Creswell (2009) commented that the validity of a mixed methods study which might well be different, in certain parts, to the validity of the component quantitative and qualitative stages. This could be based on several considerations, such as the underlying philosophies of the various methods of research, for example, and well worth considering in the design of such research. This is considered in chapter five when the research design is discussed in detail.
1.6 ETHICAL CONSIDERATIONS

‘Ethical practices involve much more than merely following a static set of guidelines’ (Creswell, 2009, p. 88). Ethical issues may arise in any of the stages of the research. Thus, for example, in devising the (quasi)experimental design of this study, an ethical decision had to be taken about providing all participants with benefits from the interventions. A design format was chosen which excluded the use of a control group, in which certain teachers would have been denied such benefits.

1.7 ORGANIZATION OF THE PRESENTATION OF THE STUDY

The study involved a multi-faceted approach to research. On the one hand, it concerned the professional development of teachers of the life sciences and focused on the use of higher-order thinking skills and deep learning. In order to achieve such learning, the teachers were introduced to two teaching strategies which are designed to encourage higher-order thinking skills. On the other hand, the evolution of life as a scientific theory, was used as the conceptual underpinning of the workshops focusing on the two teaching strategies dealing with the use of concept cartoons and the design of narratives about the evolution of life on Earth.

A conceptual framework of this study was devised to identify and describe what the research was about. To clarify the research further, the various topics and ideas that made up the conceptual framework were discussed with reference to the literature, in order to create a more comprehensive visualization of the study. Owing to the complexity of the conceptual framework of the study, it was decided to cover it in two separate chapters.

In chapter 2 the professional development of teachers is considered and the importance of pedagogical content knowledge (PCK) in achieving effective teaching of evolution of life is discussed. This also involved examining the available literature about the use of concept cartoons and narratives in the life sciences.
The discussion of the conceptual framework is continued in chapter 3. In this chapter the theory of evolution, and macro-evolution in particular, and the nature of science are considered in detail. Concepts associated with macro–evolution and the nature of science formed the basis of the questions of the questionnaire, used in the pre-test and in the post-test. Conceptual knowledge structures do not develop in a vacuum, and the importance of the teachers’ conceptual ecologies of evolution are also considered in this chapter.

Theories are used to explain observations, relationships between variables, phenomena and models. A theoretical framework was devised to explain the findings of the study. A multi-theory platform was necessary to explain the observations generated by the mixed methods approach. The focus of chapter 4 is mainly on a constructivist theoretical framework, which consisted of several theories. However, it was noted that a tension arose between adopting a constructivist approach to science teaching and also doing justice to the post-positivist approach used by scientists when investigating the world around us and the evolution of life on Earth. Introducing a post-positivist approach as reflected in the nature of science, into a constructivist view of the ecologies of evolution is a challenge reflected upon in this study.

In chapter 5 the theoretical underpinnings of a post-positivist research paradigm are considered. The importance of constructivism in qualitative research and the consideration of pragmatism in justifying the use of a mixed methods approach are examined. The research questions, which were used to define the study, as well as the proposed method to find answers to these questions, are justified. An important part of research design also involved ethical considerations, which were included in this chapter.

Chapter 6 involved the analysis of both the quantitative and qualitative data. Statistical analyses were used to interpret the quantitative data and to establish any trends and patterns indicated by the data. The qualitative data reflected the personal worldviews of teachers and were used to explain and corroborate some of the trends identified in the quantitative part of the study.

Finally, in Chapter 7 the conclusions based on the results discussed in chapter 6 were examined and linked to the research questions posed in chapter 5. Based on these conclusions, certain
recommendations were made and further areas of research identified. The organization of the presentation of the study is summarized in figure 1.1.

Figure 1.1  The organization of the presentation of the study
CHAPTER 2
THE PROFESSIONAL DEVELOPMENT OF TEACHERS IN IMPLEMENTING STRATEGIES, SUCH AS THE USE OF NARRATIVES AND CONCEPT CARTOONS, TO DEVELOP HIGHER-ORDER THINKING SKILLS AND DEEP LEARNING

2.1 INTRODUCTION
The conceptual framework of the research is structured around two main themes. These two themes focus on the following concepts:

- the professional development of teachers in implementing strategies, such as the use of narratives and concept cartoons, that develop higher-order thinking skills and deep learning, and,
- the evolution of life, including the geological history of the Earth, and the implications for developing higher-order thinking skills and deep learning.

There is a complex interplay between all the components, stated above, in giving structure to the conceptual framework of this research. Owing to the complexity of the study, it has been decided to deal with each theme in a separate chapter.

2.2 THE PURPOSE OF PROFESSIONAL DEVELOPMENT OF TEACHERS

One of the purposes of professional development of teachers is to ‘promote change or improvement within the current curricular framework’ (Rogan, 2004, p. 155). In their examination of how action and collaborative research contribute to the professional development of teachers, Savoie-Zajc and Descamps-Bednarz (2007) explore this point of view further, by highlighting the idea that teachers collaborating in their project, started to appreciate the importance of how ‘they are the ones that must begin the improvement and stimulate the learning process’ (p. 588). Although this study does not involve action research, it shares the importance attached to the fact that the teachers are the agents of change and that improvement should be initiated by them.
One approach to promote change has been to present teachers with a once-off workshop conducted by an ‘expert’. This usually involves an aspect of the subject-matter or policy. The teachers are then left on their own to reflect on the new information and its implementation. The effectiveness of such an approach is criticized because the teachers, who are expected to implement change, are not really involved in the workshop and have little opportunity for discussion, sharing of ideas and reflection. The criticism is addressed in the research design of this study. The workshop design (also once-off options) provided for much additional material about the evolution of life, but also focused on collaboration, sharing of ideas, discussion and feedback to activities by the participants.

Developing the idea of teachers ‘stimulating the learning process’ further, Savoie-Zajc and Descamps-Bednarz (2007) describe another aspect of professional development which involves ‘the broadening of perspectives, the restructuring of practice, the new risk-taking orientation’ (p. 590). This requires confidence, they point out, a confidence in which teachers examine their own knowledge and abilities to develop new ways of teaching. This ties up with the point of view of Gravett and De Beer (2010, p. 3) that to be effective, good teachers need to be ‘constantly observing, inquiring, assessing, diagnosing, designing and redesigning’ their teaching. In effective teaching, Zohar (2006) maintains, changes in knowledge will affect the practice of teaching and must eventually result in the improvement of the students’ achievements.

The purpose of this study is to determine whether by encouraging the use of higher-order learning skills and deep learning, teaching strategies can be broadened but also deepened at the same time. The use of concept cartoons and the construction of narratives about the evolution and diversity of life on Earth could provide such platform for research.

2.3 PEDAGOGICAL CONTENT KNOWLEDGE AS A CONCEPTUAL FRAMEWORK FOR RESEARCH IN SCIENCE EDUCATION

Shulman (1987) in his interpretation of ‘knowledge and teaching,’ discussed the importance of different sources of knowledge that contribute to what we understand to be effective teaching. The initial results of his research on effective teaching made Shulman suspect that there must be other sources of evidence that needed to be considered in developing the ‘foundations of the new
reform in knowledge and teaching’. In fact, it led him to consider in wonder ‘how the extensive knowledge of teaching can be learned at all during the brief period allotted to teacher preparation’ (Shulman, 1987, p. 7). His next step was to outline the categories of knowledge ‘that underlie the teacher understanding needed to promote comprehension among students’.

Of the seven sources of knowledge Shulman identified as necessary for teaching, four categories relate directly to this research, and will be considered in this discussion.

- content knowledge of the subject,
- general pedagogical knowledge,
- pedagogical content knowledge and
- knowledge of learners and their characteristics.

Furthermore, Shulman (1987) also identified pedagogical content knowledge as ‘a special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding’ (p. 8). The uniqueness of pedagogical content knowledge is an important consideration of this study because it relates to how teachers cope with the perceived controversy arising from teaching the scientific theory of evolution in a situation clouded by religious perceptions of the community.

Shulman’s ideas have been developed further by Koehler and Mishra (2009) who also include the introduction of technology into teaching and learning. They interpret content knowledge to be the ‘teacher’s knowledge about the subject matter to be learned or taught’ (p. 63). Knowledge of concepts, theories and organizational frameworks are also included in this category. They also stress that teachers need to understand the ‘deeper knowledge fundamentals’ of the discipline in which they teach. In the life sciences this would include a good grasp of the nature of science and the implications of teaching scientific theories associated with the evolution of life.

In this study there are two themes. One theme involves content knowledge which focuses on the evolution of life, the geological history of the Earth, and the nature of science. The other theme of the research involves general pedagogical knowledge, which is defined by Koehler and Mishra (2009, p. 64) as ‘teachers’ deep knowledge about the processes and practices or methods of
teaching and learning’. The implementation of teaching strategies, such as the use of narratives and concept cartoons, will be examined in this study as part of the overall pedagogical content knowledge of teachers.

Although Shulman (1987) placed the knowledge of ‘learners’, as a separate knowledge category, Koehler and Mishra (2009) interpret this as part of pedagogical knowledge because it encompasses how knowledge is constructed, how children learn and includes techniques and methods used in the classroom. Within the context of this study, the teachers are thus interpreted as being ‘learners’, and their higher-order thinking abilities in the development of deep learning is investigated.

It is not surprising that Koehler & Mihra’s interpretation of pedagogical content knowledge will contain elements which were not conceived by Shulman twenty years earlier. This includes ‘an awareness of common misconceptions and ways of looking at them’, and, ‘the flexibility that comes from exploring alternative ways of looking at the same idea or problem’ (Koehler and Mihra, p. 64). However, what remains the same is the kernel of what is meant by pedagogical content knowledge and that is the ‘notion of the transformation of the subject matter for teaching’ (Koehler and Mishra, 2009, p. 64), where the teacher interprets the subject matter to find different ways to represent it and in the process adapts and tailors it to meet the needs of the learners.

The various sources of information, as identified by Shulman and later adapted by Koehler and Mishra to include technology; also feed into a useful interpretation of the pedagogical content knowledge of the life sciences and help to define the conceptual framework of this study. In particular, the focus is on teachers as the primary source of information about evolution of life.

2.3.1 The teacher as the primary source of student understanding

In enumerating the sources of knowledge that teachers can draw on, Shulman (1987) stated that teachers are part of a ‘scholarly community’ in which scholarship of the content disciplines, such as the life sciences, is an important source of knowledge. Teachers have a ‘special responsibility in relation to content knowledge, serving as the primary source of student understanding’ (p. 9).
Furthermore, the teachers decide what they consider to be ‘essential and what is peripheral’. Taking these decisions ‘challenges the teacher’s own depth of knowledge’ and construction of knowledge structures. In making these decisions, the teachers also convey their ‘attitudes toward and enthusiasms for what is being taught and learned’ (p. 9). This consideration is particularly important when researching aspects of the teaching of evolution of life and the worldviews held by teachers and learners alike.

However, it must be pointed out that although the teacher plays an important role in teaching and learning, it is ultimately the learners who decide what is acceptable and how it should be incorporated into their knowledge structures. This highlights the differences in interpretation of pedagogical knowledge shown in the earlier work of Shulman and the later explanations of Koehler and Mishra, who use constructivism as an underpinning of their definition.

‘Teachers cannot teach effectively what they do not know’ Zohar (2006, p. 335) maintains. However, changes in the teachers’ subject-matter, or content knowledge, seem less difficult to achieve than changes in teachers’ views about teaching and learning. Zohar also points out that ‘not all teachers change at the same extent and some teachers do not change at all’ (p. 333).

Experienced teachers are inclined to develop a personal pedagogical content knowledge which they usually do not share with other teachers. This led Loughran, Mulhall and Berry (2008) to consider ways of how new teachers could tap into this knowledge. In their lesson preparation these new teachers were encouraged to consider the conceptual development, and knowledge structures of the subject content; called CoRes or ‘Content Representations’; as well as the possibilities that teaching strategies generate, as used by experienced teachers; called PaP-eRs or Pedagogical and Professional-experiences Repertoires. This in turn, could provide new entrants, to the profession, mechanisms to give them more confidence and added insights into the complex processes of teaching and learning and thus become more effective teachers.

By studying why many experienced teachers are effective, this idea may be developed further by drawing on the interpretation of effective teaching in Mathematics proposed by Kraus, Brunner, Kunter, Baumert, Blum, Neubrand and Jordan (2008). They point out that ‘deep understanding of
mathematical concepts may enable teachers to access a broader repertoire of strategies for explaining and representing mathematical content to the student’ (p. 716).

In contrast to the observations that teachers, who have a deep understanding of the content knowledge, are more effective in their teaching, Mason, Gava and Boldrin (2008) found that pre-service teachers who held beliefs in knowledge as being simple (presented in a superficial manner) were less likely to engage in deep thinking about the content of mathematical texts. If deep thinking is seen as the belief in complex, hypothetical and evolving knowledge, then it is not surprising that these pre-service students were unwilling to change their beliefs about how they felt Mathematics should be taught. This in turn, could lead to students being encouraged to focus only on items of factual knowledge in a superficial approach.

In order to study the implementation of educational reform in history and science classes, Hugo, Bertram, Green and Naidoo (2008) video taped grade 10 lessons in two schools in the Pietermaritzburg area. Their description of lessons observed in one of the schools, showed a ‘superficial approach’ to knowledge adopted by the teacher who looked only for ‘yes/no’ answers to questions; generally ignored incorrect answers and sought no explanations for the ‘wrong answer’ given; and accepted correct answers with no further discussion. In another school, a ‘deep approach’ to learning was used by a teacher who asked the learners to elaborate on their answers or comments and who then ‘signaled’ what was missing from the learner’s response.

The authors used Bloom’s Revised Taxonomy (1956) to help them categorize the questions which the teachers asked and thus compare the different approaches adopted by the two teachers. The authors felt that Bloom’s Revised Taxonomy was a ‘tool most useful for analyzing the cognitive complexity of the questions asked in the classroom’ (Hugo et al., 2008, p. 47). Upon analyzing the complexity of questions used in the classroom interaction between teacher and learners, it is not surprising that they found that the teacher who adopted a ‘superficial approach’ to questioning in class asked questions of which only 18% could be categorized as of a higher-order in nature. However, 60% of the questions posed by the teacher using a ‘deep approach, involved in using higher-order thinking, but not requiring recall or memorization only; but incorporating the categories of understanding, analysis, application, evaluation or creation.
Although ‘Bloom’s Taxonomy’ is useful, it is a uni-dimensional tool for categorizing the cognitive processes of to ‘remember’, ‘understand’, ‘apply’, analyze’, ‘evaluate’ and ‘create,’ which happened in the classrooms sited above. There are other aspects of deep learning and higher-order thinking skills that cannot be identified by using this approach. For example, Hugo et al. (2008) also use Krathwohl’s revision of Bloom’s Taxonomy, which includes a knowledge dimension (based on factual, conceptual, procedural and metacognitive levels of knowledge) as well as the dimension, based on cognitive processes, which has already been discussed. As will be shown later, other aspects such as the construction of knowledge and the role played by discussion should also be considered when researching deep learning.

Examining recent research on the impact of professional development on the effectiveness of teachers, Zohar (2006) concludes that if adequate methods are used, professional development courses can induce some changes in teachers’ thinking and practice toward a more sophisticated model of learning and instruction. However, he cautions that ‘these studies also have shown a repeated pattern implying that such a change is a difficult and slow process’ (p. 335).

2.3.2 Deep learning and higher-order thinking skills

2.3.2.1 Defining deep learning

A deep approach to learning, or deep learning, according to MacFarlane, Markwell and Date-Huxtable (2006, p. 13) involves an ‘intention to understand’ which focuses on relating new knowledge to existing knowledge in solving problems and involves motivation of a personal and an intrinsic nature. ‘Superficial knowledge’ or a surface approach, on the other hand, is the ‘intention to complete a task’, with memorization of facts, not reflecting on knowledge and in response to extrinsic motivation.

Andersson and Wallin (2006, p. 685) concur and add the following points to the interpretation of what deep learning is, in that the learners:

- “twist and turn’ the new knowledge in their head ( transformation instead of memorization),
- ask questions and suggest ideas,
• use knowledge as a tool for seeing the world around them with new eyes,
• discuss what is new with classmates and others, and
• accept challenges (e.g., in the form of set problems).

Goodyear and Zenois (2007) develop the idea of deep learning further by linking the importance of discussion to improving ‘understanding through analysis and reflection’. They also point out that when deep leaning occurs, an inward turn happens in the learner because ‘higher conceptions are more about internal change or personal conceptual development than they are about the ideas of others’ (pp. 362-3).

Of interest to this study, is the point raised by Barak and Dori (2009), that in the teaching and learning situation, assessment will reinforce the learning approach (either ‘deep’ or ‘surface’) which is adopted by the learners. Thus it is desirable for teachers to include some assessment requiring ‘deep learning’, tested by using ‘higher-order’ thinking skills.

2.3.2.2 Defining ‘higher-order’ thinking skills

In more traditional terms, the idea of ‘higher-order thinking’ skills is usually interpreted as involving cognitive activities that require processes beyond that of ‘memorize/recall’ and ‘understand/comprehension’ of Bloom’s Taxonomy of 1956. However, Zohar (2006) points out that there are more recent examples of cognitive activities such as constructing arguments, making comparisons, dealing with controversies and establishing causal relationships which were not included in Bloom’s taxonomy of cognitive processes. In fact, most classical scientific inquiry strategies, such as formulating hypotheses, planning investigations, controlling variables or drawing conclusions are all higher-order thinking skills Zohar maintains.

Barak and Dori (2009) describe higher-order thinking as a complex mode of thinking which may involve multiple solutions. They define higher-order thinking further, as that which ‘involves uncertainty, application of multiple criteria, reflection and self-regulation’ (p. 460). The development of higher-order thinking skills is seen as a central goal of science education. This goal requires of students the ability to ‘think critically, ask significant questions, reason and solve problems’ (p.
Critical thinking, they interpret as the ability to analyze complex situations with the production of good arguments. Unfortunately, they feel, these skills are not emphasized enough in the professional development courses of teachers.

Barak and Dori suggest that one way of developing higher-order thinking skills is to involve students in the exchange of ideas in discussion – a participation in educational discourse. This provides opportunities for students to ‘discuss ideas, teach their peers, and learn from each other’. Furthermore, it allows the students to communicate their own understanding and build upon other’s ideas’ (p. 461). The authors conclude their ideas about educational discourse as: ‘since a good discussion involves posing questions, expressing critical views, and providing arguments to support one’s point of view, it enhances higher-order thinking skills’ (p. 462).

Allowing students to collaborate in the construction of knowledge and not merely to ‘observe and memorise the outcomes of other people’s knowledge work’ is an area of interest of Goodyear and Zenois (2007, p. 360), and, in particular that of collaborative knowledge-building in online communities at higher institutions of education. These authors also make a distinction between learning and knowledge-building in the following manner: ‘engagement in collaborative knowledge building can engender learning, but the two are not the same’. They explain this observation by stating that ‘learning is personal …; knowledge-building is public’ (p. 359).

2.3.2.3 Learning through discussion

Goodyear and Zenois (2007, p. 360) quote the work of Askell-Williams and Lawson in identifying five categories of the use for discussion, which emerged from their interviews with students involved in ‘learning through discussion’. These five categories are used to explain the processes that happen when teachers collaboratively discuss their designs of concept cartoons and narratives during the workshops (shown in brackets).

- **Information acquisition**: (by examining the content material in the workshop handouts) discussions help gather information, discussions help to clarify information.
• **Knowledge construction:** (by making sense of the content materials)
  discussions open their minds to new points of view,
  contributing to discussions helps to formulate their own thoughts,
  discussions help to clarify their own opinions,
  discussions with a mentor (more knowledgeable members of the group) help to expand their thinking,
  discussions facilitate co-construction of knowledge.

• **Motivation:** (to encourage better participation by the teachers attending the workshops)
  discussions make the lesson more interesting,
  discussions generate engagement.

• **Remembering:** (to encourage the teachers to draw on their own experiences in order to make the workshops a richer experience)
  discussions trigger their memories about things they had read, heard or questioned,
  discussions reinforce learning.

• **Comparisons:** (important for teachers who usually work in isolation in their classrooms)
  discussions allow them to compare themselves with others in the group,
  discussions inform self-efficacy beliefs.

Goodyear and Zenois (2007, p. 362) used in-depth interviews and also incorporated a broader questionnaire-based research to establish four categories of ‘conceptions of learning through discussion’. The categories involved either a ‘deep approach to learning’ or a concern with the more ‘surface form’ of the task. The category descriptions are given as follows:

• **Category A** involves discussions ‘as a way of challenging ideas and beliefs in order to arrive at a more complete understanding’.

• **Category B** involves discussion ‘as a way of challenging and improving your ideas’.
• **Category C** involves discussions ‘as a way of collecting ideas’.

• **Category D** involves discussions ‘as a way of checking your ideas are right’.

Discussions described in categories C and D are more superficial in that they deal with the collection and checking of facts necessary to complete the task and little construction of knowledge happens. Discussions that fall in the categories A and B show ‘an intention to come to an improved understanding through analysis and reflection’ (Goodyear and Zenois, 2007, p. 362) and are more about construction of knowledge and personal conceptual development than about how others think about the matter. This can be interpreted as another aspect of deep learning.

The way we construct knowledge is a personal journey in learning and as the above authors point out, it is not the same as collaborative knowledge building, which is in the public sphere such as in workshops. The teachers who attended the workshops were involved in much discussion about evolution, and the design of concept cartoons and narratives. What they learned from the workshop, however, would depend on their ability to analyze and reflect on their own understanding about evolution of life and the geological time scale of the Earth’s history.

### 2.4 CONCEPT CARTOONS AS A TEACHING STRATEGY TO DEVELOP HIGHER-ORDER THINKING SKILLS

Concept cartoons were first created by Brenda Keogh and Stuart Naylor in 1992 to meet a need for finding new ways of challenging teachers who attended in-service courses in science teaching. A constructivist approach to science had come to the fore and various ways were designed to probe what was considered to be ‘children’s science’, alternative viewpoints and misconceptions.

#### 2.4.1 Defining concept cartoons

Naylor and Keogh (2000, p. 1) describe concept cartoons as ‘cartoon-style drawings which put forward a range of viewpoints about the science involved in everyday situations’. Although concept cartoons are not normally humorous, several characters offer various points of view which are designed to stimulate discussion and encourage scientific thinking.
Considering the tentativeness of science is encouraged, because there is not necessarily a single 'right answer' to the problem shown in the concept cartoon. 'This helps to reinforce the view of science as tentative, in which beliefs are justified by the evidence available but can be modified if additional evidence emerges', Naylor and Keogh (2000, p. 1) explain in the introduction to their book on concept cartoons.

2.4.2 The use of concept cartoons

'Concept cartoons are used for promoting learning across a wide age range and in a variety of settings, both formal and informal', Naylor and Keogh (2000, p. 5). It is interesting to note that the authors have used concept cartoons in every age group from young children to mature adult learners. In this study, teachers (who are 'mature adult learners') are the participants, with the objective to improve their own knowledge as well as introducing them to an effective teaching strategy which they can use in their own classrooms.

2.4.3 Concept cartoons and the professional development of teachers

Concept cartoons are designed to probe understanding and can play an important role in developing the teacher's content knowledge and understanding. Some of the points of view raised by the characters of the concept cartoons may be foreign or even aligned to the teacher's own misconceptions. It becomes a useful exercise for the teachers to review their own understanding of the subject so that they can justify the arguments presented.

In some instances it might also inspire teachers to want to find out more about the topic or points of view dealt with. With this in mind, background information and additional sources of knowledge were included in the design of the workshop materials.

Naylor and Keogh (2000, p. 8) explain their constructivist approach to science teaching as a 'creative subject, one where there are always new possibilities to explore and new factors to consider, rather than as a subject where there is always a single right answer'. Concept cartoons can provide opportunities to develop higher-order thinking skills, such as hypothesizing, predicting,
using analogies, evaluating evidence, asking questions and justifying points of view. These are opportunities which teachers do not usually experience in the many workshops they attend.

2.4.4 Concept cartoons and social interaction

Concept cartoons may be used by individual learners, or in small groups. It is the potential for collaborative learning which is of importance to this study’s the workshop design because interaction between participants formed a vital role in the discussion and ultimate design of concept cartoons. Thus concept cartoons provide ‘a focus, a context and a purpose for the discussion and legitimizes debate or argument between learners’ (Naylor and Keogh, 2000, p. 6). It is also possible to present complex ideas such as ‘adaptive radiation in evolution’ or ‘Charles Darwin as a scientist’ in a seemingly simple situation. Because the text in the concept cartoon is limited to an observation or a short statement, even learners with poor literacy skills can become involved in stimulating and even complex debates, which in turn develop higher-order thinking skills.

In challenging and developing the ideas of learners when involved with group work discussion of concept cartoons, Keogh and Naylor (1999, p. 438) observed the following processes:

- a constant shifting of ideas,
- introduction of new ideas to the discussion,
- realigning of positions, and,
- the introduction of a justification to support ideas.

When the teachers in the workshop sat down to construct their own concept cartoons covering aspects of ‘science and religion’, the steps involved were similar to Keogh and Naylor’s observations:

- a period of conflict concerning the brainstorming of ideas,
- a discussion causing them to settle, somewhat tentatively, on a choice of theme for the concept cartoon,
- also, noting that even the more confident of participants, when discussing alternative ideas, needed to question and argue about the choice of statements or characters selected in the concept cartoon design.
2.4.5 The use and design of concept cartoons as part of a teaching strategy to encourage higher-order thinking skills

In many life sciences classrooms learners are not familiar with teaching strategies which encourage discussion or even working in groups to find a solution to a problem. Hence the first step would be to develop skills associated with group work, such as tolerance and respect for different points of view, following a certain protocol of behaviour to avoid unnecessary rowdiness and developing the will to participate, present an argument and to listen to others.

Concept cartoons are not easy to design because the statements attributed to the characters should be carefully worded to encourage discussion. Ideally these statements should be partially correct or incorrect and linked to possible misconceptions.

In Figure 2.1, the concept cartoon depicts various ideas about “Charles Darwin – the nature of science and religion”. Statements such as ‘evolution of life is the view of scientists only’ and ‘evolution proves that God does not exist’ are incomplete and require further explanation and reasons for agreement or rejection. This is best achieved in a group setting in which the various members all express their opinions and in certain instances need to defend their points of view.
2.4.5.1 Work in small steps

It is advisable to start ‘small’ in developing higher-order thinking skills. The concept cartoons developed by Naylor and Keogh (2000) are well designed, researched and extensively piloted and are easily used in the classroom. These concept cartoons work best if the learners can relate to the topics and have some knowledge which they can use in the discussions. Reluctance to participate in a discussion is usually a problem and hence familiarity with the topic encourages participation. It is best to start with only one concept cartoon and to allocate only a short period of time for the discussion.
2.4.5.2 Techniques to encourage social interaction and talk

The skill of the teacher is to encourage learners to express their opinions and to give reasons why they think so. If discussion is not forthcoming, then other techniques may be employed. One method is to ask the learners to rank the statements in the concept cartoons, from the ones they agreed with most to the ones they disagreed with most, giving their reasons for such choices. This will also develop skills relating to how to present an argument. The learners could then suggest alternatives for some of the statements in the concept cartoons and elicit further discussion. The concept cartoons could also be modified to suit the needs of the community and the classroom. Alternatively, a series of concept cartoons could be created about the same topic, allowing for a more varied approach to group work, and differentiation in the classroom.

Ultimately, the learners could suggest topics for more concept cartoons to be designed. These topics could relate more to the context and the settings of the world in which these specific learners live. A word of caution about designing concept cartoons from first principles come from Naylor and Keogh (2000) and also from the researcher’s own experience, in that it can be a time consuming process, especially in constructing short yet challenging statements that challenge the reader to use higher-order thinking skills.

Contrary to the comments by Kabapinar (2005) about the use of concept cartoons in Turkish schools, discussed further in the next section, the teacher should not dominate the discussion about the various statements in the concept cartoons. Learners should have the opportunity to express their own interpretations and develop the skills necessary to conduct an argument and analyze the statements carefully. If unscientific explanations are favoured by the learners, then the possibility of introducing further investigations and research should be explored.

2.4.6 Concept cartoons and research findings

Keogh and Naylor (1998) based their research findings about concept cartoons on extensive evidence they derived from a variety of sources, such as interviews with teachers and learners,
observations of lessons conducted by both primary and secondary school teachers and even parents. The authors make four interesting points about their findings:

- Concept cartoons give easy access to the learners’ ideas, which is an important component of constructivist teaching. Several teachers felt that this was a strategy which encouraged learners, normally reluctant to participate, to volunteer their ideas.
- Concept cartoons can promote conceptual change because a more focused discussion is initiated on a deeper level.
- The learners were involved and motivated – even those with behavioural problems became interested and participated positively in the discussions.
- The ease of use of concept cartoons in encouraging group discussions and working towards the same goal of the science lessons.

Kabapinar (2005) comments about the use of concept cartoons in Turkish schools seem to concur with the observation that ‘the concept cartoon teaching approach was effective in creating focused discussions where reasoning behind students’ misconceptions could be uncovered’. However, he added a cautionary note emphasizing ‘especially via teachers’ thought-provoking questions’ (p. 144). This points to a Vygotskian approach of the importance of an ‘expert’ in providing ‘scaffolding’ to develop the learners’ conceptual understanding and is not necessarily accepted by all science educators.

### 2.5 THE USE OF NARRATIVES AS A TEACHING STRATEGY TO DEVELOP HIGHER-ORDER THINKING SKILLS

Although narratives occupy a prominent place in education studies as a research methodology, the use of narratives in science education is limited. Norris, Guilbert, Smith, Hakimelahi and Phillips (2005) contend that this is mainly because science aims for generality rather than for the uniqueness of situations being studied. However, the use of ‘narrative explanation’ has possibilities when ‘one aims to make unique, non-recurrent evolutionary events intelligible’ (p. 549). This interpretation fits well into the design of a study which investigates teaching strategies, such as the use of narratives, in developing higher-order thinking skills in promoting a better understanding of evolution.
2.5.1 Defining narratives

A narrative may be seen simply as ‘someone telling someone that something happened’ (Norris et al. 2005, p. 538). Thus there are four elements: the narrator, the narratee (receiving the story), events, which happened in the past (the fourth element). A narrative may also be seen as a communicating device, for motivation and enjoyment. It communicates ideas by making them memorable and meaningful, assisting the student ‘in recapturing the experience of those who one participated in exciting events’ (Norris et al. 2005, p. 535), in scientific history, or even in the geological history of the Earth, for example.

The above authors have identified seven elements that are necessary for the development of a theoretical framework for narratives in science, and in particular, as a ‘narrative explanation’ to be used in science education. In order to determine whether the narratives, constructed by the teachers during the workshops, satisfied the framework requirements devised by Norris et al. (2005), these seven elements will be discussed with reference to what the teachers did in the workshops (given in brackets and written in italics). Where it is relevant, other narratives explaining the evolution of life, will also be considered.

1. Something happened (event tokens)

The narrative shows an account of a sequence of events about a unified subject. The events must be connected so that individual events are ‘causes’ only because of the occurrence of later events that happen in the story, which are the ‘effects’.

(Example from the workshop: teachers constructed a narrative about the evolution of one, of six different organisms, based on the information given in the workshop content materials. The choice of one such ‘organism’, for example could be ‘the dinosaurs’, or ‘the chimpanzee’ or ‘the protea’, which created the ‘unified’ theme or subject of the narrative. The individual events could be connected over time as part of the geological time scale. Environmental changes, for example, could then result in adaptations happening in the organisms which evolved and reproduced further.)
2. **Narrator**

The way in which the narrator tells the story strongly affects the narrative quality of the story.

*Example from the workshop:* this was a difficult part of the narrative construction, partly because of the time constraints of the workshop. It also involved group dynamics in terms of negotiating the selection and presentation of the information. To help structure the presentation of their narratives, the groups had to structure a broad outline, which summarized the events that made up their narratives. The summary, written on A3 paper, served as a basis for their presentation to their colleagues and also as a useful artifact for further analysis.

3. **Narrative appetite (wanting to know what happened)**

The stories must not only account the events, but also do so in such a way that the audience cares to know more about what will happen next.

*Example from the workshop:* the narrative about the evolution of the chimpanzee worked the best in creating a narrative appetite. A possible reason could be that the chimpanzee is so closely related to humans and also shares a common ancestor. The origin of humans always seems to stimulate the interest of the members of the audience.

Another example of this point is how Dawkins (2004) creates a ‘narrative appetite’ in ‘THE ANCESTOR’S TALE: A Pilgrimage to the Dawn of Life’. He explains that ‘evolutionary history can be represented as one damn species after another (p.1), but that would be an impoverished view’. He starts out in a ‘backwards pilgrimage’ and introduces the first common human ancestor in ‘The Tasmanian’s Tale’ in which the first sentence states: ‘Tracing ancestors is a beguiling pastime’ (p. 41).
4. **Time (the past)**

By manipulating ‘time’ in flashbacks, going forward or going backward in time, can make the story more interesting and entice the audience to want to know what is next.

(*Example from the workshop: in my research ‘time’ is seen as the geological time scale of the Earth’s history. The narratives that were constructed by the teachers all moved in one ‘direction’ – from more ancient history to more recent times. Norris et al. (2005) stress the importance of establishing a good conceptual framework of knowledge, before starting out on the construction of narratives. Some teachers encountered difficulties in structuring the sequence of events correctly and had to rely heavily on the workshop content materials, which made the exercise time consuming.*)

The narratives devised by Dawkins (2005) in ‘THE ANCESTOR’S TALE’ adopt an interesting approach to ‘time’ because the ‘tale’ starts with to-day and works backwards towards the beginning of life. The story ends with the original ancestors of all life on Earth – ‘the oldest concestor is the grand ancestor of all surviving life’ (p.7).

5. **Structure (events structured in time)**

The elements of both time and structure are important because the narration may focus more on certain parts deemed more important as the ‘causes’ of certain ‘effects’ such as ‘mass extinctions of life’.

(*Example from the workshop: to structure a narrative requires a ‘bird’s eye view’ of the evolution of dinosaurs, for example. This requires a good framework of knowledge to underpin the narrative. The narratives which worked best in the workshops involved the choice of organisms which were best known to the teachers, or were of interest to them. This may also account for the fact that the stories of the ammonites and trilobites, which were not familiar to the teachers, were not chosen.*)
A different narrative structure is adopted by Southwood (2003, p.1) who interprets the story of life as a ‘kaleidoscope’ in which ‘every now and then it is given a shake so that some components of the picture disappear, others remain, some are altered and some new ones appear’. His interpretation of the story of life emphasizes the importance of seeing this type of narrative in a more global picture, ‘the shakes (or causes), are due to changes in the physical environment, such as a collision with an asteroid or climate change which can lead to the fall or rise of the sea level or the spread of ice sheets (the effects)’.

6. **Agency**

This is the role played by the characters or ‘agents’ of the story. Usually humans are the agents, and are involved in some ethical element of the narrative, because they are a responsibility for their actions.

*(Example from the workshop: in the original design of this workshop, the narratives constructed by the teachers, were envisaged to emphasize the idea of that this was how scientists constructed the story of life. This caused some difficulties with the construction of the narratives because most of the teachers were not familiar with the techniques used by scientists to find out more about the story of life. The source material was structured to provide such background information, but many teachers encountered difficulties in building this information into the narratives. An important feature of the original design of the workshop on ‘narratives’, was to show that scientists are the ‘agents’ in constructing our understanding of how life evolved on Earth. However, this idea was too difficult for the teachers to conceptualize in a workshop of four hours duration. The ‘characters’ of the narrative became the organisms chosen by the teachers.)*

The role played by scientists in constructing a narrative about the evolution of life as seen through the eyes of scientists, underpins ‘Walking with Dinosaurs’, a ‘wildlife’ documentary set in the Mesozoic Era. ‘Never before has a television series attempted to portray accurately the life habits of dinosaurs as though they were being filmed alive’ (Martill and Naish, 2000, p. 7).
In order to produce such a ‘gripping story’ of the lives of dinosaurs, many eminent scientists, specialists in various areas of Mesozoic palaeontology, contributed to the scientific methodology involved in making the narrative of these prehistoric animals tenure on Earth come alive. This emphasizes the importance of knowledge which is well constructed and based on the latest scientific models and interpretations.

7. Purpose – to entertain only?

Explanatory narratives are not only written to entertain, but also to help understand the world in which we live. This constructivist approach is based on the idea that in order to understand things better, new ideas and concepts need to be incorporated into what is already known (Norris et al., 2005).

(Example from the workshop: none of the teachers had used narratives in their teaching before. Some coped well and adapted and built on their knowledge about constructing summaries to encourage a better understanding of the world in which their chosen organisms survived. Others did not adopt a constructivist approach, and merely copied all the information from the source material without being selective about what they considered to be relevant to the narrative account which they were designing, showing a ‘superficial approach’ to learning.)

8. Someone Receiving – the listener

‘Just as telling of a story is and interpretive act for the narrator, the reception of that story requires interpretation’ (Norris et al., 2005, p. 543). To derive meaning from an explanatory narrative requires various higher-order thinking skills such as imagining, inferring, hypothesizing and anticipating.

(Example from the workshop: teachers acted both as narrators and receivers of the stories. Higher-order thinking skill were important in constructing the narrative by linking events, looking for causal relationships between the effects of geological activities causing
changes in the environment, with the processes of natural selection involved in the
evolution of various organisms. In order to follow the sequence of events presented in the
narratives, the audience of 'listeners' had to make meaning of the stories presented by
their colleagues, by using similar higher-order thinking which their fellow teachers had
utilized in designing the narrative.)

2.5.2 The advantage of using narratives in science education

There has been little research done to investigate the use of narratives in science education and
also to compare the narrative directly with other types of texts, such as expository forms (Norris et
al., 2005). Much of the claims are based on the presumptions of the nature of a narrative effect.
These include improvement of memory for content, enhanced interest in learning, greater
comprehension of what is learned and motivation.

‘Walking with Dinosaurs’, ‘Earth Story’ and ‘First Life’ are successful television documentaries
based on a narrative format. They have created interest and motivated people to find out more,
which is shown by the continued sales of both the DVDs and books based on these series. Martill
& Naish, (2000) conclude that ‘Walking with Dinosaurs brings to life the most amazing animals… –
not, as many people think of them, as dusty bones in dingy museums. Let’s hope that this new
genre of prehistoric documentaries continues to flourish: long may dinosaurs walk’ (p. 21).

This may also be a pointer to the possibilities offered by explanatory narratives of the evolution as
a teaching strategy which develops interest, generates motivation for finding out more, and the
acquisition of higher-order skills.

2.5.3 The use and design of narratives as part of a teaching strategy to encourage higher-
order thinking skills

Planning, designing and presenting narratives require more time than the use of concept cartoons
in a lesson. Although the focus should be on encouraging learners to construct new knowledge
structures, social interaction between learners working as a group contributes to the development
of other skills. These are important because they involve the ability to discuss and select relevant material; sequence information in the correct order and negotiate on how to make the narrative presentation interesting and accessible to the audience.

The geological time scale spans a very long time because it represents the Earth’s history and deep time. In many instances learners encounter difficulties in comprehending the magnitude of deep time, in millions, tens of million, hundreds of million or billions of years. It is worthwhile to consider this problem in the early stages of the planning of certain narratives. The story of the evolution of humans which is in terms of a couple of millions of years, is easier to plot on a geological time scale than representing the evolution of dinosaurs or the evolution of early land plants which gave rise to coal in Southern Africa.

The construction of narratives is also based on the learners’ ability to solve problems in terms of what is the basic storyline, what should be included and what information is not that important and could be excluded. It is this part of the debate which, if handled correctly, could contribute greatly to the development of higher-order thinking skills and the structuring of knowledge about the autobiography of life on Earth.

2.6 SUMMARY

- **Professional Development of Teachers**
  One of the purposes of professional development courses for teachers is to produce more effective teaching, which involves a good grounding in professional content knowledge, unique to the teaching profession.

- **Professional content knowledge (PCK)**
  PCK forms the conceptual framework of my research. It is interpreted as a ‘notion to transform knowledge of subject matter for teaching. Research seems to indicate that changes to the teachers’ subject matter knowledge, or content knowledge, is easier to achieve than for teachers to change their views about teaching and learning.
• **Deep Learning**
Deep learning involves the processes of adding new to existing knowledge and the solving problems as a personal experience, which is intrinsically motivated. The opposite is ‘superficial knowledge’ concerned with completing a task, which is extrinsically motivated.

• **Higher-order thinking skills**
Higher-order thinking skills are necessary to achieve deep learning. In terms of ‘Bloom’s Taxonomy’, this would involve skills higher than ‘recall or memory’. The interpretation of higher-order skills goes further than ‘Bloom’s Taxonomy’ and involves critical thinking and the skills involved in experimental design such as hypothesizing, controlling variables and categorizing. Learning through discussion is important in developing higher-order skills.

• **Concept Cartoons**
Develop higher-order skills by generating discussion about different points of view. Concepts cartoons are also useful in the professional development of teachers because teachers can review their own understand of content knowledge. Research indicates the use of concept cartoons is effective in challenging ideas and generating discussion.

• **Narratives**
Narratives are not always suitable in science teaching where generalizations are considered. However it is suitable for dealing with topics concerning non-recurring events that are unique, such as in the evolution of life. Higher-order thinking skills are involved in the construction of the narrative as well as in listening to the narrative and interpreting the story.
There is little research on this topic available in the area of science education.
CHAPTER 3

THE EVOLUTION OF LIFE, INCLUDING THE GEOLOGICAL HISTORY OF THE
EARTH, AND THE IMPLICATIONS FOR DEVELOPING HIGHER-ORDER
THINKING SKILLS AND DEEP LEARNING

3.1 INTRODUCTION

The first part of the conceptual framework was discussed in chapter 2. It dealt with the professional
development of teachers and the use of concept cartoons and narratives to promote more effective
teaching of evolution. In particular, effective teaching of evolution was linked to the development of
a deep learning approach, which incorporated higher-order thinking skills.

In this chapter, the second part of the conceptual framework, the knowledge frameworks required
for this study will be examined. The focus is on evolution of life, the geological history of the Earth,
the nature of science and the conceptual ecologies of evolution that teachers have.

Evolution deals with the complexity and diversity of life on Earth and is a suitable topic for
developing higher-order skills and promoting deep learning. There are two approaches to
evolution, at a macro-level and at a micro-level. The macro-level or macro-evolution, creates the
larger picture of evolution, explaining how scientists view the evolution of life and that of the Earth
itself, over a long period of time. At a micro-level or micro-evolution, the processes involved in
bringing about change and diversity of life are examined. These processes give rise to the natural
selection of organisms explained by the theory of evolution.

The focus of this study is on macro-evolution in which the Earth’s geological history plays an
important role in creating the ‘larger picture of evolution of life’. The topic is complex because it
links a variety of different concepts and uses a range of theories and models to explain these
ideas. It also lends itself to the use of ‘narratives’ in explaining the Earth’s story or ‘autobiography’,
which forms part of the design of my study. Concept cartoons, the other teaching strategy used in
the workshops, are most useful in promoting the development of higher-order skills by examining
and discussing evidence and developing good scientific arguments about aspects of evolution, such as the story of life which may not be well understood or seen as being controversial.

3.1.1 Knowledge frameworks underpinning the conceptual framework of the study

Knowledge frameworks form an important part in the design of the workshop materials. The factual knowledge, contained within these materials, is designed to help control for the impact of a lack of knowledge about evolution of life that some of the teachers may have. Because higher-order thinking skills are based on a good factual grasp of the topic, it is important that teachers attending the workshops have access to such information.

In turn, the questionnaire designed to examine the teachers’ higher-order thinking skills, is based on the knowledge frameworks contained within the workshop materials. As will be shown below, care was taken that the knowledge frameworks underpinning both workshops contained sufficient commonality to ensure that the basic factual knowledge was covered in the material design.

The two different workshops conducted were:

- workshop 1 dealt with ‘the story of life and the Earth’s geological history – as told by scientists’ and focused on the construction of narratives, and
- workshop 2 dealt with ‘issues relating to the teaching of evolution of life, science and the community’ and focused on the use of concept cartoons.

3.1.1.1 Knowledge frameworks which underpin the workshop materials

The two workshops focused on different teaching strategies and this required that the information was presented differently, though still covering the same basic themes. These themes served as the basis for the questions of the questionnaire, and are as follows:

* the story of life and the geological time scale of the Earth (macro-evolution), and
** the nature of science, and ideas about facts, theories and laws of evolution of life.
The knowledge framework for workshop 1 thus involved:

- the techniques that scientists use to construct the geological time scale, *
- the construction by scientists of the story of life, *
- the nature of science, facts, theories and laws, **
- ‘design a beak’ an activity based on ‘Darwin’s Finches’ with reference to Darwin’s travels to the Galapagos Islands. **

Workshop 2 was based on four concept cartoons and the accompanying source material.

Each concept cartoon covered a different theme.

- Coelacanth – ‘fish out of water?’ which looked at different points of view about the story of life and the idea of ‘missing links’, *
- Galapagos Islands – ‘Darwin’s Finches’ which examined Darwin’s travels to the Galapagos Islands and his observations about the different islands (geological time scale) and diversity of life found thereon (story of life), *
- Charles Darwin – ‘a unique scientist’ which focused on why Darwin is considered to be such a good scientist, **
- Charles Darwin – ‘the nature of science and religion’, considered the nature of science and perspectives on the controversy of science and religion. **

3.1.1.2 Knowledge frameworks and themes which underpin the questionnaire

A questionnaire was designed to probe the teachers’ ability to use higher-order thinking skills to answer open-ended questions based on the factual knowledge covered in the workshop materials and subsequent activities using this information. Five questions were designed to assess thinking skills.

The final question of the questionnaire, question 6, related to opinions and beliefs and was not designed to probe the teachers' knowledge frameworks. This question will be considered at the end of the chapter.
The questionnaire included the following five open-ended questions:

| Question 1: | What can we learn from the evolution of life and the changes that the Earth has undergone in the past? * |
| Question 2: | Does environmental change drive evolution? Explain your answer. * |
| Question 3: | What evidence do we have that mass extinctions happened in the past? * |
| Question 4: | Although Darwin was born two centuries ago (1809 – 1881), he is still considered to be a great scientist to-day. Explain why this is so. ** |
| Question 5: | Explain how ‘Darwin’s Finches’ found on the Galapagos Islands, illustrates that evolution is a fact; evolution is a theory; evolution can be a law. ** |

The introductory discussion, as given above, is about the knowledge frameworks that underpin the design of this study. Given below are the main topics which give structure to the conceptual framework discussed in this chapter.

3.1.2 Topics considered in this chapter

The discussion, in part, will be based on the questions of the questionnaire. These questions probe the knowledge structures constructed by the teachers in the workshops. The other part of the discussion will be a review of the literature examining the findings of other researchers. Of particular interest are their findings about the acceptance and understanding of evolution, the geological time scale and the nature of science.

The following topics will be discussed next:

- Macro-evolution as part of the knowledge framework of this study.
- Darwin as a scientist, as a man of his time but equally relevant to-day.
- Understanding the nature of science and the theory of evolution as a scientific theory.
- Acceptance and understanding of evolution.
- Conceptual ecologies of evolution.

3.2 MACRO-EVOLUTION AS PART OF THE KNOWLEDGE FRAMEWORK OF THE STUDY

Whereas evolution may be described simply as ‘the process that explains how organisms change
over time’ (Krukonis and Barr, 2008, p. 8), macro-evolution is seen by many researchers as changes that happen over longer periods of time and may involve such events such as mass extinctions. One such researcher is Richard Dawkins (2005) who distinguishes macro-evolution from micro-evolution as involving evolution on a ‘grand scale over millions of years’ as opposed to a scale of individual life-times, or micro-evolution which happens in a time scale that we as humans can observe. This may account for why micro-evolution is seen to be ‘easier’ to comprehend. Dawkins thus describes macro-evolution as ‘lots of little bits of microevolution joined end to end over geological time’ (p. 620).

Others such Stephan J Gould and Niles Eldredge, as stated by Rice (2007), would interpret major environmental changes, such as relatively sudden cooling or drying of the environment, to trigger either extinction or quick evolutionary change in organisms. This would indicate that extinctions, and in particular mass extinctions, occurred by chance irrespective of the evolutionary processes involved. Thus there are different perspectives on the interpretation of macro-evolution. What is accepted is that macro-evolution is seen as a historical record of the key events in the history of life on Earth (Zook, 1995). Geological time is also described as ‘deep time’ or a metaphorical geological clock of the Earth’s history.

The links that can be made between the geological history of the Earth and the evolution of life, are important references in assessing higher-order thinking skills used by teachers. These links may result from the identification of ‘cause – and – effect’ or develop from complex interactions between various factors.

Darwin (1859/ *1968) stated these links in the first paragraph of ‘The Origin of Species’:

When on board H.M.S. Beagle, as naturalist, I was much struck with certain facts in the distribution of the inhabitants of South America, and the geological relations of the present to the past inhabitants of that continent. These facts seemed to me to throw some light on the origin of species – that mystery of mysteries, as it has been called by one of our greatest philosophers. (p. 65)

(* This reference is from the 1968 reprint.)
The first two questions of the questionnaire focus on the relationships between geological time and evolution of life, their causes and effects on the diversity of life. The third question links this to the idea of mass extinctions.

| Question 1: What can we learn from the evolution of life and the changes that the Earth has undergone in the past? |
| Question 2: Does environmental change drive evolution? Explain your answer. |
| Question 3: What evidence do we have that mass extinctions happened in the past? |

Trend (1998) points out that the concept of time lies at the heart of geology and seeking reasons for arranging events in a certain order to create a framework of reference for the Earth’s history. To Bizzo and Bizzo (2006) it is difficult to conceive biological evolution without a clear understanding of geological time. They quote Darwin’s experience in the Andes of South America, when his observations opened the ‘door of geological time’, moving well ahead of what was accepted by the ‘learned society of his time’ (p. 69).

Describing his travels in the Andes in 1835, Darwin (1845/*1997) found fossilized trees at an elevation of seven thousand feet, or at approximately two thousand three hundred metres, the tree stumps projected about a metre above the ground.

*It required little geological practice to interpret the marvellous story which this scene at once unfolded; though I must confess I was at first so much astonished, that I could scarcely believe the plainest evidence. I saw the spot where a cluster of fine trees once waived their branches on the shores of the Atlantic, when the ocean (now driven back some 700 miles) came to the foot of the Andes. I saw that they had sprung from volcanic soil which had been raised above the level of the sea, and that subsequently this dry land, with its upright trees, had been let down into the depths of the ocean...*(p. 316).

(* This reference is from the 1997 reprint.)

By examining the geological evidence, Darwin had become aware that land surfaces had risen and subsided repeatedly, and formed part of cyclical forces acting in nature. The fossilized remains of the trees which he had found high up in the Andes indicated that the land had been at a much lower elevation when the trees had originally grown there. With subsequent subsidence the area was below sea level causing fossilization of the trees to occur, in sediment now also containing
marine shells. As part of the cyclical nature of land surface evolution, the whole area had been raised again to form the summit of the mountain range, where these trees now were part of a desert where ‘even the lichen cannot adhere to the stony castes of former trees’ (Darwin 1845/ *1997, p. 317).

Darwin’s initial fame was based on his work as a geologist and it is interesting to see how he used this knowledge as a framework to interpret the world around him, in this case the Andes Mountain Range of South America. ‘Thinking on such a large scale, Darwin developed his own interpretation of the Earth’s crust as huge sheets of rock – a similar concept to modern plate tectonics’ (Pearn, 2009, p. 83).

On the one hand, Dodick and Orion (2003) feel that at the core of geology as a discipline are the concepts of deep time and plate tectonics. These concepts play an important part in the understanding of not only geological processes, but also that of cosmology and evolutionary biology. On the other hand, at the core of the life sciences according to Dempster and Hugo (2006), is Darwinian evolution as a unifying theme of biology – the highest ordering principle of biology which deals with questions relating to the ultimate causation of form and function at all levels of life. Thus macro-evolution as a topic incorporates both the cornerstones of geology, geological time and plate tectonics, and the unifying principle of biology in the form of Darwinian evolution. This makes macro-evolution a suitable topic for researching higher-order thinking skills because inter-relationships between the various key concepts can be explored fully.

A member of the ‘Modern Synthesis’ movement, which developed a modern understanding of how evolution works by merging Darwinian evolution and Mendelian genetics, Ernst Mayr suggested that biology is structured around three questions, termed, ‘what’, ‘why’ and ‘how’ questions (Dempster and Hugo, 2006). Thus,

- descriptive biology answers the ‘what’ questions,
- functional biology answers the ‘how’ questions, and
- the highest level of questions focuses on ‘why’, seeking the ultimate causes for structures and functioning of living organisms.
Because ‘why’ questions explore causation, they examine historical and evolutionary factors that help to explain the observed structures and functioning of organisms. However, ‘it is possible to teach biology at the level of descriptive and functional biology, without ever addressing ultimate causation’ (Dempster and Hugo, 2006, p. 106). This is an important consideration when examining the outcome of effective teaching of evolution and the development of higher-order thinking skills. In their research about beliefs about evolution and student learning, Cavallo and McCall (2008) point out that students ‘seem to struggle with the complexities of the theory itself’ (p. 524). Although evolution is a difficult theory to learn, it is further compounded by a failure to understand the importance of the unifying aspects of the theory, the same authors maintain.

In terms of understanding of geological time, Trend (2001) feels that, as with events related to macro-evolution, many students encounter problems because they cannot observe geological change directly and fail to grasp the magnitude of time involved. As a consequence, they resort to interpreting change as being caused by catastrophes rather than seeing it as a gradual process over long periods of time.

Trend (2000) also stresses that the failure of teachers to grasp deep time or geological time, affects their ability to teach the topic effectively. The teachers’ quality of engagement with the ‘broader matters, ranging from environmental issues (e.g. sea-level changes and coastal retreat) to longer-term matters (e.g. asteroid impacts, periods of enhanced volcanic activity, mass extinctions, and evolution of the Universe)’ will hence impact on their ability to incorporate higher-order thinking skills into their teaching (p. 539). An insecure framework of geological time also leads to an inability to accommodate new learning into existing knowledge structures and could lead to an avoidance of such understanding by both teachers and learners (Trend, 2000).

Little research about the understanding of geological time is available (Dodick and Orion, 2003; Trend 2000; and Hildalgo, San Fernando, San Fernando and Otero, 2004). Of particular interest is probing the understanding of the reasons for the arrangement of events in a certain order, which give rise to a geological time scale, and why this is based on the sequence of rock strata and fossils.
3.3 DARWIN AS A SCIENTIST, AS A MAN OF HIS TIME BUT EQUALLY RELEVANT TO-DAY

The fourth question of the questionnaire relates to Darwin as a scientist:

**Question 4**: Although Darwin was born two centuries ago (1809 – 1881), he is still considered to be a great scientist to-day. Explain why this is so.

### 3.3.1 Darwin as a scientist

Writing in his ‘Recollections of the development of my mind and character’ in 1876, Darwin described why he saw himself as a good scientist ‘in noticing things which easily escape attention, & in observing them carefully’ (Darwin 1876/ *2010, p. 423). It is worthwhile quoting most of rest of the paragraph that follows because it describes so succinctly why Darwin was such a good scientist.

> My industry has been nearly as great as it could have been in the observing and collection of facts. What is far more important is my love of natural science has been steady & ardent. This pure love has however been much aided by the ambition to be esteemed by my fellow naturalists. From my early youth I have had the strongest desire to understand or explain whatever I observed, - that is to group all facts under some general laws. These causes combined have given me the patience to reflect or ponder for any number of years over any unexplained problem. As far as I can judge I am not apt to follow blindly the lead of other men. I have steadily endeavoured to keep my mind free, so as to give up any hypothesis, however much beloved (& I cannot resist forming one on every subject) as soon as the facts as facts are shown to be opposed to it… (p. 423).

(* This reference is from the 2010 reprint.)

Developing these comments further, it is apparent that although all natural scientists have skills such as observation, description and classification, for Darwin this was not enough in that he strove to find explanations underlying even the most commonly observed phenomena. In approaching systems of classification he looked for patterns of similarities between organisms rather than ascribing this to divine creation as was the habit of many fellow naturalist of his time. Darwin also conducted many investigations involving the reproduction of plants and domestic animals such as...
pigeons, breeding new varieties for further study. ‘He never tired of observing living things for new insights into behaviour and ecology’ (Thomson, 2007, p. 273).

Darwin sought information from a wide range of experts from all over the world with whom he corresponded and obtained many specimens from. ‘This was natural history on a grand scale, involving the synthesis of almost all of contemporary biology into evidence for his theories’ (Thomson, 2007, p. 273).

Darwin’s belief was that all knowledge could potentially be of use to him. ‘Knowledge was knowledge, whether it was a pigeon-fancier’s knowledge or a professor’s knowledge. As a result he was simply better informed than anybody else’ (Aydon, 2008, pp. 286-7). Darwin not only had the ability to observe things that other people did not notice, but he also had the ability to see the significance of such observations and make connections that other scientists would not have thought of.

It is not surprising that in collecting all this information that Darwin varied his approach to suit his needs by using both deductive and inductive reasoning in developing his ideas further. This was unusual in a time when most naturalists were inclined to assemble facts from which they could construct theories inductively.

3.3.2 Three men who served as role models for Darwin as a scientist

Charles Lyell, Alexander von Humboldt and John Herschel greatly influenced Darwin in the way he recorded his observations, how he interpreted them and the scientific methodology which he used to construct his theories. Thus Lyell provided a theoretical framework, Humboldt adopted a holistic approach to observing the world and Herschel gave the philosophical underpinning of scientific reasoning.

Darwin read Lyell’s ‘Principles of Geology’, published during 1830 to 1833, whilst traveling around the world in the Beagle. Lyell’s work gave Darwin the theoretical framework which he needed to support his observations about the Earth’s surface and the features relating to the geology of the
areas which he visited such as mountain ranges. In particular, Lyell promoted the idea that changes to the Earth’s surface happened gradually and over long periods of time. This was in direct contrast to the ideas of that time in which features of the Earth’s surface were seen to be as the result of brief, rapid and catastrophic events.

The narratives of Humboldt were based on his travels to South America. He was a proponent of holistic scientism in which his observations were made in terms of not only the geology, but also looked at the soil, the climate, the biology, the people and their culture of the area described.

Underlying all Humboldt’s study was his view of the natural world as an organic whole – a living unity of diverse and interdependent life forms rather than some mechanical structure. He developed this universal concept of nature beyond anything that was professed at the time, heralding the study of ecology and environmentalism. (Magee, 2007, p. 224)

Humboldt insisted that conclusions were drawn only from the rigorous collection of data, accurately and directly observed from nature. He possessed ‘an extraordinary breadth and depth of interest in science incomparable to his day and since’ (Magee, 2007, p. 232). It is not surprising that Humboldt inspired a whole generation of scientists, Darwin included.

From his mentors, Lyell, Humboldt and Herschel, Darwin was influenced by their beliefs about the world and how it should be studied. ‘In the cause of the voyage, however, he found himself applying, testing and modifying these beliefs against a set of personal experiences that far transcended those of his teachers and intellectual heroes’ (Sloan, 2009, p. 32). Thus in his writing Darwin incorporated a synthesis of description, causal explanation and even reports of experimental enquiries, and explored geological and biological questions which related to his travels.

3.3.3 How Darwin structured the Origin of Species

The Origin of Species was structured as ‘one long argument’ rather than as a history of the evolution of life. The argument for evolution was developed according to the ideal for scientific
reasoning as described by John Herschel who was an influential philosopher of Darwin’s time. Firstly, it was required that Darwin should establish the existence of natural selection. This he did by drawing on his wealth of knowledge about artificial selection, variation under domestication, and citing many examples from pigeons to fruits of the orchard. Next, he justified that such selection also happened in nature, as ‘variation under nature’. In the final part of the argument he explained why the processes of natural selection were the real causes of, and responsible for, the origin of species and the preservation of favoured races in the struggle for life.

3.3.4 Two central ideas in the Origin of Species: Natural Selection and the Tree of Life

Natural selection explained how species could change. Darwin explained how species changed in nature through a process of selection similar to the methods of artificial selection used by breeders to modify domesticated varieties of plants and animals. The tree of life represented a model of how over time, some species became extinct while other species continued or split to form various descendent species.

Waters (2009) explains these ideas further:

*The tree of life and natural selection played distinct roles in the ‘Origin’ and it is important to distinguish between them. It is also helpful to keep in mind that the tree of life itself involves two different ideas: the idea of one species changing into another, or ‘transmutation’; and the idea of species splitting into two or more species, resulting in ‘common descent’. The claim of common descent distinguishes Darwin’s theory of evolution from those of his precursors.* (p. 123)

The idea that species could evolve challenged the notion of immutability of life. The fact that species were thought to be fixed and the unchanging ‘essence’ held by individual species, dated back to the ancien regime and the philosophies of Plato and Aristotle. Many of Darwin’s contemporaries, including his mentors Lyell and Herschel, were deeply unsettled by his ideas on the origin of species and the contention that life could evolve, diversify and become more complex without evolving towards a goal.
3.3.5  A paradigm shift

In terms of Thomas Kuhn’s philosophy of science, a regime shift happens when too many and anomalous facts fail to fit, or fit uneasily, with the current theoretical explanations. What follows, Hodge and Rodick (2009) explain as a ‘crisis, resolved only through a revolutionary upheaval suddenly resulting in a regime shift … to give rise to a new paradigm’ (p. 247). The crisis about the explanation of the evolution of life continued over many decades, and still exists in some quarters. However, generally to-day, evolution is accepted by biologists as a fact that all living things are related (Dawkins, 2009). The *Origin of Species* caused a paradigm shift in the biological sciences and gave a new framework of thinking about the evolution and diversity of life. Grayon (2008) concludes about the impact of Darwin’s initial sketch of his idea of a tree of life as: ‘retrospectively, the sudden and dramatic effect of the famous tree of life diagram constitutes one of the most spectacular examples of a shift of paradigm’ (p. 282).

In writing the *Origin of Species* Darwin was a man of his time, following the trends of scientific methodology prescribed by members of the scientific community such as Herschel, Sedgewick, Lyell, Humboldt and Sir Joseph Hooker. However, Darwin as a scientist is still respected to-day which leads Waters (2009, p. 120) to comment: ‘Reading *On the Origin of Species* is a rite of passage for many biologists and its reasoning continues to play a pivotal role in biological thought’.

### 3.4 UNDERSTANDING THE NATURE OF SCIENCE AND THE THEORY OF EVOLUTION AS A SCIENTIFIC THEORY

The fifth question of the questionnaire probes the teachers’ understanding of the nature of science and their ability to relate this to evolution interpreted at different levels of generality (fact, theory and law).

**Question 5:** Explain how ‘Darwin's Finches’ found on the Galapagos Islands, illustrates that evolution is a fact; evolution is a theory; evolution can be a law.

Question 5, given above, is a difficult question because it probes how teachers perceive the nature of science in terms of their understanding of what is meant by a scientific fact, theory and law. The
question also probes their understanding of ‘Darwin’s Finches’, how they evolved and why this information is important in evolutionary theory.

The nature of science is socially constructed by the scientists of a scientific community. What makes science unique is that different scientists interpret observations, theories and laws in their own way. Thus there exists no single interpretation of what constitutes ‘the’ scientific method and what are the characteristics of the nature of science. As an introduction to this section, two different points of view expressed by Medawar and Bronowski are given below to highlight the individuality of perspective held by scientists.

3.4.1 Two scientists' views on the nature of science

Sir Peter Medawar was involved in research in immunology which made the transplant of organs such as the heart possible. He was awarded the Nobel Prize for Medicine in 1960. He wrote several books and ‘classic essays on science’ for the general public. It is from the latter that the following quotations about the ‘two concepts of science’ are derived (Medawar, 1965/ *1996, p. 63).

Every advance in science is therefore the outcome of a speculative adventure, an excursion into the unknown. According to the opposite view, truth reside in the nature and is to be got at only through the evidence of the senses: apprehension leads by a direct pathway to comprehension, and the scientist's task is essentially one of ‘discernment’. This act of discernment can be carried out according to a Method which, though imagination can help it, does not depend on the imagination: the Scientific method will see him through.

(* This reference is from the 1996 reprint.)

Medawar continued his argument about the contradicting opinions of what scientists should be, by giving his perceptions about the two sides of scientists:

For a scientist must indeed be freely imaginative and yet sceptical, creative and yet a critic. There is a sense in which he must be free, but another in which his thought must be very precisely regimented: there is poetry in science, but also a lot of bookkeeping. (p. 63)
It is interesting to notice how Medawar had identified various characteristics of the nature of science, formulated later in the century (that of empirical evidence, discernment or tentativeness, creativity, and the use of the scientific method – laws and theories).

**Jacob Bronowski** was a mathematician, scientist and broadcaster who wrote about the essential nature of science, the common sense of science, and how this affected our everyday lives. He saw three ideas which were central to science: they are ‘the idea of order, the idea of causes, and the idea of chance’ (p. 18). These ideas are not unique to science only and do not relate directly to the characteristics of the nature of science discussed below, but rather to the ‘common sense of science’ in our everyday lives.

About order, Bronowski (1951) commented on how the structure or hierarchy of ordered knowledge in the Middle Ages was ‘overthrown’ by the Scientific Revolution: ‘We could say that the Middle Ages saw nature as a striving towards its own inner order; and that the Scientific Revolution overthrew this order and put in its place the mechanism of causes… and a mechanism of events’. He concluded that the Scientific Revolution was a ‘change from a world of things ordered according to their ideal natures, to a world of events running in a steady mechanism of before and after’ (p. 31).

In considering the idea of chance, it is worthwhile examining what Bronowski had to say about laws first. By examining facts and events, there is an attempt to establish a pattern, which gives order and structure to these events. This can be translated into a law. A law may contain the words ‘always’ or ‘more often than not’. It is the latter form which usually applies to the biological sciences. It is at this point that the idea of chance is introduced, when considering laws that do not contain the word ‘always’. The idea of chance thus affects the ‘incisiveness of the simple laws of cause and effect’ (p100). Bronowski (1951) explained this further:

> Essentially the thought depends not on unlimited accuracy in measuring a character, but on judging the accuracy by a measure of the inherent variation from individual to individual which we cannot escape. We look for a trend or systematic difference. The line of this trend will itself be blurred by the unsteady hand of chance or random fluctuation. (p. 98)
The idea of chance features prominently in natural selection, both in how the variation of these characteristics in individuals arises and in how the concept of fitness is used to predict their chances of survival. In order to study the fitness of individuals and populations to survive, scientists have introduced probability models based on the effect of chance using statistical procedures. The ‘language of probability’ is also used in developing procedures in predicting how organisms are related, as represented by the tree of life, a vital component of the theory of evolution’ (Sober, 2009, p. 320).

### 3.4.2 The nature of science and relevant research in science education

An understanding of what is science, and what is not science; what science can do and what it cannot do, are important considerations in defining the nature of science (Schwartz, Lederman and Crawford, 2004). Thus what makes science ‘science’, is determined by the characteristics, or combination of characteristics, which will make it unique. Although some disagreement exists among scientists, science educators, historians and philosophers of science as to what this uniqueness really is, there are general characteristics or tenets of the nature of science which are accepted by most. These aspects of the nature of science are useful in guiding researchers in the assessment and analysis of the understanding of the nature of science by students and teachers (Liu and Lederman, 2007).

There is no single understanding of what is the nature of science. However, within a postmodernist view it is accepted that ‘science is a human endeavor, directed by theory and culture, reliant on empirical observation, and subject to change’ (Schwartz et al., 2004, p. 612).

Although the characteristics used to describe the nature of science have only been devised within the past couple of decades, it is an interesting exercise to examine Darwin as a scientist of the eighteen hundreds in terms of these criteria. (Within the brackets are examples from the previous section on Darwin as a scientist, as well as other suitable quotations, which illustrate how well the criteria link a scientist of two centuries ago (Darwin) with the current ideas about the nature of science.) These characteristics are discussed below with the examples of Darwin as a scientist.
The aspects or tenets of the nature of science which are described below, are based on the work by Schwartz et al., 2004, p. 613).

**Tentativeness** – scientific knowledge is subject to change and with new observations a reinterpretation of existing observations may occur.

*(Having read Lyell’s books about the Principles of Geology during his voyage around the world, Darwin initially accepted Lyell’s explanation of Special Creation. In this interpretation each species originated in one place, which was providentially determined. The species could multiply and even adapt to the environment, but could not change into new species. Darwin’s collection of bird species, observations about tortoises that occurred on the various islands of the Galapagos and plant specimens such as those from the prickly pears, made him become suspicious of Lyell’s explanation attributed to Special Creation. From his observations regarding the similarities between the species that occurred on the mainland of South America and those that occurred in the Galapagos, Darwin concluded that they shared common hereditary characteristics. Each species was not specially created. This lead Darwin to formulate his interpretation of a ‘tree of life’, in which one species can change to form new species and that all species are related.)*

**Empirical basis** – scientific knowledge is based on/or derived from observations of the natural world.

*(Darwin drew on his wealth of knowledge about facts concerning artificial breeding of plants and animals to help establish the ‘long argument’ for his theory of natural selection.)*

**Creativity** – scientific knowledge is created from the human imagination and logical reasoning. This creativity is based on observations and inferences of the natural world.

*(Darwin created his vision of the ‘tree of life’ to explain the descent of species from earlier ancestors, based on his observations of the many examples he saw during his voyage around the world, including his visits to islands, such as those of the Galapagos Islands.)*
**Subjectivity** – science is influenced and driven by the presently accepted scientific theories and laws. The development of questions, investigations, and interpretations of data are filtered through the lens of current theory. On the one hand, it allows science to remain consistent but may contribute to change if the evidence is examined from the perspective of new knowledge. Personal subjectivity is unavoidable because personal values, agendas and prior experiences dictate what and how scientists conduct their work.

*(The current theories, in Darwinian times, about the Earth’s history were based on the idea that the Earth was only a few thousand years old and that the geological events, such as mountain building, happened quickly and catastrophically. Lyell’s theory, on the other hand, was based on slow and gradual change of the Earth’s surface which required long periods of time for this to happen. Darwin was greatly influenced by this ‘new’ theory, which opened the ‘door to geological time’ and how he interpreted his observations of the geology of the Andes in South America.)*

**Socio-cultural embeddedness** – science is a human endeavor and is influenced by the society and culture in which it is practiced. The values of the culture determine what and how science is conducted, interpreted, accepted, and utilized.

*(The publication of the ‘Origin of Species’ in 1859 caused Lyell and Herschel to reject Darwin’s theory because Herschel in particular, felt God created the primary laws of the universe and that humans created only the secondary laws. Lyell objected to the fact that Darwin had not acknowledged the role of the Creator in his theory, which was interpreted as a ‘primary law of the universe’. These objections were subjective and influenced by what was the interpretation of what scientists were allowed to do and how they should construct their theories in the mid-eighteen hundreds.)*

**Observation and inference** – science is based on both observation and inference. Observations are gathered through human senses or extensions of those senses. Inferences are interpretations of those observations. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.
(Darwin read the essay by Malthus (a clergyman who used his essay to argue against the doctrine of Divine Providence) about the control of population growth of humans. From Darwin’s long-continued observations of the habits of animals and plants in the natural world, he appreciated that the struggle for existence also happened in human populations. Darwin could now infer from a natural world perspective and thus from a different perspective to that of Malthus, that the struggle for existence also happened in the natural environment, where favourable variations would tend to be preserved and unfavourable ones would be destroyed.)

Laws and theories – laws and theories are different kinds of scientific knowledge. Laws describe relationships between phenomena, and may look at ‘cause - and - effect’. Theories explain these natural phenomena and may also explain the relationships among natural phenomena. Hypotheses in science may lead to either theories or laws with the accumulation of further supportive evidence and acceptance of the scientific community. Theories and laws do not progress into one and another, in the hierarchical sense, for they are distinctly and functionally different types of knowledge.

(In the Origin of Species Darwin cited laws based on ‘cause and effect.’ In his chapter on ‘laws of variation’, Darwin quoted a law relating to ‘compensation or balancement of growth; or, as Goethe expressed it, ‘in order to spend on one side nature is forced to economise on the other side’ (Quammen, 2008, p. 158).

Another example of a law, which in this case, relates to the geographical distribution of species, in chapter xii, is that inhabitants of an archipelago such as that of the Galapagos, ‘though specifically distinct, to be closely allied to those of the nearest continent’, (Quammen, 2008, p. 409).

Darwin stressed the explanatory power of his theory on natural selection by stating in chapter xiii, ‘that natural selection, which results from the struggle of existence, and which almost inevitably induces extinction and divergence of character in the many descendents from one dominant parent-species, explains that great and universal feature in the affinities of all organic beings namely, their subordination in group under group, (Quammen, 2008, p. 456).)
Southerland, Johnson and Sowell (2006), in their survey of existing science education literature on the nature of science, also identified the ‘bounded nature of science’ as a central concept in teachers’ conceptual frameworks. In focusing on how teachers established their own understanding of the nature of science, the notion of the ‘bounded nature’ of science helped them to compare and to contrast religion and science which provided the researchers with ‘unique this portraits of how they drew boundaries around science, defining it as a unique and distinct way of knowing’ (p. 883).

**Bounded nature of science** – ‘there are things that are better explained by science, however, there are things that science cannot explain’ and ‘science and religion are different in the way they interpret the world, and with what each considers to be a reliable means to validate these interpretations’ (Southerland et al., 2006, p. 885).

*(Darwin (1876/ *2010), writing about his recollections in his autobiography, acknowledged the boundary of science when he noted: ‘the mystery of the beginning of all things is insoluble by us, & I for one must be content to remain an Agnostic.’ (p. 396))

(* This reference is from the 2010 reprint.)*

From the above discussion, it is apparent that Darwin was a ‘man of science’, even in modern terms according to the tenets of the nature of science, only recently constructed. In commenting on how pre-service teachers may be introduced to ‘how science works’, Hutton (2008) suggests that by studying the lives of scientists they can appreciate the methods of science, the nature of science and how scientists working in different fields have adapted these principles within the contexts that they work.

Although the nature of science focuses on what science is and what it is not, misunderstanding of the nature of science lies at the root much of the confusion about evolution (Scotchmoor and Janulaw, 2005). These authors refer to ‘Understanding Evolution’ (http://evolution.berkeley.edu), a web-based resource developed to address such misunderstandings, which was designed by the University of California’s Museum of Paleontology and the National Center for Science Education. One of the aspects that arise from this web-site resource is the ‘bounded’ nature of science, which
emphasize that although creative flexibility is essential, scientific thinking follows ‘a process guided by certain parameters’. These ‘parameters’ are embedded within the culture of science, at a specific time, and that scientific ideas are developed through reasoning. Much of the knowledge that we have is based on inferences which are drawn from data empirically derived. Good examples of this would be ‘no person has ever looked inside an atom but we know what is there’ and ‘no person has lived through deep time but we know it has occurred’.

In addition to the characteristics of science already discussed, ‘Understanding Evolution’ web-site also includes:

- **Science is not democratic** – science is based on evidence, not votes. The example cited is that of the question of plate tectonics. When first presented in the early twentieth century, based on a democratic vote, it would have been rejected – thus removing a valuable explanation for the origin of much of the Earth’s terrain from our knowledge today.

- **Science is non-dogmatic** – ‘to ask someone to accept ideas purely on faith, even when these ideas are expressed by “experts”, is unscientific’. This is an important consideration when dealing with the science and religion controversy in the classroom.

- **Science cannot make moral or aesthetic decisions** – ‘being human, scientists make moral and aesthetic judgments and choices, as do all citizens of our planet, but such decisions are not part of science’. Again this is an important consideration when debating the science and religion controversy in the classroom.

- **Scientific claims are subject to peer review and replication** – ‘peer review is an integral part of genuine scientific enterprise. The process of peer review includes examination of other scientists’ data and logic. It attempts to identify alternative explanations, and attempts to replicate observations and experiments’. This point clarifies why science is not democratic, is non-dogmatic and should not make moral decisions in the name of science.

A characteristic of science is, therefore, to examine evidence carefully in order to determine whether there exists another, more feasible, explanation possible. This leads to the importance of falsification of theories of science.
3.4.3  The theory of evolution is a scientific theory

Karl Popper originally was a psychologist interested in the methodology associated with the psychology of thinking. With the publication of his work, ‘The Logic of Scientific Discovery’, Popper made the transition from being a psychologist with a strong inclination towards the philosophy of science to a philosopher of science with a background in psychology (Kurz, 1996). He was also a colleague and friend of Sir Peter Medawar, quoted earlier in this section.

According to Popper all genuinely scientific theories can be falsified. This is so, because based on empirical data there could exist, somewhere, a possible observation that could falsify such a scientific theory. ‘A properly scientific statement makes a positive claim about how the world might be. It runs the risk of being false – the world may turn out not to be as the theory claims’ (Law, 2007, p. 187). This distinguishes scientific theories based on evidence, from non-scientific theories which are not based on empirically derived data.

Theories are not confirmed inductively, but they are falsified by deductive reasoning (Law, 2007). Thus scientists construct theories from which they can derive or deduct testable conclusions. If these conclusions are incorrect or false, then the theory has been falsified and is discarded. New theories, replacing the falsified theory, are then constructed to account for the incorrect conclusions of the previous theory. (This is an important consideration when dealing with null hypotheses and statistical procedures. Null hypotheses may either be rejected or not rejected. They cannot be accepted, which would indicate that they cannot be falsified. In other words, by rejecting a null hypothesis, it is falsified and the ‘world’ has turned out differently to what the hypothesis ‘claimed’ it is. A new hypothesis is required, perhaps the opposite to the falsified null hypothesis. If the null hypothesis is not rejected it has not been falsified. This indicates that the world described by the null hypothesis may indeed reflect the ‘real’ world but is not considered to be scientific yet because it has not been falsified.)

How the falsification of a theory may occur, is illustrated by considering an aspect of evolution which is debated by several evolutionary biologists. In his view, Darwin perceived evolution to happen gradually over a long period of time. This was called gradualism. However, as more fossil
data became available, an alternative pattern emerged to that of gradualism. This involved some organisms that had existed over a long period of time, such as the trilobites and ammonites. Stephen J Gould and Niles Eldredge proposed the theory of *punctuated equilibrium*, based on their observations of how certain fossil species remained relatively unchanged for a long time and then diversified rapidly over a comparatively short period of time. This was not in accordance with Darwin’s perception of ‘gradualism’ (Rice, 2007).

By examining the theory of evolution by natural selection, it was apparent that the processes associated with natural selection had not been affected by the new theory of punctuated equilibrium. However, the patterns associated with how organisms evolved over long periods of time could be different.

Thus the definition of evolution now reads simply that ‘evolution is the process that explains how organisms change over time’ (Krukonis and Barr, 2008, p. 8) and does not state that they evolved ‘gradually’ as the only option. It must be remembered though, that Darwin presented his theory as having five tenets:

- Species are not constant and change over time.
- All organisms had a common ancestral population.
- *Evolutionary change occurs gradually.*
- One species can diversify into more than one species.
- Evolution happens by natural selection.

It is only the third tenet which has been modified by Gould and Eldredge to include more than one pattern in which change can occur. This leads to a better and more comprehensive understanding of evolution as a scientific theory (Rice, 2007). However, it demonstrates that the theory of evolution is based on evidence, may be falsified if new evidence is discovered, and may be seen as a genuinely scientific theory.

### 3.4.4 Research findings about the nature of science

Researchers have identified a misunderstanding of several aspects of the nature of science. They
have labeled these either as ‘naïve views’ (Abd-El-Khalick and Akerson, 2004) or ‘misconceptions of science’ (Cooper, 2004; Cavallo and McCall, 2008) or ‘myths’ (Liu and Lederman, 2007).

The first common trend seems to involve laws and theories of science. Abd-El-Khalick and Akerson (2004) found that about 90% of their sample believed that scientific laws are ‘proven true’ and consequently not liable to change. The majority of this sample (75 – 82%) did not show an understanding of the inferential, creative or theory laden aspects of science. Thus they saw science as knowledge gained by using the senses only (not the importance of inferences based on these observations), that there was only one scientific method used by all scientists, and that a theory is ‘someone’s idea’ of what happens and can be proven to be true.

Cavallo and McCall (2008) identified a similar trend, a view that in science things are ‘proven’ to be true:

- Experiments were designed to create answers to questions and that experiments also proved that the ideas were definitely either right or wrong.
- Some students believed that scientists wanted to be personally correct and that science moved forward through correct answers, experimental results were not objective and that theories were proven hypotheses.
- Theories became laws if they were proven to be correct.
- Laws were seen to be absolute knowledge and that the difference between a law and a theory depended on the level of confidence (how correct) of the knowledge contained therein.

In a similar trend, Liu and Lederman (2007) found that it was considered to be ‘more scientific’ if experimental work was involved in a laboratory under controlled conditions and less scientific if the investigations were of a historic or comparative nature. Thus Cooper (2004) identified a major misconception, responsible for rejecting evolution, was that ‘when’ evolution occurred, there was no one present to witness it and to see what had happened. A lack of understanding exists of how evolutionary biology, a historical science, is based on interpreting the past by studying the patterns shown in existing evidence. It is still based on inferences derived from empirically derived data, used to identify the processes and causes that contribute to evolutionary change of organisms.
Furthermore, Cavallo and McCall (2008) point out that student beliefs about the nature of science provide a context for probing how they go about understanding and learning evolution as a topic. The students may hold the following beliefs:

- Science is dynamic and tentative – scientific conclusions are based on evidence and conjecture, and thus are connected to an understanding of the world.
- A static view of science which is fixed – a tendency to believe that science always arrives, or attempts to arrive, at the truth, and thus ‘learning science through memorization, diverted from their everyday lives’ (p. 523).

Liu and Lederman (2007) also found that in ‘non-European’ countries, such as Taiwan, that teachers view science as being close to technology and thus as being useful for future careers, but school related and with little evidence to everyday life. ‘Science is materialistic and not involved in the learners’ everyday thinking’ (p. 1284), these authors conclude. Furthermore, ‘many researchers believe that the teachers’ social and cultural values might affect their implementation of the school curriculum’ (p. 1302), the same authors contend.

In constructing a ‘nature of science profile’ Nott and Wellington (1993) developed an interesting activity to encourage science teachers to explore the image they have of science. The authors devised a set of statements about science which the teachers had to score according to how well they agreed with each item. The profile is based on five axes. For each of the axes, the teachers rank their beliefs according to responses to certain statements about the nature of science. The first axis explores relativist versus positivist; the second axis looks at inductivism versus deductivism; the third axis concerns the truth of scientific knowledge as contextual or decontextual; and the last two axes measure process versus content and instrumentalism versus realism.

The brief explanations given below are adapted from the definitions offered by Nott & Wellington (1993, p. 111):

- a relativist sees the truth of a theory as based on the norms of the rationality of a social group; that truth is relative and not absolute; or,
- a positivist considers scientific knowledge as more valid than other forms of knowledge
and sees science as the primary source of truth,

- a scientist's job is to interrogate nature by using inductivism or deductivism,

- a view that the truth of scientific knowledge is contextual and is interdependent with the culture in which scientists live and in which it takes place, or, decontextual in which scientific knowledge is independent of its cultural position and sociological position,

- a view of science as characterized by a set of methods and processes (process); or by facts and ideas that should be acquired and mastered as a 'body of knowledge' (content),

- a view that scientific theories and ideas allow for predictions to be made, are instruments but say nothing about independent reality (instrumentalism); or scientific theories are statements about a world that exists independent of the scientists’ perceptions (realism).

The exercise was designed to encourage teachers to reflect on how they view science and to accept that there are different points of view and many ‘natures of science’. Nott & Wellington do stress that the way teachers teach science and the pedagogy they use, may well be linked to their understanding of the nature of science.

(Researcher's comment: It is interesting to note that when I completed the profile I was rather surprised to find that I was inclined slightly more towards being a relativist on the relativist-positivist scale; more inclined towards deductivism than inductivism; seeing scientific knowledge much more as being decontextual than as contextual; slightly more inclined towards content rather than process and finally, tending more towards realism than instrumentalism.)

3.5 ACCEPTANCE AND UNDERSTANDING OF EVOLUTION

One way of measuring the effectiveness of instruction in evolutionary biology, is by assessing the change in acceptance of evolution, rather than monitoring a change in beliefs about evolution
An instrument to measure such acceptance, called MATE, or Measure of Acceptance of Theory of Evolution, was developed by Rutledge and Warden (1999). MATE is ‘designed to measure teachers’ overall acceptance of evolutionary theory by assessing their perceptions of evolutionary theory’s scientific validity, ability to explain phenomena and acceptance within the scientific community’ (pp. 13-14). Consisting of twenty items, some correct and others not, the instrument addressed the following six concepts, given with selected examples to illustrate each concept:

- **The process of evolution**, for example -
  - **Statement 1**: Organisms existing today are the result of evolutionary processes that have occurred over millions of years.
  - **Statement 19**: With few exceptions, organisms on earth came into existence at about the same time.

- **Scientific validity of evolutionary theory**, for example –
  - **Statement 2**: The theory of evolution is incapable of being scientifically tested.
  - **Statement 13**: Evolutionary theory generates testable predictions with respect to the characteristics of life.

- **Evolution of humans**, for example –
  - **Statement 15**: Humans exist today in essentially the same form in which they always are.

- **Evidence of evolution**, for example –
  - **Statement 16**: Evolutionary theory is supported by factual historical and laboratory data.

- **Scientific community’s view of evolution**, for example –
  - **Statement 5**: Most scientists accept evolutionary theory to be a scientific theory.

- **Age of the Earth**, for example –
  - **Statement 11**: The age of the earth is at least 4 billion years.

Teachers recorded their responses to the twenty items using a five point scale ranging from ‘strongly agree’ to ‘strongly disagree’.

Rutledge and Warden (2000) used MATE to research the acceptance of evolution by Indiana teachers. Two further sub-scales were included to cover ‘understanding of evolutionary theory’ and ‘understanding of the nature of science’. Their findings showed a significant relationship and positive correlation, between the acceptance of evolution and understanding of evolution; and between the acceptance of evolution and understanding of the nature of science.

Teachers are critical in providing quality classroom instruction and in their ability to make professionally responsible decisions in terms of how they interpret the curriculum and implement it.
in achieving effective teaching. About one fifth of the Indiana sample of teachers did not accept evolution or were undecided about evolution, which raised the question about their effectiveness in teaching evolution as a scientific theory.

Trani (2004) repeated a similar study using a sample of Oregon teachers. He concluded that the strength of their religious beliefs negatively correlated with the teachers’ understanding of the nature of science and their understanding of the theory of evolution.

He also found that teachers who had a good understanding of the nature of science and the theory of evolution, accepted evolution even if they were religious. ‘In other words, you can be religious and accept evolution’ (p. 425). As was the case with the Indiana group of teachers, Trani’s survey also identified a similar proportion of teachers (16%) who did include evolution in their teaching, who did not understand the theory of evolution or the nature of science; and had strong or extreme religious convictions. This led him to suspect that the rejection of evolution was based not on religious convictions but was based on a lack understanding of the theory of evolution itself and a lack of understanding of the nature of science.

Ingram and Nelson (2006) developed the idea of acceptance of evolution further by interpreting ‘acceptance’ as an attitude and measuring ‘understanding’ of evolution by the achievement of grades obtained by their students. For these researchers, understanding was more important than accepting evolution. They found that a good understanding of evolution could be achieved despite having a negative attitude towards evolution. This sentiment has also been expressed by Sinatra, Southerland, McConaughy and Demastes (2003). However, students were more positive towards the individual tenets of evolution, such as species are not constant but change over a period time, or the process of natural selection; than towards the general statement of evolution. This was probably linked to the belief, that in order to accept evolution, one must reject God.

Of South African interest is the work done by Chinsamy and Plagányi (2007) who used first year science students at the University of Cape Town, to find out more about their attitudes towards and acceptance of evolution, and also to assess their background knowledge and understanding of the topic. They found that students accepted more readily factual information about evolution, such as
the age of the Earth, than evolutionary concepts such as natural selection. There was, however, no change in their religious-based concepts related to evolution after instruction. An example of such a religious-based concept which they used in their study was ‘evolution is the creator’s method of creation’.

These researchers recommended developing ‘reasoning skills’ further by covering less content but in greater depth (deep learning), similar to the recommendations made by Rutledge and Warden (2000). Chinsamy and Plagányi (2007) also pointed out that some textbooks had created a ‘false evolution-religion dichotomy’ which should be ‘destroyed’ and replaced with textbooks in which the texts were ‘underpinned with clear science and evolutionary principles’ (p. 252).

Using an on-line questionnaire, Gregory and Ellis (2009) surveyed the acceptance of evolution among Canadian post-graduate science students from various disciplines. They found that 70% of the respondents accepted that evolution was a fact, supported by overwhelming evidence. Only 11% of the respondents felt that evolution was ‘just a theory’. Even though many of those who responded were not from the life sciences, there was a positive correlation between the acceptance of evolution and the understanding of evolution. An area of concern was the concept of a scientific theory. Although 70% of the respondents knew that theories do not become facts but explain facts; 40% felt that theories could become facts when there was overwhelming support, rather than having an explanatory role. This seems to indicate that even at post-graduate level an understanding of what theories are, falls in an area where improvement could be achieved.

In general, the Canadian sample of post-graduates, demonstrated a better understanding and acceptance of evolution than under-graduates, even if the respondents had not attended any courses in evolution. This seems to support the proposals made that the development of ‘reasoning skills’ or higher-order skills and a greater in-depth study of topics, not necessarily evolution, could contribute the understanding of evolutionary concepts and acceptance of evolution.

Although the topic ‘understanding of evolution’ has been shown to be an interesting area of research, its complexity is reflected in the wide range of results obtained. This is further
compounded by the additional components of the conceptual ecologies of evolution, which will be discussed next.

3.6 CONCEPTUAL ECOLOGIES OF EVOLUTION

Question 6, the last question of the questionnaire, dealt with the conceptual ecologies of the teachers who attended the workshop. The responses to this question were analyzed as part of the qualitative study of this mixed methods research.

| Question 6: (a) Why do you think that the teaching of evolution of life is controversial? (b) What can you as a teacher do to address the issue? |

3.6.1 Conceptual ecologies, conceptual change and learning

In the science education literature much has been written about learning and conceptual change and less about conceptual frameworks, a later interpretation. Probably the most often cited reference with regard to conceptual change is the work by Posner, Strike, Hewson and Gertzog and in particular, their publication of 1982. Herein they described their model for conceptual change, based on the Kuhnian notion of ‘scientific revolutions’.

Before considering how the process of conceptual change is explained, it would be worthwhile returning to what is considered to be ‘learning’. Demastes, Good and Peebles (1995) define learning as ‘a change in the preexisting conceptual frameworks’ (p. 638). A network of related conceptions, or a conceptual framework, is developed by learners to help them understand a topic such as biological evolution.

The Conceptual Change Model, or CCM, proposed by Posner et al. was based on the assumption that when learners were confronted with new knowledge, they would evaluate this rationally and logically, against their existing conceptual frameworks. Based on how useful the opposing knowledge was considered to be, it could either be rejected or accepted holistically into the conceptual framework, thus replacing the previous knowledge and concepts, which were now
abandoned. The Conceptual Change Model referred only to the cognitive domain, and was based on the assumption that learners dealt with knowledge in a rational and logical manner.

Some of the major criticisms of the above model related to its ‘boundaries and blind spots’. In learners a rational and logical assessment of the competing knowledge frameworks did not always happen. Conceptual change could also be affected by factors such as motivation beyond the barriers of the cognitive domain, rationality and logic. Furthermore, what counted as ‘evidence’, could be based on an affective consideration such as a ‘personal need to know’ which is not based on rational decisions. The learner ultimately decided what knowledge to embrace, whether the reasons were rational or not. This aspect gives rise to a ‘blind spot’ in the model’s construction (Demastes et al., 1995).

3.6.2 Learners’ disposition to change: cold and warm tendencies to conceptual change

A decade after Posner et al. had proposed their Conceptual Change Model, in the 1990s, a widespread acceptance of constructivist views changed the way in which the learning and construction of knowledge was perceived by researchers. Thus the Conceptual Change Model was seen to be ‘cold’ because it was an ‘overtly rational model of conceptual change’ i.e. ‘cold and rational’ which focused only on the students’ cognition without considering motivational beliefs about themselves as part of a classroom learning community (Abd-El-Khalick and Akerson, 2004, p. 788).

In the revision of the above model, another dimension was added to include the constructivist position, which acknowledged the role played by personal, motivational, social and historical processes. By considering these processes on which learning depended as well as how learning was perceived, the idea of a conceptual ecology was proposed to incorporate both the ‘what’ of learning and the factors on which it depended.

Mason, Gava and Boldrin (2008) describe this ‘warming’ trend, i.e. ‘affective and warm’, in the theory and research on conceptual change as going further than only cognitive factors, also taking into account ‘the affective, motivational, and social and contextual aspects that may affect
knowledge revision’ (p. 291). Multiple factors are seen to be involved in shaping the process of conceptual change, with complex dynamics underlying the ‘warming tendencies’ of such revision of knowledge frameworks. However, Solomon (quoted in Abd-El-Khalick and Akerson, 2004, p. 788) cautioned that the social perspectives on learning should not overshadow the importance of personal cognition and reflection in ‘how the personal integrates with the social’. Or, stated in another way, not to ignore the fact that learning is a personal experience which is socially constructed.

3.6.3 Instructional conversations

In describing their study on how the design of instructional materials and their presentation affected the manner in which students conceptualized the process of natural selection, Demastes, Settlage and Good (1995) questioned whether a simple comparison of scientific and alternative explanations could be sufficient to cause a process of conceptual change to happen. The number of students in their study who showed evidence of having undergone conceptual change was not significant, which made the researchers aware of the possible role that instructional conversation could play in motivating such changes.

Demastes et al. (1995) thus recognized the importance of how opportunities for interactions ‘among learners and between teachers and students becomes a key aspect of effective conceptual change instruction’ (p. 547). Vygotsky’s theories centred upon explaining the importance of social interactions, and thus on instructional conversations. This is seen as arriving at a social agreement about the meaning of observations and hence also of knowledge. Thus in the absence of true instructional conversations student passivity becomes a barrier to effective learning about science concepts such as natural selection.

The restructuring of concepts which are central to the understanding of natural selection, for example, could depend on how the material was presented as well as the time spent on actively dealing with these concepts, Demastes et al. (1995) concluded. They also suggested that further studies include the role played by the ‘teacher’s theory of learning on the students’ abilities to negotiate conceptual change through instructional conversation’. The same authors also
recommended that future studies ‘should give as much attention to the instructor’s conceptual framework as to the students’ conceptual frameworks in science learning’ (p. 549).

Commenting on learning ecologies rather than conceptual ecologies, Abd-El-Khalick and Akerson (2004) point out that not all the factors, such as motivational, affective, contextual, social and cultural factors and content, gain equal prominence when learning about specific subject matter. This makes the design of effective instruction difficult. A shift in focus of such factors happens when dealing with for example evolutionary biology, where worldview and cultural considerations may move to the fore ground, whereas in dealing with orbital valence theory, these would move to the background. Generally, these authors contend that in learning science content, it moves to the fore and the beliefs about the nature of science are pushed to the background, and vice versa.

3.6.4 Evolution as a conceptual ecology

The choice of biological evolution, as a topic for research on the influence that a learner’s conceptual ecology may have on effective learning, is particularly useful because of its ‘controversial intersection with religion’, Demates, Good and Peebles (1995, p. 638). In their study, these authors interviewed four pre-service teachers in depth to determine firstly, what constituted their specific conceptual ecologies of biological evolution and secondly, how this in turn, influenced their ability to restructure their conceptual frameworks of evolution. They found that participants did not always select evidence based on rational and logical reasons but that what counts as ‘evidence’ is affected by what knowledge they chose to embrace, or a ‘personal need to know’ (p. 661). However, the authors also found that in a supportive classroom atmosphere, ‘students can progress towards understanding a scientific conception even though it conflicts with their cultural beliefs’ (p. 661).

Researchers such as Sinatra et al. (2003), Southerland et al. (2006), and Deniz, Donnelly and Yilmaz (2008) all felt that the influence of religion was not ‘productive’ in understanding the conceptual frameworks of teachers. Each group of researchers, in their own way, identified learning and conceptual dispositions which could be more important in establishing the constraints and barriers influencing effective teaching of evolution. Southerland et al. (2006) for example, state
that the teachers’ actual religious beliefs were less important than a ‘need for a single authority linked to some religious beliefs’, the need for a single right answer and lack of comfort with ambiguity (pp. 897-8).

Another study which used the conceptual ecology for biological evolution as a theoretical lens is that of Deniz, Donnelly and Yilmaz (2008). In an extensive review of the literature on acceptance of evolution they identified various factors which could be involved. They also established that there seemed to be a ‘complex web of connections’ between these factors (p. 421). In studying the variance in acceptance of these factors, the authors found that it would be more ‘promising’ to use the students’ conceptual ecologies of evolution than looking at the acceptance of evolutionary theory in isolation. The factors which were identified included affective constructs relating to epistemological beliefs and the effects of thinking, or cognitive dispositions. Mason, Gava and Boldrin (2008) identified epistemological beliefs and interest as important factors in motivating conceptual change.

3.6.4.1 Epistemological beliefs

Epistemological beliefs concern beliefs about knowledge and knowing (Mason et al., 2008) and are about ‘individual representations about the nature, organization and source of knowledge, its truth, and the justification of criteria of assertions’ (p. 292). A sequence showing a shift in how beliefs in knowledge may develop is illustrated in the following way:

- which starts with, a belief in knowledge as absolute, simple, certain and transmitted by authorities, and develops to
- a belief in knowledge as being relative, idiosyncratic and uncertain, and develops further
- into, a belief in knowledge as complex, evolving and derived from reason.

Adapted from Mason et al. (2008, p. 292), four epistemological dimensions are identified:

1. The nature of knowledge – involves the beliefs about simplicity versus complexity.
   (The authors explain this as the degree to which knowledge is conceived as compartmentalized or interrelated. Thus knowledge may range from discrete simple facts,
to complex and interrelated concepts).

2. **Certainty and complexity of knowledge**, which ranges from stable to changing, and may develop from the absolute to the tentative to finally, knowledge which is evolving.

3. **Belief about the sources of knowledge** – whether knowledge resides outside oneself and is transmitted, or whether knowledge is constructed by oneself.

4. **The justification of knowledge** – as belief in observation, or in authority, or a belief in the use of rules of inquiry and the evaluation of expertise.

How epistemological beliefs affect the acceptance of biological evolution becomes an interesting area of research because all four epistemological dimensions can be studied in terms of the range of beliefs in the nature of science and beliefs about religion. Epistemological beliefs may also have a direct effect on the levels of thinking used in constructing knowledge frameworks about evolution. If learners adopt a belief about knowledge that is simple and certain, they are likely to focus only on items of factual knowledge, using lower levels of thinking thus failing to comprehend the concepts of evolution using higher levels of thinking. If higher-order thinking levels are used, this would involve the belief that knowledge is changing, constructed by the learners themselves by using the rules of the nature of science to evaluate evidence.

Kardash and Scholes (1996) feel that there is a growing body of evidence that the ‘individual’s “epistemological beliefs” play an critical role in strategic learning in general and higher-order thinking and problem solving in particular’ (p. 261). They conducted a study in which they examined the influence of students’ beliefs about the certainty of knowledge and the strength of such beliefs about controversial topics such as whether AIDS is really caused by HIV. Kardashian and Scholes found that epistemological beliefs affected the critical interpretation of knowledge by students who were given a text to read about HIV-AIDS which was inconclusive, tentative and consisted of mixed evidence both for and against the topic. The students were then asked to write a concluding paragraph to the text. The students’ beliefs influenced the contents of the paragraph.
The students who interpreted ‘knowledge as a certainty’, were inclined to distort both the highly tentative as well as the highly contradictory information in order to confirm with their belief system.

From the same study, Kardash and Scholes (1996) also found that the strength of ‘specific beliefs about controversial topics is as important as general epistemological beliefs in determining how they will interpret mixed and inconclusive evidence’ (p. 269). What is interesting is that they also found that there was no correlation between the general epistemological beliefs of the students and their specific beliefs about a controversial topic. This may account for the fact that some scientists who subscribe to the nature of science in general, may react differently when confronted with a controversial topic such as biological evolution, in which they adopt a stance of absolute knowledge in dealing with this topic. The same authors also noted that students who had a low need for cognition of a controversial topic elected to reduce both the amount and the contradictory nature of the information by ignoring the information not in line with their beliefs.

3.6.4.2 Cognitive disposition

Mason et al. (2008, p. 293) posed the question ‘why do more sophisticated epistemological beliefs act as a resource whereas less sophisticated beliefs act as a constraint in conceptual change?’. The authors put forward one explanation which deals with intentionality in the knowledge revision processes, which they interpret as an example of cognitive disposition. Students must have a goal in terms of wanting to understand the material or the topic, such as evolution. The beliefs that the students have towards achieving this goal of understanding, will determine whether they are prepared to recognize that there is a mismatch between their existing knowledge and the new conceptions; or that they acknowledge the potential of achieving such new understanding and knowledge. Thus, beliefs in knowledge that is complex and evolving will expedite this process of dealing with the mismatch. Once this is recognized, then effort must be ‘invested’ to achieve this understanding, and bring about ‘intentionally produced changes in knowledge’ (Mason et al., 2008, p. 293). Deep learning, the systematic and deep processing of content, is important and plays a role in mediating such epistemological beliefs of bringing about intentional conceptual change. Cognitive disposition is seen as ‘effortful and open-minded thinking’ (Mason et al., 2008, p. 293).
The students’ disposition towards change may play an important role in learning about evolution. In order to compare and assess a ‘rival’ explanation about evolution, a non-absolutist and an open-minded disposition is required. This involves thinking deeply about complex problems and also questioning their own beliefs. Sinatra et al. (2003) also highlight the importance of instructional approaches that portray science as powerful, yet bounded by human enterprise. It is possible that students, under these conditions, may still reject or show disbelief in evolution but it does not negate their ability to understand evolution.

3.6.4.3 Interest

The beneficial effect of interest seems to be associated with ‘energizing the cognitive processes’ as well as encouraging greater ‘effort and willingness to persist in the task’ (Mason et al., 2008, p. 294). Furthermore, high interest also ‘sustains deep processing, which is beneficial to knowledge revision and requires engagement in deep thinking about the content to be learned’ (p. 295).

In examining the relationship between interest and prior knowledge, one study indicated that a high prior knowledge could often trigger a resistance to change and become the cause of a lack in change and revision of knowledge frameworks. It is possible that ‘a well-developed interest acts as a barrier to conceptual change when related to highly developed alternative conceptions’ (Mason et al., 2008, p. 294).

When examining the role that interest plays in topics such as human evolution, a barrier may arise to the revision of conceptual knowledge about the origin of humans because of prior knowledge based on certain epistemological beliefs. These beliefs could be related to a lack of open-mindedness and a need for only one right answer. Accepting evolutionary theory has a deep social and cultural implication. Many religious people though greatly interested in human evolution, would feel compelled to reject evolution because of a notion that evolution and a belief in God cannot co-exist (Deniz, Donnelly and Yilmaz, 2008).
3.6.4.3 Variance in the acceptance of evolution

In a study involving Turkish pre-service teachers of biology, Deniz, Donnelly and Yilmaz (2008) aimed to determine the extent to which they could account for the variance in the acceptance of evolution by considering factors which they perceived as part of a conceptual ecology of biological evolution. The authors identified the following factors, ‘understanding of evolutionary theory’, ‘epistemological beliefs’, ‘thinking dispositions’, or conceptual/learning dispositions, and ‘parental educational levels’, which they could use as independent variables of their study. These independent variables could influence the acceptance of evolution, which in turn, served as the dependent variable of the study.

A statistical analysis of the data involving a multiple regression approach was used. This quantitative approach highlights several problems in, firstly, identifying the factors that contribute to the conceptual ecology and defining them as discrete units that can be used for statistical analyses. Secondly, designing instruments that measure the effect of these variables reliably and give results that are valid in terms of ‘measuring what they were designed to measure’. Deniz at al. (2008) found that MATE, the instrument developed by Rutledge and Warden (1999) was reliable (which accounts for why it has been used in several other studies) and has subscales to measure acceptance and understanding of evolution. A further scale measuring thinking dispositions also met the requirements for multiple regression analyses. Interestingly, the scales designed to measure epistemological beliefs could not be used in the analyses because they did not show a high enough reliability reading.

The results indicated that there was a significant correlation between the pre-service teachers’ knowledge and their acceptance of evolution. This showed that those participants who have a good understanding of evolution will be more likely to accept this theory. The acceptance of evolution was also significantly correlated with thinking dispositions. This could be interpreted that cognitive flexibility and openness to belief change played a role in the acceptance of evolution. An interesting observation relates to the fact that this is similar to the findings of Sinatra et al. (2003), who used American, not Turkish, subjects. Finally, there was also a significant positive correlation between the educational levels of the parents and acceptance of evolution by the pre-service teachers.
By determining the intercorrelation of these three factors, the authors found that learning dispositions (5% of the variance in accepting evolution) accounted for the most of the variance in accepting biological evolution. Understanding of evolution contributed 3.3% of the variance in accepting evolution and parental level of education. In total, understanding of evolution, thinking dispositions and parental level of education accounted for a total of 10.3% of the variance in accepting evolution. These findings do not necessarily indicate that these three factors have a minimal impact on the acceptance of evolution, but rather that they were the only three factors that could be identified successfully in the analysis.

Although this indicates that almost 90% of the variance in accepting evolution is not accounted for, it must be remembered that imposing statistical measures on a model such as the conceptual ecology of evolution will be difficult. Dynamic interrelationships between the various components of the model, as well as the ability to fashion distinct and discrete variables to measure with accepted reliability and validity contributed to the difficulties experienced in analyzing the information statistically.

Furthermore, Abd-El-Khalick et al. (2004) have also pointed out that the conceptual ecologies of different topics and subject matter will show a different dynamic in the interrelationships of the component factors. Added to this consideration, is the possibility that the conceptual ecologies of the individual learners, of the same topic, such as biological evolution, may also vary in the interrelationships of the components of the conceptual ecologies and hence their contribution to the variance of, say, the acceptance of evolution.

The findings of conceptual change research, and that of conceptual ecologies, have highlighted the need for new, or at least revised, models of knowledge restructuring. In the process of developing these models it is important to ‘take into consideration the complexity of the process, its multifaceted interactive nature’ (Mason et al., 2008, p. 304).
3.7 SUMMARY

Introduction
The focus of this chapter is on the knowledge frameworks that underpin the design of workshop materials and the questionnaire. The open-ended questions of the questionnaire form the basis of the conceptual framework which is discussed in this chapter. The conceptual framework includes a wide range of topics which involve the concepts related to evolution itself, the nature of science, and a literature review of research findings about the understanding of evolution, the nature of science and the associated conceptual ecologies.

Macro-evolution
Macro-evolution represents the large picture of the evolution of life and the Earth’s ‘autobiography’. The first three questions of the questionnaire focus on probing teachers’ understanding of macro-evolution, which involves the relationship between the evolution of life and the geological history of the Earth, including the concept of mass extinctions.

Darwin as a scientist, as a man of his time but equally relevant to-day
Teachers need to appreciate Darwin in the context of the time in which he lived and devised his theory of natural selection and the ‘Origin of Species’. The fourth question of the questionnaire is designed to probe not only why Darwin was such a good scientist, but also why he is still regarded as such to-day.

Understanding the nature of science and the theory of evolution as a scientific theory
The fifth question seeks clarification of how well teachers understand the nature of science and whether they can explain why evolution is a scientific theory. Research findings seem to show a misunderstanding about what the nature of science is, its characteristics, and in particular a difficulty in explaining the difference between laws and theories of science. The beliefs that teachers hold about the nature of science also affect the way they teach evolution.

Acceptance and understanding of evolution
Measuring the acceptance of evolution is more effective than monitoring a change in beliefs about evolution. Several studies have found a positive correlation between the acceptance of evolution,
the understanding of evolution and the understanding of the nature of science. These studies also seem to indicate that this happens even if the participants are religious.

Conceptual ecologies of evolution
The Conceptual Change Model (CCM) proposed in the 1980s was based on explaining the ‘what’ of learning and focused only on the cognitive domain (now seen as a ‘cold’ tendency towards conceptual change). With the widespread acceptance of constructivist views, a change happened in the perception of learning and the construction of knowledge. The focus now included not only the processes involving learning happening in the cognitive domain, but also concerned the broader notion of conceptual ecologies. These ‘warm’ tendencies towards conceptual change not only incorporated factors in which learning and knowledge construction depended, but also the affective, motivational, social and contextual dimensions of conceptual ecologies.
CHAPTER 4

A CONSTRUCTIVIST THEORETICAL FRAMEWORK

4.1 INTRODUCTION

Theories form an important component of the ‘nature of science’ and are interpreted as overarching and well substantiated explanations used to make sense of aspects of the natural world (which, in this instance, also interpreted to include human ways of thinking and construction knowledge). Theories also provide the researcher with a framework to structure investigations about certain phenomena, for example, how concepts about evolution are developed by teachers who attend workshops about this topic.

A specific interpretation of constructivism will be used in this study which is preferred by many researchers in science education, rather than a more general social sciences perspective. The ‘Hard Core Assumptions’ about the characteristics of constructivism in science education are described by Taber (2006, p. 139) as follows:

- Knowledge is constructed by the learner, not received.
- Learners come to science learning with existing ideas about many natural phenomena.
- Each individual has a unique set of ideas.
- Knowledge is represented in the brain as a conceptual structure.
- It is possible to model learners' conceptual structures.
- The learners' existing ideas have consequences for the learning of science.
- It is possible to teach science more effectively if account is taken of the learners' existing ideas.

Working within this constructivist theoretical framework, a multi-theory platform must be adopted to explain, and help interpret, the results from this study. The following aspects form part of this framework and will be discussed separately in terms of which theory or theories are more suitable in explaining the following phenomena:

1. the construction of knowledge structures,
2. the role played by social interaction and by talk in the construction of knowledge,
3. levels of conceptual understanding of evolution,
4. worldviews and border crossings into the 'culture of science', and
5. beyond constructivism.
4.2 THE CONSTRUCTION OF KNOWLEDGE STRUCTURES

In science education research there are mainly two constructivist points of view which appear in the literature. One of these approaches involves the Piagetian theory of cognitive development, which was most influential in the 1960s and 1970s, though still relevant to-day (although some authors such as Solomon, quoted in Taber (2006), have preferred a Vygotskian interpretation). The second perspective, concerns alternative ideas and misconceptions which are resilient and not necessarily based on the developmental stages described by Piaget (Pozo and Carretero, 1992).

In context-independent learning, according to the Piagetian tradition, there is an age related graduation in the levels of understanding of concepts. The opposite view is that there is no evidence of age relatedness and that the misconceptions appear as a consequence of the interaction between the learners’ ideas, school learning and educational experiences (Gilbert and Watts, 1983).

Owing to the nature of this research, which is based on different levels of understanding of evolution, the Piagetian theory of concept development is of interest. The notion that concepts and misconceptions about evolution may be resilient and context-dependent will also be explored further.

4.2.1 The cognitive development theory of Jean Piaget

Most of the discussion given below is based on the explanations of Piaget's work given by Ginsburg and Opper (1969). These authors have presented a concise and clear analysis of Piaget’s work and thought, suitable for my research which focuses only on one small part of Piaget’s theory of cognitive development.

Two major areas of interest to Piaget were biology and epistemology, and how they influenced his approach to the psychology of intelligence. Biology was important because it concerned the ideas of growth, and the stages of growth in organisms, adaptation and equilibrium.
Epistemology, the second area of interest, focused on the investigation of the origin of knowledge in children about their understanding of topics such as space, time and causality. This was illustrated by the various topics Piaget (1929/ *1973) explored in ‘The child's conception of the world’, for example:

- The Origin of the Sun and the Moon.
- Meteorology and the Origin of Water.
- The Origin of Trees, Mountains and of the Earth.

(*This reference is from the 1973 reprint.)

Thus for Piaget the primary goal was not the mere description of the content of thought, but rather identifying the basic processes underlying and determining the content of such thought. His study of concept development thus involves both the structures and functions of intelligence.

4.2.1.1 The role of hereditary/ genetic structures

Biological factors which are genetically determined and are inherited, involve physical structures such as the development of the nervous system. These factors influence at what age certain intellectual achievement may or may not occur. One of the greatest criticisms of Piaget’s theory of cognitive development is based on the way he imposed his idea of age-related development in stages on the constructivist formation of concepts. This created a tension between the constructivist framework of his theory and its structuralist stage model (Bidell and Fischer, 1992) and has been the subject of later neo-Piagetian revisions, interpretations and theories.

4.2.1.2 General principles of the functioning of intelligence

Two basic tendencies affect intellectual functioning – that of adaptation and organization.

In considering organization, Piaget viewed all organisms to have a tendency to systematize and organize both their physical as well as their psychological components coherently and hierarchically into higher-order systems. This would relate to the development of the nervous system and the brain for example, as well as to knowledge structures.
Adaptation is seen as the ability to interact with the environment. The tendency to adapt to the environment is dependent on two complementary processes that happen simultaneously — assimilation and accommodation. Whereas assimilation has to do with an organism’s ability to deal with the environment in terms of its structures, accommodation involves transforming these structures in response to the environment.

Adaptation and organization result in a number of psychological structures which take different forms at different ages. Thus the child, according to Piaget, progresses through a series of stages, each characterized by different psychological structures. These structures take on different forms or organized patterns of behaviour in each of the stages, which happen at specific ages in the child’s life time. The organized patterns of behaviour are called schemes which are not innate but are based on experience, involving activity on the part of the child.

One way in which children construct concepts is by describing their actions, for example, in the manner in which they classify objects and experiences by grouping them together. By placing objects in certain groups or classes, children then go on to create hierarchies of classes by using a series of intellectual activities suited to their stage of development. These hierarchies of classes of information form a psychological structure or scheme. In his publication ‘The child’s conception of the world’, Piaget (1929/ *1973) probed the concept ‘life’ and how children decided (by using classification) whether something was living or was non-living. His summary of the chapter on ‘The concept of life’ reads as follows:

- The first stage: life is assimilated to activity in general.
- The second stage: life is assimilated to movement.
- The third and fourth stages: life is assimilated to spontaneous movement, then later restricted to animals and plants.

(* This reference is from the 1973 reprint.)

Thus in the first developmental stage, children would group together all examples that showed some activity (the sun rising in the morning, a moving motor car, running water, a dog chasing the car and a door opening and closing) and then classified them as being ‘living’. In the fourth stage,
however, they would have narrowed the characteristic of ‘living’, and attributed it only to animals and plants (the dog, mentioned in the grouping above).

Piaget believed that organization, adaptation and the resulting psychological structures were all inextricably intertwined. Thus when involved in organizing activities such as classifying various objects, child or individuals would assimilate novel events into their pre-existing structures at the same time as they accommodated these pre-existing structures to meet the demands of the new situation. As a result new structures were continuously created out of older structures, allowing individuals to interact with the world. However, individuals could neither adapt to the environment nor organize these processes if there were no basic structures, such as knowledge structures and a nervous system, available at the outset of the activity.

Individuals tend toward equilibrium with their environment and have a tendency to organize these psychological structures into coherent and stable patterns to achieve such balance within the world they live. When a new event occurs, such as attending a workshop on evolution, it means that the participants can apply to this new situation their experiences and the lessons of the past (in other words, assimilate this event into their already existing structures). This means that they could modify their current patterns of behaviour to respond to the requirements of the workshop. And here is the problem with the theory: this does not always happen. Furthermore, according to the theory, with increasing experiences, more and more structures should be acquired to allow the participants to respond to the new situations created by the workshop. In practice, sometimes barriers prevent this from happening.

Some neo-Piagetian theories shift the emphasis from the global structures, operating across a variety of content domains and contexts as proposed by Piaget, to more ‘local’, content- and context-specific structures. Apart from the universal pathway, initially described by Piaget, alternative developmental pathways are acknowledged to exist that may occur in different contexts and also in certain content specific areas (Bidell and Fischer, 1992).
4.2.2 Alternative ideas and misconceptions

Driver, Guesne and Tiberghien (1985) adopted a model which they felt explained the interaction between the ideas that learners have and how these ideas evolve with teaching. ‘What children are capable of learning depends, at least in part, on ‘what they have in their heads’, as well as on the learning context in which they find themselves’ (p. 4).

According to this cognitive model, elements of information, or groups of such elements, are stored in the learners’ memories and influence everything they do or say. Such elements, or groups of elements are called ‘schemes’. Thus a ‘scheme’ may concern knowledge about evolution, or may contain more complex reasoning structures such as the causes and effects of natural selection on the diversity of life on Earth. The term ‘scheme’ may involve many diverse elements that are stored and interrelated in the memory. These ‘schemes’ also influence the manner in which the participants could react to a workshop on evolution, for example, and in turn could affect the feedback achieved from the participants in terms of their answers to a questionnaire.

Describing their interpretation of how ‘schemes’ can be integrated into larger structures and how a new ‘piece of knowledge’ is acquired, Driver, Guesne and Tiberghien (1985) used the following analogy of grouping students in a class:

Students relate to and with one another and form groups for different activities such as sports, drama and science lessons. These groups are not static but change as friendships and interests change; some students may not relate to others at all but remain isolates. Consider what may happen when a new boy arrives in the class. When he arrives, there are various possibilities for what might happen: he might not relate with other students at all and remain isolated; he might join a group that already exists; or his presence might provoke a reorganization of friendship groups of the class as a whole. The same student could also be integrated differently depending on the class that receives him. (p. 5)

The analogy with learning is clear, these authors maintain, because the manner in which a new piece of information is assimilated ‘depends both on the nature of the information and the structure
of the learner’s ‘schemes’ (p. 5). All learners have a unique and characteristic organization of such schemes. When several learners link the same new piece of information to other information, the links which they have established will most likely be different, even though the original piece of knowledge was the same.

Thus when the teachers attending the workshops presented contradictory ideas in their discussions about constructing concept cartoons and narratives, different schemes were brought into play. In particular, schemes relating to their understanding about the role played by science in the understanding of evolution and the barriers created by certain religious beliefs. Many of these ideas presented by the teachers are stable because they are part of schemes that are integrated into larger structures. Thus to bring about change involves not only changing some of the ‘elements’ that make up the schemes, but in fact modifying the structures as well.

Generally, in learning science the learners may be aware of information contrary to their expectations because this knowledge does not ‘fit’ in with their schemes. However, simply noting such a ‘discrepant event’ will not necessarily bring about a change and the restructuring of ideas. The possibility exists that they will also have to re-organize larger and pre-existing structures. This may be a time consuming process, will require more experiences and demand reflection on the part of the learner.

Two constructivist points of view have been examined in this section. These perceptions differ in terms of ‘what is it that changes and what type of changes ought to be promoted through instruction’ (Pozo and Carretero, 1992, p. 231).

According to Piaget the changes in science knowledge is structural and that the main goal of teaching is to foster structural changes which would result in the acquisition of formal operational thought (or ‘abstract’ thinking). Some of the characteristics of this type of thinking would include the mastery of scientific procedures such as the control of variables, proportional reasoning and the notion of causality in the ‘if – then’ thinking of propositional logic. These logical structures allow for more complex levels of scientific thought, which could be applied to content (Inhelder and Piaget,
1958). Propositional logic will also open a whole range of possibilities, far greater than the simple groupings of classes apparent in a ‘concrete’ thinker’s domain of knowledge.

In contrast to the Piagetian interpretation that conceptual change is in essence structural; in dealing with misconceptions and alternative frameworks, a conceptual approach is used which occurs separately from structural changes. The learners develop their own concepts independent of instruction. Driver, Guesne and Tiberghien, (1985) commented on the context dependency of the learners which often resulted in them using different ideas to interpret situations which scientists would explain in the same way.

Some neo-Piagetian theorists give another slant to the idea, in that they see the ‘universal’ path of concept development as the ‘mind’s potential for constructing conceptual structures, once a particular developmental capacity is attained’ (Case, 1992, p. 319). This would account for why scientists, on the whole, give a more ‘formal’ explanation of certain situations than learners generally do.

4.3 THE ROLE PLAYED BY SOCIAL INTERACTION AND BY TALK IN THE CONSTRUCTION OF KNOWLEDGE

One way to encourage the re-organization of pre-existing structures is to introduce social interaction and talk between the participants, whether they are peers or, between the learner and an ‘adult’ or ‘expert’.

In exploring the cognitive development of ‘the child as a problem solver’ Garton (2004) compares the models proposed by Piaget and Vygotsky. Both regarded the social environment as important for concept development, but their explanations in terms of the processes involved are different.

Vygotsky’s model, on the one hand, is seen as explaining this in terms of the role of teaching and learning, which requires at least one additional person, in the form of a teacher or another capable peer; and the learner. Development and learning are intertwined, and interpreted as a product of the immediate and broader social and cultural environment. Society and history play an important
role in transforming the child’s developing mind. This happens, through acculturation, into a particular system of meanings by which the child will make sense of the world and experiences. Knowledge is co-constructed, with the expert giving support and guidance to the child who is a learner in a specific space and time. The social interaction, itself, enables this shared thinking between ‘the expert’ and the learner to construct a single view or position jointly and together (Garton, 2004).

The Piagetian model, on the other hand, restricts the social world to the interpersonal (usually to that of similar peers) without considering the broader social and cultural milieu. Growth and development happen at an individual level. Individual learners exchange their ideas by processes such as communication, reciprocity and recognition of contradictions. Thus conflict and disagreement are characteristic of the establishment of a shared understanding. Social interaction is seen as an opportunity for learners with different opinions and perspectives to engage in discussions and to exchange these points of view. Genuine exchange of ideas involves the recognition of alternative points of view, the ability to maintain and alter these perspectives when necessary and to argue and justify the rationale for having such ideas (Garton, 2004).

In a different perspective on peer interaction, a study devised by Kruger (as quoted by Garton, 2004) found that through the discussion of more than one possible solutions to a problem, better scores were achieved when the peers collaborated to find one possible answer. However, improved scores in subsequent testing were not achieved when only the solution that was finally accepted was discussed. What Kruger found to be the deciding factor in further improvement of the scores was whether they could describe why they had rejected the alternative solutions. Although discussion about individual ideas led to higher levels of understanding about the problem considered, it was the processes involved in the rejection of the alternative perspectives which led to increased benefit of the individuals in terms of cognitive development and hence improved scores.

The Vygotskian approach, on the other hand, has given rise to the interpretation that there is less to be gained for the child, as a learner, by interacting socially with his/her peers. The argument being that the interaction between peer – peer relationships cannot adequately expose the learners
to appropriate forms of ‘stretching’ activities (as found in the Vygotskian perception of the zone of proximal development). With this comes the shift away from the constraints of the Piagetian levels of cognitive development. It is assumed, with appropriate instructional interactions, the unlimited cognitive potential of children can be realized (Forrester, 1992).

In summary, Garton explains how she views the difference between these two models as:

Unlike the Vygotskian view where the interaction itself enables the construction of shared thinking, the Piagetian framework regards the children’s views as independent. These views are then shared in social interaction and comparisons made of the information. This is not the same as co-constructed collaboration where a single point of view or position for the intersubjectivity created by the interaction. Thus the two theoretical positions offer quite different ways of regarding the role and function of social interaction. It can also be claimed that cognitive change resulting from cognitive conflict results in cognitive development, since Piagetian theory can explain and predict cognitive change. Alternatively, cognitive change resulting from intersubjectivity and collaboration is a manifestation of learning and not of cognitive development at all. (pp. 22-23)

(Note: that the term ‘intersubjectivity’ refers to the establishment of mutual agreement in finding a single and agreed upon solution or answer.)

Owing to Vygotsky’s untimely death, his theories were not fully developed to explain aspects of the norms of cognitive development regarding what it is and how it takes place. In a developmental sense it does not distinguish between the knowledge held by the child and that of the adult. Thus change is described but not its development (Garton, 2004).

Taber (2006) explains this differently in that he feels that the Vygotskian notion of two different classes of concepts may be a useful perspective for further research. The first class of concepts is made up of concepts that arise spontaneously and emerge from the child’s own reflections about everyday experiences. The second class of concepts are labeled as ‘scientific – or academic’, which are taught explicitly and given verbal definitions using non - spontaneous operations, in terms of guidance and support from and ‘expert’.
The role of language in concept acquisition is explained, but how the spontaneously derived concepts change and develop into ‘scientific – or academic’ concepts is not clarified. For the purpose of my research I will use the Piagetian theory of cognitive development in describing the levels of concept development of evolution.

Another aspect of the role played by language is the relationship between talk and problem solving. In a study by Teasley (as quoted by Garton, 2004), it was found that children who talked during the problem solving activity did better than those who did not. Greater learning was achieved when the talk involved interpretative processes such as formulating plans and strategizing, than when no talk or irrelevant talk happened.

Learners who worked with peers were inclined to produce more interpretative talk than those who worked on their own, but still used talk in the process of solving the problem. In the latter case, talk centred more about descriptions than about strategies. In general, the talk/ no talk variable was of greater importance than whether the learners operated in groups of two or were alone.

4.4 LEVELS OF CONCEPTUAL UNDERSTANDING OF EVOLUTION

In considering the levels of conceptual understanding, it is important to recognize the two main positions regarding whether the human mind develops in a general or in a specific way. Case (1992) describes the interpretations about the generality or the specificity of cognitive development as, firstly, those theorists who interpret cognitive development as ‘proceeding through a sequence of general stages, often ones that are presumed to be universal in their character’. Secondly, the opposite view, that of specificity, holds that the child’s development proceeds ‘along many fronts at once, at different rates, in a continuous and contextually sensitive manner’ (p. 343).

This has led Case (1992) to propose a theory of intellectual development that occupies a middle ground on the issues of generality or specificity. In doing so, he has also stressed that cognitive development cannot be understood without studying the cultural milieu of the child and how the social and the symbolic supports provided by these specific contexts, affect the development of central conceptual structures representing even basic domains of knowledge about number, time, space and causality.
Case (1992) draws on certain foundational elements from the ‘classical’ Piagetian theory with regard to ‘the universal sequence of structural levels: from concrete to abstract’, which he explains as follows:

The content of children's cognitive structures may vary from task to task, or from culture to culture. The rate of development may also vary across different contexts within and across cultures. What is universal, however, is the progression from simple sensorimotor structures to representational structures of increasing complexity, abstractness, and power. (p. 370)

Thus the level of understanding of evolution will range from the intellectual manipulation of only specific content using ‘concrete’ thinking to ‘if – then’ thinking associated with causality and abstract thought. Facts about evolution obtained from textbooks which are ‘concrete’ materials and are referred to directly, and, linking two given facts from workshop materials are characteristics of ‘concrete’ thinking. A progression to abstract thinking, which is not ‘constricted’ by specific content or factual knowledge, allows for the ability to establish and name links, identify ‘if – then’ thinking of causality and the ability to create explanations of increasingly greater complexity.

In this study’s research design it is accepted that growth, development and cognitive change happen at an individual level. Even when involved in group activities, individuals work independently on the ideas and actions that arise as a consequence of discussion. In this Piagetian framework, cooperation between peers happens as a result of communication and the recognition of contradictory points of view in establishing solutions. During the workshop interventions of this study, cooperation between peers and the recognition of discerning points of view, were important in the design of concept cartoons and the construction of narratives about the evolution of life on Earth.

4.5 WORLDVIEWS AND BORDER CROSSINGS INTO THE ‘CULTURE OF SCIENCE’

The ‘world view’ model proposed by Kearney in 1984 has been adapted by several science education researchers. This model serves as a framework for interpreting the ideas that learners bring to their classes and which influence their learning in science (Cobern, 1994; Cobern, 1996; George, 1999; and Aikenhead and Jegede, 1999).
4.5.1 Defining worldviews

Cobern (1994) interprets worldview as providing ‘a nonrational foundation for thought, emotion, and behavior’ (p. 584). It can supply an ideal platform for qualitative research because it creates a window into the way individuals perceive the world. Cobern continues to quote Kearney’s description of a worldview as

*culturally organized macrothought: those dynamically inter-related basic assumptions [i.e. presuppositions] of a people that determine much of their behavior and decision making, as well as organizing much of their body of symbolic creations.* (p. 584)

The power of worldview theory lies in its logico-structural model which consists of seven interrelated categories which are universal to all worldviews. The content of these categories or ‘universals’ may vary from culture to culture and could even be used to identify, in principle, groups of persons, or even individuals. These seven universals, or cognitive categories, of worldview are: ‘The Self’, ‘The Other’, ‘Classification’, ‘Relationship’, ‘Causality’, ‘Space’ and ‘Time’. To give a brief indication of how these ‘universals’ allow the structure of worldviews to be determined, two examples of such studies are given below.

In her analysis of how traditional practices and beliefs impacted on the health regimes of the villagers of ‘Seablast’ in the Caribbean, George (1999) found the universals of ‘the self’ and ‘the other’ most prominent in her study. ‘The self’ occupied an important part of the villagers’ worldview because ‘taking care’ of oneself was considered to be necessary in surviving life. The natural environment was part of ‘the other’ and the proper management of the interaction between ‘the self’ with the environment was portrayed as critical in the survival of ‘the self’. In comparing ‘the self’ with ‘other’ human beings in the village the third universal, that of the ‘relationship’ emerged. Hence some members of the village considered themselves to be better at surviving than others because of their knowledge of foods and herbs, bringing into play the next ‘universal’ to be considered, which is ‘classification’ of foods and herbs which contribute to healthy living.

In their study of Lebanese college students’ perceptions of the theory of evolution, Hokayem and BouJaoude (2008) set out to probe how these students perceived evolution with regard to their beliefs about science and their beliefs concerning religion and science. As part of their research the
authors also set out to describe the worldviews of their subjects by focusing, in particular, on two of the seven universals, ‘causality’ and nature as part of ‘the other’.

Hokayem and BouJaoude (2008) chose ‘causality’ because it forms a cornerstone of ‘scientific reasoning’. By probing the students’ assumptions about causality, the authors hoped to establish their subjects’ positions about causality and scientific theories. By selecting nature as part of ‘the other’ the researchers hoped to derive additional views about science and science and religion, giving a ‘more complete picture of how students relate evolution to their worldviews. They also compared the students’ positions with that of the professor teaching the course on evolution, to create a ‘clearer picture of the differences between the worldview of a scientist and that of students learning science’ (p. 400).

The universals ‘space’ and ‘time’ George (1999) felt were more difficult to identify in her conversations with the villagers of Seablast. The notion of ‘space’ is interpreted to be the surrounds of people as well as the imagined space in with they live. The universal ‘time’ may also refer to different dimensions of the world we live in, hence the path of time may be linear, circular or part of a continuum which is not measured in units but in experiences of the past, today and the feature.

A recurring theme arises from the publications by Hokayem and BouJaoude (2008); Aiken and Jegede (1999); George (1999); Cobern (1994, 1996) and Smith (1994) and that is ‘know your students’ with respect to teaching the theory of evolution. One of the problem areas identified by these authors is what is understood by ‘belief’.

Smith (1994) cautions about the use of the word ‘belief’ which has a different meaning in science in comparison to the everyday use of the term. In scientific terms ‘belief’ is ‘well grounded in evidence’ (p. 592), whereas in everyday conversation ‘belief’ and ‘faith’ are used interchangeably. Thus ‘belief’ may or may not imply certitude in the believer, ‘faith’ always does, even if there is no ‘proof’ Smith points out. Science, on the other hand, can not offer any guidance about what one should believe nor whether God exists or not.

The debate whether ‘belief’ should form part of a course on evolution is highlighted by Cobern’s stand, in which he feels that in a constructivist approach to teaching of evolution, belief plays an important role in the worldviews of many learners when they consider aspects of science and
aspects of science and religion. Cobern (1994) concludes his argument as follows: ‘I also offer the observation that the gap between understanding and belief varies with the concept in question and, when the concept is evolution, the gap is enormous’ (p. 586).

In contrast to Cobern’s assertions about the importance of beliefs in the teaching of evolution, Smith (1994) responds:

“Cobern’s premise that ‘constructivism suggests that belief be allowed a legitimate role in the Science classroom’ is troubling. Constructivism does indeed maintain that students build their own understandings of the world around them and that these understandings may differ from individual to individual, but it does not imply that Scientists (and Science students) are free to construct any explanations they choose based on idiosyncratic and unsubstantiated beliefs. (p. 594)

4.5.2 Border crossings

In many instances, the fact that scientists have worldviews developed in a culture of science, and construct meaning in a different way to non-scientists, has had a major influence on science education, not only in developing countries but also in the industrialized nations (Aikenhead and Jegede, 1999). Using the empirical results of research conducted in both cultural anthropology and science education, these authors have examined the notion of ‘cultural border crossings’ as a way to help make science more accessible to everyone.

Border crossings ‘take place between cultures or between microcultures’ (Aikenhead and Jegede, 1999, p. 271). These authors have used the meaning of ‘culture’ to be ‘an ordered system of meanings and symbols, in terms of which social interaction takes place’. They also quote a further interpretation of culture as the ‘norms, values, beliefs and expectations, and conventional actions of a group’ (p. 272), which in turn may influence the worldviews held by members of specific cultures. This leads to the view that cultures may also consist of subgroups, or micro–cultures, which share a unique combination such beliefs and expectations and hence similar worldviews.

Border crossings happen frequently within the school day and in everyday life. Thus by moving from the school classroom in to a workshop on evolution would constitute such a border crossing. Aikenhead (in Aikenhead and Jegede, 1999) describes the different types of border crossings in the following manner. Many border crossings happen smoothly, because the micro-cultures
involved are very similar. When it becomes apparent that these micro-cultures are less similar, a certain degree of discomfort exists, and the border crossing has to be managed consciously to achieve success. As the discomfort levels rise, unwillingness to take a risk in crossing these borders develops, making the crossing hazardous. An extreme case of discordance between the micro-cultures will usually be reflected in the avoidance of border crossings, which renders such a crossing impossible.

4.5.3 Successful border crossings

Although difficult to negotiate, hazardous and even border crossings that seem impossible, have been done by individuals who have been skillful, creative and enriching in their practices without losing their self identity. Aikenhead and Jegede (1999) give one such example, Maria Lugones. She advised ‘flexibility’, best achieved by an attitude of ‘playfulness’ which allowed her to become a ‘different person’, with a worldview to suit the micro-cultures into which she negotiated such border crossings, without losing that personal part of her own worldviews. Thus having a sense of flexibility, playfulness, and ease, or ‘the capacity to think differently in different cultures’ (p. 274), will have a direct effect on the students’ success at learning science, these authors conclude.

Successful border crossings are most frequent when the learners’ worldviews, or life-world cultures, are in harmony with the culture of science. Science instruction will usually tend to support this worldview. However, when the learners’ worldviews are at odds with that of the culture of science, then science instruction will ‘tend to disrupt the student’s worldview by trying to force that student to abandon or marginalize his or her life-world concepts and construct new (scientific) ways of conceptualization’ (Aikenhead and Jegede, 1999, p. 274). This may cause the learners to become alienated from their indigenous worldviews, or, it may cause them to devise ways in which they can pass the science subjects with the minimum of effort. Such techniques could involve avoiding meaningful learning by going through the motions of making it appear that such learning has occurred or resorting only to the rote memorization of key words and processes, these authors explain.

4.5.4 Potential scientists are found in all cultures

Whereas the enculturation of potential scientists into ‘western’ science will usually happen fairly
harmoniously in western countries such as the United States and those of the European Union, learners and students from ‘non-western’ countries are more likely to experience a conflict between their worldviews, based on indigenous knowledge, and the tenets of ‘western’ science. In response to this conflict of worldviews, Jegede used the idea of collateral learning to explain how these problems can be dealt with (Aikenhead and Jegede, 1999). Collateral learning happens when science concepts, based on the tenets of the nature of science, are constructed side by side with the corresponding ideas derived from another worldview, such as an indigenous worldview.

‘Collateral learning generally involves two or more conflicting schemata held simultaneously in long-term memory’ (Aikenhead and Jegede, 1999, p. 278). Based on the degree in which the conflicting concepts interact and how the resulting conflict is resolved, there are different possibilities in how collateral learning happens. One extreme involves conflicting concepts and schemes that do not interact, and are accessed separately depending on the perceived context of the situation (this is called parallel collateral learning). Thus in dealing with evolution and the process of natural selection in giving rise to the diversity of life on Earth, one set of concepts will deal with the Darwinian interpretation and will be accessed in the life sciences classroom, whereas, the creation story of life according to indigenous beliefs may predominate in the learner’s worldview outside the classroom

On the other side of this continuum lies another possibility. A dynamic interaction between conflicting worldviews and that the conflict of ideas may be resolved in some manner (this is called secured collateral learning).

Between these two extremes of collateral learning lie various possibilities, grouped together as dependent collateral learning. This depends on the learner’s ability to modify certain aspects of the conflicting worldviews without incurring a radical restructuring. For many learners learning science meaningfully will involve some conflict in worldviews which will result in parallel, secured or even dependent collateral learning

Instead of choosing to participate in cultural border crossings, learners may also choose to avoid such collateral learning. Adopting a cultural anthropological perspective in an attempt to find solutions for dealing with conflict in worldviews, the following should be considered:
• the difference between a learner’s cultural identity and the culture of school science,

• the effectiveness with which the learners are able to cross the cultural border between their own life-world, and hence worldviews, and the worldview espoused by school science,

• the assistance that could be offered to make the negotiation of these cultural border crossings more meaningful.

Participation in the culture of science is possible as the testimonies indicate of African scientists and students who have overcome potentially wide cultural gaps to move from African worldviews to that of worldviews of ‘western’ science. Documented cases of African scientists, who moved effortlessly between the microcultures of their scientific laboratories and that of their tribal villages, showed that even when they recognized the conflicts between the two cultures, they felt that: “It’s not that we are behaving in a different way to please them. It’s that we are thinking differently”. Also, ‘that they felt at ease in both cultures’ (Aikenhead and Jegede, 1999, p. 283).

The authors attributed the motivation for participating in different cultures to the feeling of being at ease in different settings. The attitudes of curiosity and risk-taking were involved when going to new places, learning new things, meeting new people, this all with a certain degree of adventurousness, the same authors contended.

4.5.5 Border crossings between the worldviews of science and religion

The above comments also relate to learners who negotiate border crossings between the culture of science and that of religion with regard to the teaching of evolution. Anderson (2007) interprets this as follows:

Most public discourse, having to do with the teaching of evolution focuses on “content” and typically does not attend to the nature of scientific endeavors that produced this knowledge. Even rarer is any attention to the philosophical ideas connected to evolution or how the study of evolution relates in any way to individual students, the preconceptions with which they enter the classroom, or its relationship to their broader worldviews. (p. 665)

Science and religion are two different ways of knowing and ‘scattered among the writing on science and religion are a number of attempts to categorize and describe the varied ways of dealing with
the relationship between these two endeavors’ (Anderson, 2007, p. 666). Even scholars of these topics understand the interface between science and religion differently.

When examining the categories identified by Anderson, the similarities are apparent with those described by Aikenhead and Jegede above. Both deal with different types of border crossings between various worldviews. In Anderson’s paper, he looks at four approaches to dealing with the ‘interface’ between science and religion.

Anderson (2007, pp. 666-7) has based his descriptions of the four approaches on the work of Barbour and are briefly summarized as follows:

- **Conflict.** We have on the one hand, the biblical literalists who say that evolution is in direct conflict with their faith. On the other hand, there are the atheistic scientists who claim that their understanding of evolution is not compatible with any theistic outlook.

- **Independence.** Science and Religion are seen as different endeavors with different epistemologies, and focus on different types of questions. Science and Religion are kept in different compartments, thus avoiding conflict but also preventing any constructive interaction between these two sets of values and beliefs.

- **Dialogue.** Science and Religion are in conversation with each other. There may be different dialogues possible, for example, the similarities as well as differences between worldviews. Or, there could be a discussion about what the boundaries are of Science and of Religion, and whether there could be a perceived overlap between these two realms.

- **Integration.** A closer partnership is sought between Science and Religion. This may involve using a particular philosophical system, for example, to interpret both scientific and theological ideas within a common conceptual framework.

As mentioned, these four approaches also link up with the ideas about border crossings between different worldviews as explained by Aikenhead and Jegede (1999). Thus ‘conflict between science and religion’ means ‘avoidance’ of one or the other worldview, if these worldviews are considered to be incompatible and ‘at war with each other’. The conflict approach also indicates a narrow understanding of the nature of science, or religion, or both.
An example of this approach is the misconception that to ‘believe’ in evolution automatically shows that such a person is an atheist, who does not believe in the existence of God.

Independence is obtained by compartmentalization of these two worldviews and thus treating them as separate and as two different worlds, acknowledging the idea of an existence of multiple worlds of interpretation (Cobern, 1996; Aikenhead and Jegede, 1999). With no contact or border crossing between these worlds, there is little of no conflict. However, this position excludes the opportunity to consider the relationship between the theory of evolution and religious and philosophical ideas. Anderson (2007) believes that ultimately such compartmentalization of worldviews breaks down when the learner, ‘pursuing some of life’s deepest questions’, will draw upon both science and religion’ (p. 668). A better and more complete education may be possible by understanding how the role played by biological/ original ancestors in giving rise to the diversity of life on Earth, the origin of life, chance and causality and the purpose of life, for example, relate the learner’s worldviews. Also, how these ideas shape the construction of such worldviews.

A constructivist approach will encourage a move away from compartmentalization of knowledge because the focus is on how learners construct knowledge based on their past knowledge and ‘need to know’ and should involve multiple sources of information. Both dialogue and integration are examples of such constructionist and holistic approaches in which there are attempts at integrating different worldviews by negotiating smooth or managed border crossings as described by Aikenhead and Jegede (1999).

Theistic evolution is a position taken by ‘serious biologists who are also serious believers’ (Collins, 2007, p. 199). Among those people who have been able to synthesize, or integrate, their acceptance of evolution of life with their faith, are Theodosius Dobzhansy who was considered to be one of the twentieth century’s architects of evolutionary thought, Pope John Paul II, and many other Christians, Jews, Muslims and Hindus. Although there are many subtle variations of theistic evolution, Collins (2007, p. 200) lists six premises that are commonly used:

1. The universe came into being out of nothingness, approximately 14 billion years ago.
2. Despite massive improbabilities, the properties of the universe appear to have been precisely tuned for life.

3. While the precise mechanism of the origin of life on earth remains unknown, once life arose, the process of evolution and natural selection permitted the development of biological diversity and complexity over very long periods of time.

4. Once evolution got underway, no special supernatural intervention was required.

5. Humans are part of this process, sharing a common ancestor with the great apes.

6. But humans are also unique in ways that defy evolutionary explanation and point to our spiritual nature. This includes the existence of the Moral Law (the knowledge of right and wrong) and the search for God that characterizes all human cultures throughout history.

The above premises illustrate an attempt to interpret both scientific and religious points of view from a common framework. This requires an epistemological belief in knowledge as complex and evolving as part of a framework that is adapted to new interpretations and findings as they arise.

It is also possible to consider the classification based on the relationship between science and religion proposed by Anderson (2007), from an epistemological point of view. It is interesting to note how the progression in beliefs about knowledge is apparent in the four approaches discussed by Anderson. The progression in beliefs about knowledge is adapted from Mason, Gava and Boldrin (2008). It starts with:

- A belief in knowledge as absolute, certain and transmitted by authorities; the nature of knowledge is made up of discrete facts that are stable and absolute. The sources of knowledge reside outside the person.

- A belief in knowledge as being relative, idiosyncratic and uncertain; knowledge is tentative and progresses to:

- A belief in knowledge as complex, evolving and derived from reason. Knowledge is justified as a belief in the empirical, or an interpretation of authority in the use of rules of inquiry and the evaluation of expertise.

When there is a conflict between worldviews, it usually indicates that knowledge is viewed as absolute and transmitted by an authority. This is not only the case in religion but also exists in an
absolutist view of the nature of science. Compartmentalization of knowledge may include the possibility of different epistemological views but these are not shared. In seeing knowledge as complex, evolving and based on interpretation by different levels of authority, scope is created for integration because the frameworks underpinning both the worldviews of religion and science, are open to interpretation and can evolve further.

Anderson (2007) makes a call for avoiding the philosophical narrowness of some educationists who wish to protect the teaching of evolution by limiting it to the teaching of the nature of science without relating it to the epistemology of science and also to other epistemologies concerning the origin of knowledge about religion and the history of human civilization, for example. A challenge indeed to teachers, when one considers that constructivist approaches to teaching demand a broader perspective in education, incorporating deeper social, intellectual and pedagogical contexts than is usually encountered in the science classroom.

4.6 BEYOND CONSTRUCTIVISM

'It is suggested that some researchers seem to present learners’ alternative ideas as having as much validity and significance as the consensual models of science that they are alternatives to.' (Taber, 2006, p. 143).

Most science education researchers will accept that ‘learning to know the learner’, and how knowledge is constructed through cognitive processes within learners, are an important part of the principles of science teaching. However, some of the strongest criticisms of constructivist studies have been from researchers who object to the relativist epistemology used in some of these studies, equating findings and explanations derived from using the consensual models of science with many alternative interpretations constructed by individuals in various contexts.

A function of science instruction is to convey conventions that concern an agreed way of collecting, analyzing and interpreting evidence about the events in the world in which we live. The ‘target knowledge of science’ is derived by consensual agreement between members of the science community. The science community thus defines the ‘context’ in which the ‘target knowledge’ is constructed and hence the tenets of the nature of science.
The active role of the learner is the cornerstone of science research. But Taber (2006) feels that research into the construction of knowledge is only one component, because other considerations also affect change in the construction of scientific knowledge. These may be the availability of cognitive resources, the effectiveness and quality of teaching, and the importance of triggering new ideas through dialogue, for example.

Research in the future Taber maintains, should not only concentrate on the fact that knowledge is constructed, but should consider the constraints on constructing scientific knowledge in the classroom and such contingencies that channel the scientific connections made in the construction process – moving beyond constructivism. This is very much the tone of my research into how certain pedagogical strategies, such as the use of concept cartoons and narratives about the evolution of life, could be used to improve the effectiveness of teaching of evolution, as a scientific theory, in the classroom.

4.7 SUMMARY

Introduction

In my research I have used a theoretical framework which is specific to constructivism in science education.

The construction of knowledge structures

Mainly two constructivist points of view appear in the science education literature. These are the Piagetian theory of cognitive development (though some authors prefer the Vygotskian approach) and the alternative frameworks and misconceptions model.

The Piagetian theory of cognitive development in individuals, which is context-independent, is used in my research because it provides the norms and characteristics for describing the different levels of concept development, which have been adapted to measure the levels of understanding of evolution.

The alternative frameworks and misconceptions model, which is context-dependent, is used to explain how concepts evolve with teaching and why certain concepts remain unchanged after interventions.
The levels of conceptual understanding of evolution is based on Case’s Neo-Piagetian interpretation which acknowledges the importance of contextual specificity as well as the universal sequence of structural developmental levels, which progress from the concrete to the abstract.

Worldview Theory

Worldview theory is used as a framework to analyze the ideas that learners and teachers bring to the classroom, and which influence learning in science.

Different types of border crossings between worldviews have been described by Aikenhead and Jegede (1999). These border crossings explain why certain learners make a smooth transition between their life-world view, or worldviews, and the worldview of school science; whereas others find these border crossings hazardous or even impossible, often resulting in the ‘avoidance’ of science.

Border crossings between the worldviews of science and religion are classified by Anderson into four approaches which range from ‘conflict’ to ‘integration’. One of the possible reasons for the existence of these approaches concerns the effect of different epistemologies of science and religion.

Beyond constructivism

Although research in the construction of science knowledge is well and alive, Taber has suggested other areas of research, beyond constructivism, which involve the contingencies that constrict and channel the scientific connections made into the construction of knowledge frameworks in science.
CHAPTER 5
RESEARCH QUESTIONS AND RESEARCH DESIGN

5.1 INTRODUCTION

5.1.1 Constructing the research questions

Past experience
Experience from conducting in-service workshops for the professional development of teachers of the life sciences had shown a need for an in-depth knowledge of the subject and the ability to deal with questions requiring higher-order thinking skills. These were some of the observations that led to developing the aim of this study. In essence, the aim of the study was to explore the impact of certain teaching strategies, as part of the teachers’ pedagogical content knowledge, which could enhance the quality of teaching of complex topics such as the evolution of life.

From presenting courses to pre-service teachers specializing in the natural sciences and life sciences, it was also apparent that their knowledge about the Earth’s geological history and how it impacted on the evolution of life was problematic. Even those specializing in mathematics had difficulty in conceptualizing the magnitude of time, represented in billions and millions of years, used to describe a geological time scale which underpinned the Earth’s history (or temporal time). To overcome this problem, activities were introduced dealing with the construction of a time line which could also be used as a narrative of the history of the Earth, as well as the story of how life began and evolved.

Although these pre-service teachers/students were familiar with concept cartoons used in other courses, no concept cartoons dealing with the evolution of life or the Earth’s geological history, existed. To fill this gap, the students were encouraged to design their own concept cartoons about the evolution of life and related issues dealing with the teaching of this topic. This resulted in some great innovation and quality discussions about the evolution of life and also with issues dealing about the nature of science and religion.
From these experiences arose some interesting considerations and questions about improving the quality of teaching in the natural and life sciences which developed into research questions for this study.

In structuring the research questions, it was important to note that there were complex interactions between various aspects (or factors) that defined this study. These aspects are discussed briefly below to clarify the research questions which were ultimately formulated.

5.1.2 Aspects influencing the quality of teaching considered in this study

- **Evolution of life, the nature of science and knowledge building**
  Cognitive barriers developed not only in terms of a lack of understanding of evolutionary theory, but also in a lack of ‘further understanding of the way science works, along with its underlying assumptions and limitations’ (Cherif, Adams and Loehr, 2001, p. 569). In their meta-analysis of teaching effectiveness research Seidel and Shavelson (2007) pointed out that higher-order learning and deep understanding of the content would be affected by the ‘quality of knowledge building’ (p. 462). This in turn, affected the ability to apply knowledge to everyday issues and also to answering questions requiring higher-order thinking in the classroom, setting assignments, tests and examinations.

- **Choice of evolution of life as a topic for this research**
  It was the first time in South Africa that the topic of evolution of life had been officially included in the grade 12 life sciences curriculum in 2008. This meant that many teachers were expected to present a topic unfamiliar to them and also to most of their learners. Apart from not having a sufficient content knowledge to deal with the construction of knowledge about evolution, many teachers also did not possess a sound pedagogical content knowledge to assist them in devising good challenging lessons about evolution of life.

The knowledge component of this investigation arose from the NCS (National Curriculum Statement) grade 12 knowledge area on ‘Diversity, Change and Continuity’. Evolution of life featured in grade 12 of the curriculum. Geological time (or temporal time) was implied when considering fossil records and studying mass extinctions of life. These topics were complex,
controversial and thought provoking and ideal for promoting opportunities for in-depth study and deep learning.

- **Higher-order thinking skills and deep learning**
  Deep learning strategies usually involved ‘an intention to understand – focusing on the concepts applicable to solving problems, relating previous knowledge to new knowledge’ (MacFarlane, Markwell, and Date-Huxtable, 2006, p. 13). Suitable for these types of activities were knowledge areas encompassing complex topics such as the evolution of life and geological time.

- **Teaching strategies and the professional development of teachers**
  To teach effectively teachers needed to develop further their own understanding of evolution of life and the nature of science. This was easier said than done, because many did not have the knowledge, resources and tools to achieve a better understanding of evolution and develop a sound pedagogical content knowledge to teach evolution effectively.

- **Worldviews, values and beliefs in dealing with issues relating to science and religion**
  Dagher and BouJaarde (1997) suggested that the understanding of evolutionary theory was enhanced when students were ‘given the opportunity to discuss their values and beliefs in relation to scientific knowledge’ (p. 429). In order to achieve this, teachers as professional educators needed to have skills that could assist them in dealing with such controversial issues in the classroom.

**Central to the design of this study were two main considerations:**

- **To what extent would the use of narratives and concept cartoons, used in the professional development of teachers, encourage them to further their knowledge about evolution of life and the nature of science and encourage higher-order thinking skills and deep learning?**

- **In what ways would a better knowledge of the evolution of life and the geological history of the Earth (including the nature of science) and the development of higher-order thinking**
skills, assist teachers to recognize different worldviews; and how would this help them in addressing issues relating to science and religion?

These considerations generated the seven research questions, listed below.

5.2 RESEARCH QUESTIONS

Research Question 1
How will the design of a narrative, about how scientists construct the evolution of organisms on Earth, encourage teachers to display higher-order thinking skills?

Research Question 2
How will the use of concept cartoons generate discussion about issues relating to evolution of life, and, of science and religion, encourage teachers to display higher-order thinking skills?

Research Question 3
How will the achievement of higher-order thinking skills be measured?

Research Question 4
How can concept cartoons be used as a tool to analyze teachers’ worldviews about evolution of life, and, of science and religion?

Research Question 5
What barriers can be identified that affect teachers’ understanding of evolution of life and the nature of science and why do these barriers arise?

In research questions 6 and 7, the above research questions were combined to reflect a mixed methods research design.

Research Question 6
To what extent will the use of narratives and concept cartoons affect teachers’ ability to achieve higher-order thinking skills and deep learning about the evolution of life, the geological history of the Earth and the nature of science?

Research Question 7
In what ways will the worldviews of teachers affect their ability to achieve higher-order thinking skills and deep learning about, and deal with, issues relating to the evolution of life, the geological history of the Earth and the nature of science?
5.3 RESEARCH DESIGN

The study was based on a complex interplay of various components discussed above. A mixed methods approach would be ideal in exploring this interaction and allow for a better understanding of how the quality of the teaching of evolution could be improved in schools. Creswell (2009, p. 4) explained mixed methods research as follows:

... an approach to inquiry that combines or associates both qualitative and quantitative forms. It involves philosophical assumptions, the use of qualitative and quantitative approaches, and the mixing of both approaches in a study. Thus, it is more than simply collecting and analyzing both kinds of data: it also involves the use of both approaches in tandem so that the overall strength of a study is greater than either qualitative or quantitative research.

5.3.1 The nature of mixed methods research

This method of research design was not necessarily new because researchers had collected quantitative and qualitative data for many years. Since the 1980s, however, mixed methods research had been formalized into distinct research designs that were new in the use of notation, terminology and mixing of data.

According to Creswell (2009) philosophical ideas that underpin research usually remain hidden but do become apparent in the way they influence the practice of research. In mixed methods research pragmatism defined the worldview, or set of beliefs, that guided the researcher.

Initially, pragmatism was a distinctly American philosophical approach. One of the founders of pragmatism was Charles Saunders Peirce (1839 – 1914) who was a professional scientist rather than a philosopher. His laboratory experiences were key in influencing his thoughts. For example, Peirce interpreted the meaning of a ‘term’ in how it affects ‘... our actions and the way we conduct inquiry; and so is definable in terms of its rational usefulness’ (Law, 2007, p. 313).
William James (1842 – 1910) spent his career at Harvard, and was influenced by Peirce’s ‘pragmatism’ and this led him to propose in his publication ‘Pragmatism’ in 1907, that

..the truth of a statement is defined not by the fact that it agrees with reality, but rather in terms of the practical use to which it can be put – it can only be “true”, for example, if it accurately predicts experience (Law, 2007, p. 313).

Later, Richard Rorty developed further the idea that truth is a matter of what works rather than a correspondence between beliefs and facts. In ‘Philosophy and the Mirror of Nature’ written in 1979, he encouraged the idea to ‘…see knowledge as a matter of conversation and of social practice, rather than to mirror nature’ (Law, 2007, p. 344).

5.3.2 Pragmatism underpins mixed methods research design

The pragmatic notion of ‘the truth is what works at the time’ and ‘with what works will give a solution to the problem’ justified the mixing of quantitative and qualitative research. Both quantitative research and qualitative research were seen as important and useful. With this approach many possibilities opened up for using different methods, worldviews and assumptions which could translate into various forms of data collection and analysis. A pragmatic approach to research allowed that different worldviews, such as post-positivism and social and personal constructivism, to be accommodated in the research design.

The goal of mixed methods research was not to replace either qualitative or quantitative research, but to draw on their strengths and to minimize their weaknesses, in a single research, Johnson and Onwuegbuzie (2004) contended. These authors also maintained that in pragmatism an ‘either/or approach’ was rejected, and that both inductive and deductive logic as well as both objective and subjective points of view were important. Knowledge was seen as both constructed and based on the reality of the world we experience and live in. Views of knowledge and meaning were tentative and truths provisional.
But there was also a commonality, Johnson and Onwuegbuzie (2004) maintained, between qualitative and quantitative research. In both instances, empirical observations were used to address research problems, and to describe data, to construct explanations and speculations of why things happened the way they did. Because pragmatism addressed problems that gave workable solutions, a weakness of such a philosophical approach was that change was seen as ‘incremental’ rather than as causing fundamental, structural or revolutionary change in society, the above authors explained.

5.3.3 Concurrent embedded mixed methods strategy

In this strategy there was one data collection phase, in which both quantitative and qualitative data were collected simultaneously. The findings of quantitative and qualitative research were then mixed to find the best practical solution to the problem. Thus a primary method (quantitative phase) guided the study and a secondary (qualitative phase) database played a supporting role.

The larger quantitative study is on higher-order thinking skills achieved by teachers. Embedded within the quantitative part runs a concurrent qualitative component which focused on how teachers dealt with issues about science and religion both in their own personal lives and in the classroom.

Based on the research questions given at the beginning of this chapter, the study attempted to find some generalizations about teachers’ abilities to use higher order-thinking skills in problem solving about the evolution of life, when exposed to interventions based on teaching strategies involving the construction of narratives and concept cartoons. Because this did not happen in a vacuum, the teachers’ worldviews about science and religion also played an important personal role in affecting the context in which the study occurred and hence the outcome of the research.

Thus the research design incorporated both generalization as in quantification of the levels of higher-order thinking achieved and a contextual component analyzing qualitatively the worldviews that teachers held.
Referring back to the research questions posed at the beginning of the chapter, research questions 6 and 7 were stated in a mixed methods style. A visual representation of the ‘concurrent embedded mixed methods design’ is given in the model below which also reflects the research questions associated with each phase of the study. (Not shown in the visual model is the fact that all the data from both phases, are collected in a single collection phase. Only then can data analysis and interpretation commence.)

**Figure 5.1** A visual model of the concurrent embedded mixed methods design showing the research question for the larger quantitative phase (QUAN) and the supporting qualitative phase (qual) (adapted from Creswell, 2009)

The interpretation of the results was based on the data analysis processes shown below. This was complex because it involved the mixing of qualitative and quantitative results.
5.3.4 Seven-stage conceptualization of data analysis in the mixed methods research process model

Before considering the two phases of this study in greater detail, it would be worth examining the processes involved in the seven-stage conceptualization of data analysis as outlined by Johnson and Onwuegbuzie (2004):

- **Data reduction** involved in the reduction of the dimensionality of the qualitative data (as in exploratory thematic analysis and memoing) and via descriptive statistics in quantitative data.

- **Data display** involving pictorial description (as in use of charts or lists of qualitative data and use of tables and graphs representing quantitative data).

- **Data transformation** where qualitative data, for example, could be transformed into quantitative data, such as the use of a rubric describing numerical codes, which could then be used in statistical analyses.

- **Data correlation** involving quantitative data from statistical analyses being correlated with qualitative data presented in themes.

- **Data consolidation** wherein both the quantitative and qualitative data might be combined to create new or consolidated variables and data sets.

- **Data comparison** involving the comparison of data from both quantitative and qualitative data sources.

- **Data integration**, the final stage involving integration of data into a coherent whole.

These processes are clarified further, with specific references to this mixed methods study, in the flowchart shown in Figure 5.2.
Figure 5.2 A flowchart showing a mixed methods research design

**Content Knowledge (control variable)**
- Evolution of life.
- Geological history of the Earth.
- Nature of science.

**Feedback from previous workshops for in-service and pre-service teachers**

**Research Questions**

**Intervention:**
- Two Teaching Strategies (independent variable)
  - Construction of narratives OR
  - Concept Cartoons.

**Higher-order thinking skills (dependent variable)**

**Workshop design and presentation (control variable)**
- pre-test – intervention – post-test format
  - Ordering knowledge and brainstorming (group discussion)
  - Design of narrative or concept cartoon (group activity)
  - Presentation to and discussion with rest of workshop participants.

**Mixed methods concurrent embedded design**

**Quantitative study (QUAN)**

**Qualitative study (qual)**

**DATA COLLECTION (Workshop)**

Questionnaire: (pre-test and post-test, open-ended questions, qualitative data),
Other sources of data generated by teachers (narratives and concept cartoons, knowledge frameworks and records of investigation ‘design a beak’),
Reflections and observations by the researcher and teachers.

**QUAN DATA ANALYSIS**

Transformation of data
Rubric: higher-order thinking skills, transforming qualitative data into quantitative data,
Statistical analysis
Generalization

**qual DATA ANALYSIS**

Content analysis
Themes and categories worldview, issues and how to address these
Contextual

**INTERPRETATION OF RESULTS AND CONCLUSIONS**

QUAN mixing qual
As shown in Figure 5.2, in the quantitative phase of the study data reduction went hand-in-hand with data transformation. The answers to the open-ended questions were analyzed and classified according to the levels of thinking described in the rubric. Memoing and member checks were done to justify the decisions made in the classification (also see section 5.10.1 below).

Descriptive statistics was in the form of frequency tables and graphs. This gave a pictorial representation of the relationship between the percentage of teachers’ responses and the levels of thinking achieved, as described by the rubric.

Data analysis in a mixed methods design, according to Johnson and Onwuegbuzie (2004), would then involve the correlation, consolidation and comparison of data, both quantitative and qualitative in nature. These results were then integrated to form a coherent whole which could be used to answer the research questions posed by the researcher.

5.3.5 THE NATURE OF THE QUANTITATIVE PHASE OF THE MIXED METHODS STUDY

The quantitative phase of this mixed methods design was used to investigate how effective the two teaching strategies were in improving the teachers’ abilities to incorporate higher-order thinking skills into their conceptualization of the evolution of life.

Research question 6 was worded in a format, according to Creswell (2009) which was suitable for mixed methods design.

To what extent will the use of narratives and concept cartoons affect teachers’ ability to achieve higher-order thinking skills and deep leaning about the evolution of life, the geological history of the Earth and the nature of science?

In quantitative research the relationship between variables in testing theories is examined. In this study, according to the wording of research question 6, the relationship between the variables, which were the two teaching strategies (the use of narratives and concept cartoons) and the achievement of higher-order thinking skills and hence deep learning, was investigated. Furthermore, to determine whether teaching strategies such as the use of narratives and concept cartoons, could improve the depth and quality of understanding of evolution of life by teachers and
hence also improve the effectiveness of their teaching of the topic. In essence, research question 6 reflected the researcher’s theory about the use of different teaching strategies to improve higher-order thinking skills and hence more effective teaching.

Quantitative studies are underpinned by the ‘scientific method’, or various interpretations thereof. To-day a post-positivist philosophy is usually used in research of this nature in the social sciences. A positivist approach was originally adopted by August Comte (1798 – 1857) who rejected any claims to knowledge not grounded in scientific investigation. He considered metaphysics and theism as being ‘negative’ in their contribution to knowledge. Comte maintained that a genuinely scientific attitude was confined to description and prediction based on observable regularities, this meant that science did not explain phenomena (Law, 2007). He saw the study of human society as a science, based on laws constructed from observable (thus positive) data and named this science ‘sociology’.

To-day, a post-positivist philosophy is held by most quantitative researchers in the social sciences. ‘Post’, as in ‘post-positivism’, means that the traditional ‘positivist’ notion of absolute truth (based on observations only) of knowledge which is confined to description and prediction only, without explanation, does not hold when studying the behaviour and actions of humans. We have moved ‘beyond’ positivism into a post-positivist era of research.

Using the ‘scientific method’, researchers study the causes that influence outcomes, or, in terms the ‘cause – and – effect’ of a causal relationship. In this study, the ‘causes’ would be the teaching strategies used in the interventions and the outcome or ‘effect’ would be how well higher-order thinking skills and deep learning are achieved by the participants, the teachers.

Experiments are the primary tool in studying causal relationships. In designing such experiments the focus falls on certain variables only, to the exclusion of others which are not seen to be important in the causal relationship being studied. However, this type of ‘reductionist’ approach is criticized by some researchers because they feel that a potential for a loss of important data may be created in the research process. This is one of the reasons why a mixed methods research design is valuable in avoiding such data loss.
In this study the focus was on ‘teaching strategies’ (independent variable) and higher-order thinking skills and deep learning (dependent variable). Other possible causes in the complex interplay of factors that govern teaching and learning were controlled for (as control variables) or were excluded. The two control variables were ‘knowledge’ and the ‘design and presentation of workshops’. Both these variables had the potential to influence the outcome of the study. It must be remembered, however, that certain researchers are critical of such an experimental approach. Barab and Squire (2004) see ‘experiments’ as being ‘engineered’ because they do not happen in this form but occur in a more ‘naturalistic context’ of many variables and complex interactions.

However, Seidel and Shavelson (2007) pointed out that the advantage of (quasi)experimental studies was that the researchers dealt

  with the complexity of the field by concentrating on specific instructional measurements and attempted to provide valid measures of instructional characteristics and outcomes, often specifically tailored towards the goals of the teaching intervention (pp. 464-5).

Theories need to be tested and verified when using the ‘scientific method’ in an attempt to understand the world, and in this case that of teaching and learning. Knowledge is obtained by careful observation of the objective reality of the world ‘out there’, Creswell (2009) maintains. The approach is usually deductive and involves starting with a theory and then collecting data to support of refute the theory. To-day, however, we do accept that there is no single ‘scientific method’ and that a deductive and an inductive approach (moving from observations to hypotheses) will go hand in hand when navigating a problematic area of investigation.

In science we accept that knowledge is tentative and fallible. This means that researchers cannot ‘prove’ a hypothesis. They can merely state whether they choose to reject or not reject a hypothesis in accordance with Popper’s ideas about the falsification of theories.

Being as objective as possible, researchers are aware of the effect of bias and examine the methods used and conclusions made carefully for such effects. This explains why validity and reliability are considered to be important in quantitative research.
5.3.6  THE NATURE OF THE QUALITATIVE PHASE OF THE MIXED METHODS STUDY

The qualitative phase of the study, involved examining the worldviews of teachers and how these personal views impacted on their teaching of evolution, was reflected by research question 7:

In what ways will the worldviews of teachers affect their ability to achieve higher-order thinking skills and deep learning about the evolution of life, the geological history of the Earth and the nature of science?

In a constructivist worldview the focus is on how individuals develop meaning for their experiences. These experiences may be varied and multiple and contribute to a complex view of the world we live in and experience. Often these subjective meanings are negotiated socially and historically. They are formed through the social interaction with others, hence termed ‘social constructivism’ by various qualitative researchers who are active in this field of study. In science education we operate in a constructivist paradigm which is also influenced by the nature of science, discussed below.

In less than thirty years, constructivism has become a widely accepted, if not dominant, theoretical position in many fields of study including science education and cognitive psychology (Martinez-Delgado, 2002). Constructivism, she maintained further, covered a wide range of points of view; from philosophical considerations to pedagogical practice, and which could even be arranged as ‘patterns’ along ‘two axes’, that of “objectivist-relativist” and “personal-social”(p. 841).

In science education much research about how knowledge is constructed has been recorded for about thirty years. Taber (2006), in commenting on a debate on ‘beyond constructivism’ raises the point that a wide range of different forms of constructivism occur in science education literature. These forms range from ‘personal constructivism’ to a ‘social constructivist’ approach. ‘Personal constructivism’ is seen as an interpretation of how levels of intellectual development are constructed in the individuals, as recorded and interpreted by Piaget, for example. A ‘social constructivist’ worldview put forward in science education by Solomon, for example, illustrates how a focus on the fundamental social aspect in learning shows the importance of socially mediated processes involved in the construction of science knowledge, based on Vygotsky and the Cultural – Historical Activity Theory (CHAT).
Using a ‘social constructivist’ worldview, it is assumed that humans make sense of the world that they live in, based on the historical and social perspectives of their culture. A qualitative researcher will seek to understand the context in which the participants react to, for example, when attending a workshop about the construction of narratives about the evolution of life on Earth. On the other hand, adopting a ‘personal constructivist’ point of view, light may be shed on how the participants construct their own knowledge structures in order to understand a complex topic such as the evolution of life.

Unlike the collection of quantitative data which may be generated from responses to a questionnaire for example, information from the qualitative phase is usually gathered personally by the researcher. It is important to note that how the data are collected and interpreted is shaped by the researcher’s own experience and background. The processes of qualitative research are largely inductive and it is the researcher who generates meaning from the data collected (Creswell, 2009).

5.4 IMPLEMENTATION OF RESEARCH DESIGN

Before discussing the quantitative and qualitative phases of this study it is important to consider the ethical issues that underpin the research. Research involves collecting data from people and also about people (Creswell, 2009).

5.4.1 Ethical considerations

To promote the integrity of the research and to protect the research participants, all teachers were given a ‘letter of consent’ to consider before the workshops commenced (see APPENDIX A). The letter’s content was explained by the researcher before the participants were asked to sign the letter of consent. Ethical issues may arise in all stages of research (Creswell, 2009). The ethical issues addressed in this study are discussed below.

- The research problem was chosen not only to benefit the researcher, but was also of value to the participants who received up to date resource material about evolution.
Furthermore, the teaching profession could benefit as a whole, because new teaching strategies were explored that could develop higher-order thinking skills thus improving the effectiveness of teaching evolution.

- **The purpose of the research** was stated in the letter of consent and was explained in detail to avoid misrepresentation (see APPENDIX A). Permission was requested to take photographs during the intervention and it was explained that some of these could be featured in the text of the thesis.

- **All participants benefited** from this (quasi)experimental research design.

- **Agreement of authorities**, in this case the Gauteng Department of Education (GDE). This study was part of a GDE commissioned research project in which permission was granted to work in all, or any, districts as required by the project.

- **Data collection** was conditional to a guarantee of confidentiality as well as the assurance of anonymity of the participants. The teachers were free to withdraw at any stage of the research. Two participants attended the workshops without signing the letter of consent and were free to participate without completing the questionnaire. The name of the researcher’s supervisor was given in the letter of consent, as a contact person if any further questions needed to be answered.

- **Data analysis and interpretation** required sensitivity on the part of the researcher because many participants shared their personal worldviews. In many instances some participants also revealed a lack of understanding which if revealed, could have harmed their professional integrity. It was important to protect their anonymity, even by considering carefully which photographs of participants and their written contributions used in the text of the thesis, could have created an adverse impression of their participation in the workshops. Where possible such participants were given copies of the photographs for their consideration. The data, once analyzed will be kept for five years and will then be destroyed to avoid possible misappropriation by other researchers at a later stage.

- **Writing and disseminating the research** though very important, also involved being aware of the danger of altering, suppressing or even inventing findings of the research to support a certain theory or stance. In this study it was sometimes difficult to keep the workshop format the same, even though improvements in the presentation of these interventions became apparent as the research progressed.
5.4.2 The quantitative phase of this study
This formed the larger part of this mixed methods research design. A (quasi)experimental design was used because the participants were not randomly selected nor randomly allocated to the experimental groups. There was no control group.

5.4.2.1 Experimental design procedures

The design was (quasi)experimental, in the form of a pre-test – intervention – post-test design. The intervention was in the form of workshops, either on ‘narratives’ or on ‘concept cartoons’. There were two ‘experimental’ groups (E). The teachers who attended the workshop on ‘narratives’ were assigned to E1 and those who attended the workshop on ‘concept cartoons’ were assigned to E2.

The participants were volunteers and not randomly drawn from all the life sciences teachers in the province, who would have constituted the ‘population’ of such teachers. Furthermore, they were available only on certain Saturday mornings during a busy year end and thus could not be assigned to E1 and E2 randomly. Purposive convenience sampling, instead of random sampling, was thus adopted to address the availability of these participants in the research conducted.

Both ‘within-group’ and ‘between-group’ design formats were used. The effect of the first treatment (the use of ‘narratives’) and the effect of the second treatment (the use of ‘concept cartoons’) were studied separately, as reflected in research questions 1 and 2. To compare the effectiveness of the treatments, a ‘between-group’ design was also adopted.

Figure 5.3 illustrates the type of (quasi)experimental research design which was used. In particular, note the absence of a ‘control’ group in this ‘non-equivalent groups’ representation in the diagram given on the next page.
CHAPTER 5: RESEARCH QUESTIONS AND RESEARCH DESIGN

Figure 5.3 A diagrammatic representation of the (quasi)experimental research design used (adapted from Creswell, 2009)

Notation system (originally devised by Stanley and Campbell, 1963, as quoted in Creswell, 2009):
- X represents an exposure of a group to an experimental variable
- O represents an observation recorded on an instrument
- X’s and O’s shown in a row are applied to the same specific persons
- Separation of parallel rows by a horizontal line indicates that comparison groups are not equal by random assignment

A non-equivalent (pre-test and post-test) groups design (with no control group)

<table>
<thead>
<tr>
<th>Group A (E1)</th>
<th>O</th>
<th>X</th>
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<table>
<thead>
<tr>
<th>Group B (E2)</th>
<th>O</th>
<th>X</th>
<th>O</th>
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</table>

5.4.2.2 The use of a control groups in scientific investigations

Babbie (2005) defines a ‘control group’ as ‘…a group of subjects to whom no experimental stimulus is administered …’ (p. 223). The control group is used to indicate what the experimental group should be like at the end of the intervention, if no experimental stimulus is administered. Thus a comparison of the control and experimental groups at the end of the intervention will indicate the effect of the intervention or ‘experimental stimulus’.

In certain experiments a pre-test is not used because it is assumed that it is the comparison between the control group and the experimental group at the end of the treatment, which is of interest. (This is only acceptable if the participants, randomly assigned to both groups, belong to the same and normally distributed population.)
In this study, the teachers (participants) were volunteers and attended the workshops on a Saturday morning, in their own time, at their own expense and many traveling up to 90 minutes to reach the venue. Although the decision not to use a control group affected the experimental design, it was felt that it would be unfair and unacceptable to assign teachers randomly to either the two ‘experimental’ groups or to a ‘control’ group, thus denying some participants the opportunity of experiencing the workshops.

This quantitative study was considered to be (quasi)experimental in nature because it did not meet the criteria necessary for a true experimental design in terms of normal distribution of the population, random selection of members of E1 and E2 and the use of a control group.

Diamond and Robinson (2010) commented on the predicament experienced by the researcher when conducting an experiment outside the controlled experimental environment in that ‘there are plenty of things we can’t study using standard laboratory experiments – but there are other ways of tackling problems’ (p. 28). There are many fields in science in which ‘controlled experiments’ are impossible, such as in astronomy, evolutionary biology and in palaeontology, these authors maintain. In some of the social sciences ‘...manipulative, controlled experiments are ruled out on three grounds – they are either impossible, or they are immoral or illegal’, these authors contend, thus summarizing the reasons why I decided against using a control group in this study.

5.4.2.3 Some problems associated with data collection for the study

The participants would only be available during the workshop time because the intervention occurred at a very busy year-end. No further opportunities would be available for follow-up studies or interviews. To overcome potential problems which could have arisen if further information were needed for the study, additional sources of data were built into the workshop design which could be used to corroborate findings. Data collection for the qualitative phase also involved the construction of charts showing the structure of the narrative design, knowledge frameworks and concept cartoons designed by the teachers. Notes were also made about the discussions by the teachers, their own reflections and those of the researcher. These formed part of unobtrusive data collection about the worldviews, including beliefs, of these teachers.
5.4.2.4 Data collection considerations

This was an exploratory study based in a South African context. It explored how teachers made the connections between the geological history of the Earth, the evolution of life, the nature of science and related issues; and their ability to teach this effectively in South African schools. It was decided to create open-ended questions which could generate rich data suitable for qualitative and quantitative analyses in the South African context.

There are several closed-ended questionnaires about the nature of science, the process of evolution, and beliefs about evolution available in the literature. Examples such as the Conceptual Inventory of Natural Selection (Anderson, Fisher & Norman, 2002), Attitudes towards Evolution (Matthews, 2001) did not entirely serve the requirements of the study, but were useful references in the construction of the open-ended questions.

5.4.2.5 Statistical analysis and the (quasi)experimental design chosen

The pre-test at the beginning of the workshop served as a baseline to indicate the level of knowledge held by the teachers before the intervention started. The post-test took place at the conclusion of the workshop. A comparison between the pre-test and post-test results indicated the possible tendencies and effectiveness of the intervention on the participants, but within the limitations of the (quasi)experimental design.

The pre-test results of the two groups and their post-test results were also compared. This helped to establish any possible differences and tendencies in the effect that the two teaching strategies could have had on the ability of teachers to achieve or develop further higher-order thinking skills and deep learning. Again, these results had to be interpreted within the limitations of the (quasi)experimental design.
5.4.3  The qualitative phase of this study

Owing to the embedded nature of this study, it ran concurrently with the quantitative phase. The collection and analysis of data are discussed later in the chapter.

5.5  INTERVENTION

The workshop format and presentation formed part of the ‘control variables’ of the study. The knowledge required to handle various activities built into the workshop design was the other ‘control variable’.

In designing teaching strategies that contribute to the professional development of teachers, such as the introduction of new teaching strategies, Rogan (2004) highlighted the importance of implementing innovation in manageable steps, ‘innovation is most likely to take place when it proceeds just ahead of existing practice’ (p. 160). The workshops were designed to include several activities which were used to develop the required knowledge structures before the final activity involving either the design of the narratives or concept cartoons commenced. A similar workshop format was used for both workshops because their design formed part of the control variables of the intervention. The workshops lasted four hours and the time allocated for activities was kept the same:

<table>
<thead>
<tr>
<th>Introduction: (30 minutes)</th>
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<tbody>
<tr>
<td>A brief explanation of aim of research and a letter of consent to be signed</td>
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<tr>
<td>Completion of pre-test questionnaire, including some biographical detail</td>
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<tr>
<th>Intervention: (3 hours)</th>
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<tbody>
<tr>
<td>Source material provided in the form of a booklet</td>
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<tr>
<td>Activities involving group interactions and discussions based on the information contained in the booklet</td>
</tr>
<tr>
<td>Construction of a chart: representing either the narrative chosen, or the concept cartoon designed</td>
</tr>
<tr>
<td>Each group presenting their chart, showing the choice of narrative or concept cartoon, to the rest of the workshop members, sharing ideas. (1 hour)</td>
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</table>

<table>
<thead>
<tr>
<th>Conclusion: (30 minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion of post-test questionnaire</td>
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The design of the workshops on narratives and concept cartoons will be discussed separately. Although similar in format, these workshops contained different activities to prepare the teachers for the final part of the intervention, namely the design of the narrative or concept cartoon.
5.5.1 The steps involved in the intervention on the construction of narratives

Given below are various examples from the workshop materials as well as from the actual workshops to illustrate the various activities that happened. Examples from workshop materials only serve to highlight certain ideas and are consequently reduced, the full size pages occur in the appropriate appendices with the page references indicated in brackets.

5.5.1.1 Introduction: ‘ice-breaker’ investigation on ‘design a beak’

This activity involved teachers working in groups to design an investigation using cardboard cut-outs as ‘beaks’ and rice grains to be collected using these cardboard ‘beaks’, see Figure 5.4 and Figure 5.5. It also served as an introduction to scientific investigations and the nature of science.

![Figure 5.4](image1.png)  ![Figure 5.5](image2.png)

Figure 5.4 A page from the source material describing the importance of ‘Darwin’s Finches’ to the study of evolution and outlining an investigation about ‘design a beak’ (p. 287)

Figure 5.5 A discussion about the investigation on ‘design a beak’. Note cardboard cut outs of the beaks shown on the right
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![Figure 5.4 A page from the source material describing the importance of ‘Darwin’s Finches’ to the study of evolution and outlining an investigation about ‘design a beak’ (p. 287)](image)

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![Figure 5.5 A discussion about the investigation on ‘design a beak’. Note cardboard cut outs of the beaks shown on the right](image2)
5.5.1.2 Discussion of the ‘nature of science’ - fact, law and theory

Included in the source material was information about the ‘nature of science’ and the methods used by scientists to find out more about the Earth’s past. Too much information was deliberately given in the workshop material. This was done to encourage discussion about the selection of suitable information and thus to acquaint the teachers with important knowledge which they could use in the follow up activities, which is shown in Figure 5.7. The workshop material was also designed to serve as a source of information, which teachers could refer to at a later stage, when preparing their own lessons.

Figure 5.6 Source material outlining information about the nature of science involving ‘fact’, ‘law’ and theory (p. 252)  

Figure 5.7 Structuring information about the methods that scientist use to find out more about the Earth’s past

5.5.1.3 The construction of narratives

A video showing the introduction to ‘Walking with Dinosaurs’, a TV series telling the story of the evolution of dinosaurs, was used to illustrate how ‘narratives’ could be presented in an interesting scientific context. Because it was a new experience for teachers to design such a narrative, an example of how to structure a narrative, based on the information in the source material (see
Figure 5.9), was given by the researcher. A design of this outline for a narrative of the evolution of stromatolites is shown in Figure 5.8.

The participants then worked in groups discussing their choice of organism from a list provided. Using the workshop source material as source of information, they then constructed the narrative. This was the story of the evolution of their chosen organism. Included in the narrative was a description of what the Earth looked like at the time when the organism lived. A chart was prepared to show the main points of the story (Figure 5.10). This was then presented to the rest of the teachers in the workshop (Figure 5.11).

(Note: at no stage in the workshop did the researcher mention ‘linking of facts’ in ordering knowledge, nor the importance of ‘cause and effect’ in discussing the evolution of organisms. These were criteria used in the assessment of achievement of higher-order skills in answers to the open-ended questions of the pre-test and post-test questionnaire.)
5.5.1.4 Feedback from the pilot study

Initially a pilot study involving five participants was used to establish the suitability of the workshop materials. Several points were raised about the complexity and depth of information contained in the workshop materials. It was felt that the content was too extensive for the workshop to cover in the three hours available. The value of the activity on ‘design a beak’, and how it fitted in with the use of ‘narratives’, was also questioned.

Bearing this in mind, the following modifications were introduced.

- The activity on ‘design a beak’ was retained but more discussion was included to link it with the ‘nature of science’ and the importance of careful observation and quantification of data. During the intervention this activity was successful and generated good positive responses in terms of the variety of ‘beaks’ designed, the range of results obtained and the discussion that followed.

To deal with the large amount of information available, it was stressed that there were techniques to deal with such a problem when there was insufficient time available. Firstly, by identifying only the main points first, and structuring the knowledge in manageable ‘bits’ (hence the chart, which the teachers prepared, with only the main points about the methods that scientists use to find out
more about the Earth’s past, (see Figure 5.7).

- Secondly, a power point presentation was included on the origin of the protea family, as an illustration of why this type of narrative could be useful – even explaining why the ‘waratah’ occurring in Australia, was in fact, closely related to our own *Protea*. The protea family was one of the possible choices as a topic for the design of a narrative, and this presentation made a rather difficult option more accessible to the teachers.

- It was felt that it would be helpful to give an example of how to go about designing a narrative of this nature. Hence the story of the evolution of stromatolites was included as an example, see Figure 5.8.

- The five experts were asked to review the accuracy of the information in the workshop material and also to determine the content validity of the intervention.

- They also ranked how difficult they felt it would be to construct a narrative about each of the possible organisms listed for the teachers to choose from.

There was agreement about the ranking of the narratives in most cases:
Firstly, those ranked as ‘*easy*’, based on information given in the booklet were the Trilobites and Dinosaurs.
Those narratives seen as ‘*moderately difficult*’ were the Ammonites and the Chimpanzee.
Finally, the story of *Glossopteris* and the *Protea* (both plants) were rated as ‘*difficult*’.
There was disagreement about the difficulty of the story of stromatolites, which was ranked from ‘*easy to difficult*’. It was decided that the story of the evolution of stromatolites would be a suitable topic to serve as an example of how to construct a narrative.

### 5.5.2 Steps in the design of the intervention on the use of concept cartoons

Given below are various examples from the workshop materials, as well as from the actual
workshops, to illustrate the various activities that happened. Examples from workshop materials only serve to highlight certain ideas and are consequently reduced, the full size pages occur in the appropriate appendices with the page references indicated in brackets.

5.5.2.1 Introduction to what are concept cartoons and why the use of concept cartoons can generate discussion of contentious topics

The importance of a good basic knowledge of the topic ensured maximum benefit derived from this type of strategy. This was illustrated by showing an extract from the TV series on ‘The Galapagos Islands’ in conjunction with a power point presentation highlighting certain aspects of the video which the teachers should have taken note of during their viewing. The concept cartoon dealing with the Galapagos Islands (Figure 5.13) was then used as an example to highlight the skills necessary to examine the various statements shown in the concept cartoon. Skills involved in how to debate the various statements were also discussed (Figure 5.12).

Figure 5.12 The introduction to concept cartoons (p. 299)
5.5.2.2 Developing the skills of analyzing different arguments

The second concept cartoon (Figure 5.14) was based on a series of three letters to a newspaper commenting on the contents of an article about the coelacanth as a ‘missing link’. The letters, published in a newspaper, stated different points of view, arguments and opinions, also giving facts and misrepresentations about the topic (Figure 5.15 shows one of the letters).

Working in groups, the teachers analyzed the arguments (and information provided to substantiate these ideas) to decide whether they agreed, or disagreed, with what was stated in the letters. They decided which writer was a creationist or an evolutionist (Figure 5.16). Finally, the teachers then used the knowledge gained from the letters, to examine critically the statements given in the concept cartoon shown in Figure 5.14.
Two further concept cartoons, dealing with ‘Charles Darwin – a unique scientist’ (Figure 5.18) and ‘Charles Darwin – the nature of science and religion’ were used to show the importance of knowledge (Figure 5.17) to derive real benefit from discussing these concept cartoons. Having had the opportunity to examine and discuss these concept cartoons, the teachers had gained sufficient experience in dealing with the concept cartoon format to know what was required of them to design their own concept cartoons about the ‘issues related to teaching evolution’.

Figure 5.16 Discussion of arguments put forward by writers of letters to the newspaper who have different world views

Figure 5.17 Information about why Darwin was considered to be a unique scientist (p. 306)

Figure 5.18 An introduction to Darwin and the nature of science and religion (p. 296)
5.5.2.2 Designing their own concept cartoons examining issues affecting the teaching of evolution

Because this was a new experience for the teachers, I provided an example on how to brainstorm ideas for a concept cartoon (Figure 5.19). Working in groups, the teachers first discussed and then designed their own concept cartoon with at least four statements (Figure 5.20).

This was presented to the rest of the teachers and the issues raised in the concept cartoon presentation were discussed further (Figure 5.21). The discussion also allowed for examining and reformulating the reasons for including the ideas into the concept cartoon design.

Figure 5.19 The example used to illustrate how to brainstorm ideas (p. 337)
5.5.2.3 Feedback from the pilot study

Generally, it was felt that the concept cartoons formed part of an interesting strategy to encourage discussion and also further the teachers’ knowledge about controversial topics such as the meaning of a ‘missing link’ in evolution. No changes were recommended.

Although some good innovative ideas arose, subsequent to the pilot study, the format and presentation of both workshops (on ‘narratives’ and ‘concept cartoons’) were left unchanged. Consistency was maintained to ensure the reliability of the results obtained.

5.6 DATA COLLECTION

5.6.1 The questionnaire

A questionnaire consisting of six open-ended questions was designed for this study.

The first five questions of the questionnaire were based on four main themes, given below. These themes were used to identify the factual knowledge required for the workshops. The themes were:
• the evolution of life on Earth and the geological history of the Earth,
• mass extinctions of life on Earth,
• Charles Darwin as a scientist,
• the ‘nature of science’.

The final, sixth question, concerned issues relating to the teaching of evolution.

Figure 5.22 The questionnaire used as a data collection instrument consisted of six open-ended questions (See APPENDIX B)

1. What can we learn from the evolution of life and the changes that the Earth has undergone in the past?
2. Does environmental change drive evolution? Explain your answer.
3. What evidence do we have that mass extinctions happened in the past?
4. Although Darwin was born two centuries ago (1809 – 1881), he is still considered to be a great scientist to-day. Explain why this is so.
5. Explain how ‘Darwin’s Finches’ found on the Galapagos Islands, illustrate that evolution is a fact, evolution is a theory, evolution can be a law.
6. (a) Why do you think that the teaching of evolution of life is controversial?
   (b) What can you as a teacher do to address the issue?

The first theme, about the evolution of life and the geological history of the Earth, was covered by questions 1 and 2. Sufficient background information was given in both interventions for the participants to be able to answer these questions in the post-test. The second theme, on mass extinctions, was covered in the intervention on ‘narratives’. The third theme on ‘Charles Darwin as a scientist’ was only really covered in the intervention on ‘concept cartoons’ although some incidental information could have been ascertained during the discussion on ‘narratives’. The fourth theme, on the ‘nature of science’, information would primarily have been derived from the workshop on ‘narratives’.
The information for question 6 would be based on the teachers’ own experiences. However, observations made in discussions during the activities in both workshops could have contributed to a change in point of view expressed in the post-test.

5.6.2 Additional sources of data

Additional sources of data were collected in the form of charts prepared by the participants (the teachers) about the narratives designed and the concept cartoons developed (see APPENDIX I and J). A record of field notes on the reflections, observations and comments made by the teachers as well as by the researcher also served as additional qualitative data.

5.7 THE VALIDITY OF THE QUESTIONNAIRE

In quantitative studies validity refers to ‘the extent to which an empirical measure adequately reflects the real meaning of the concept under consideration’ (Babbie, 2007, p.146). Furthermore, he maintained, there were several ‘yardsticks’ that could be used to determine success of making such valid measurements, or ‘agreed-on meanings’.

One of these ‘yardsticks’ was content validity. The content validity of the questionnaire was determined by expert opinion used to establish how well the questions measured a range of responses to concepts such as ‘evolution of life’, environmental change’ and the ‘geological time scale’. It was also important that the experts considered the wording of the questions and the nuances conveyed by these statements in establishing the content validity of this study.

5.8 TENSION BETWEEN CRITERIA OF VALIDITY AND THOSE OF RELIABILITY

Reliability is concerned with how well the same results can be obtained with repeated applications of the same treatment. This was why the presentation and format of the workshops, which were repeated five times, were not changed.
Validity, on the other hand, shows how well the meaning of a concept has been measured. Thus many concepts are interesting because of a range of nuances that may define them. This gives validity and ‘richness of meaning’ to the concepts.

Often, by giving a reliable operational definition, the variation in meaning is lost in the process. This tension between reliability and validity was a problem which I encountered in my research when I used a rubric to transform the qualitative responses to open-ended questions into quantitative data. Because the rubric was based on levels of thinking, and not on factual knowledge, there was a wide range of answers that could be given the same score. Care was taken to define each level of thinking as a discrete unit of conceptualization, thus ensuring that the rubric was reliable. The Piagetian levels of concept development provided the characteristics which helped to define these levels of thinking. Thus the quantification of the qualitative responses was valid only in terms of the Piagetian theory of concept development and excluded other possibilities that might exist in terms of higher-order thinking.

On the other hand, the qualitative phase of this study explored the ‘richness’ of meaning as reflected in the worldviews that teachers held about the controversies associated with the teaching of evolution. Each personal worldview was as valid as the next one expressed and each workshop offered a different range of worldviews.

5.9 OBJECTIVITY AND CONFIRMABILITY

Babbie (2007) interprets objectivity as an attempt ‘to get beyond our individual views’ (p. 75). Further, by finding the ‘common ground of our experiences’ an objective view can be established. This usually happens by consensus of members of a specific community, such as scientists describing what is meant by the ‘nature of science’, which was an important focus of this study. In the analysis of the results, the ‘objectivity’ of scientists in describing the story of the evolution of life had to be considered in contrast to the many and individual worldviews held by teachers in dealing with the controversies arising from the teaching of evolution.
Objectivity, as used in quantitative research reduces the variety of responses. Thus in qualitative research confirmability is used instead. Here, an important consideration was not to impose the researcher’s own meaning of the data and own worldview on the discussions in the workshops. In the analysis of the results, an attempt needed to be made to understand and confirm the worldviews held by the participants and not that of the researcher.

5.10 DATA ANALYSIS AND INTERPRETATION

The questionnaire used for this study consisted of six open-ended questions. The first five questions were designed to measure the teachers' ability to use higher-order thinking skills in answering the questions and formed part of the quantitative study. The last, sixth, question was designed to elicit responses about how teachers felt about dealing with issues relating to the teaching of evolution in the classroom and was part of the embedded qualitative study.

5.10.1 Data transformation used to quantify the responses to questions 1 – 5 of the questionnaire

Whereas mixed methods design evolved initially from a strict differentiation between applying quantitative methods to quantitative data (numerical responses) and qualitative methods to qualitative data (verbal and non-numerical answers) there is now an ‘ongoing effort to bridge the gap’ between these methods (Loehnert, 2010, p. 2). An interesting example is how different ways are now considered to convert qualitative data obtained in surveys into quantitative indices for various economic variables used in business decision making. This highlights the importance to discern economic trends and patterns from industry surveys in which the various types data are qualitative in nature (Driver and Urga, 2004).

The acknowledgement that a need exists for transforming qualitative data into quantitative data, or ‘quantizing’, has now been identified not only in the field of business economics; but also in nursing and the health sciences; and ecological and environmental anthropology, for example (Loehnert, 2004). Similarly, in this study on higher-order thinking skills and the effective teaching of evolution of life, it would be useful to identify patterns derived from quantifying qualitative data about the way teachers make sense of teaching a complex topic, such as evolution, using various thinking skills.
The methodology used for this study was based on, and adapted from two recent studies (Jensen, Moore, Hatch and Hsu, 2007; and Mason, Gava and Boldrin, 2008). Both these studies were exploratory in nature and pushed the boundaries in research by using a rubric to transform qualitative responses into quantitative data. In particular, the study reported by Mason et al. (2008, p. 291) is pertinent because it aims

to go further than considering only cognitive factors to extend the understanding of complex, dynamic underlying knowledge revision processes.

Following the same trends as the above study by Mason et al., the qualitative responses to questions 1 – 5 of the questionnaire of the study on higher-order thinking skills and the teaching of evolution, were also transformed into quantitative data. This was done by using a rubric similar in design to the ‘scoring rubric for students’ answers to questions about evolution’ devised by Jensen et al. (2007) and the ‘response category and score’ format used by Mason et al. (2008).

Although ‘Bloom’s Taxonomy’ is useful in identifying key words that reflect certain levels of thinking, the notion of higher-order thinking in this study was closer to the ideas about intellectual development proposed by Piaget. Hence, concrete operational thinking would involve using directly the facts stated in the source material, or of previous knowledge. Higher-order thinking would be similar to formal operational thinking, or abstract thinking, involving the interplay of concepts and relationships ‘held in the mind’ and not in the ‘concrete’ realm of the printed matter.

The initial design of the rubric consisted of four levels of thinking. On the advice of one of the four evaluators used to validate the rubric, the intermediate level ‘3’ (i.e. an example given of such a link) was added. It was felt that the gap between level 2 (making a link between two facts), and identifying cause – and – effect of the next stage, was too great in the hierarchical order adopted in the rubric. The inclusion of level 3, or an example given of such a link, is justified because it involved both the identification of the characteristic or ‘link’, and the ‘name’ of such a link or concept.

In the rubric there were thus five levels identified which could be used to describe the quality of thinking. The following categories were used to quantify the qualitative responses:
Furthermore, to allow for coding of alternative responses, as well as incorrect answers, the following categories were also introduced into the rubric:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>specific facts with no relationships between the facts given,</td>
</tr>
<tr>
<td>2</td>
<td>a link made between two facts</td>
</tr>
<tr>
<td>3</td>
<td>an example given of such a link</td>
</tr>
<tr>
<td>4</td>
<td>an explanation of such a link in terms of ‘cause and effect’</td>
</tr>
<tr>
<td>5</td>
<td>an explanation consisting of multiple interactions between ‘cause and effect’.</td>
</tr>
</tbody>
</table>

The incorrect answers, scored as ‘0’, were of interest in determining possible reasons why some teachers encountered difficulties in understanding evolution.

The responses to the open-ended questions were coded with notes explaining the reasons for awarding such codes (by memoing). As a check, the responses were then recoded by the researcher using a different coloured ink, to ensure a consistency in the process of coding. The scoring of these answers did not happen in isolation and was subjected to member checks involving the study leader and fellow Ph.D. and M.Ed. students during report back sessions on research progress.

The impartiality of the scorer is important and personal interpretations may affect the outcome of a study and its validity. To minimize subjectivity, the categories of the rubric were discreet and designed to avoid overlap thus reducing the chances of differing interpretations arising. However, in scoring 340 answers it was also important to ensure that a consistency of such scoring was achieved in order to establish the validity of the study and hence it was decided not to use additional scorers.

5.10.2 Validity and reliability of the rubric

Internal validity, which Babbie (2007) interprets to include construct validity, was established by comparing the logical relationship between the levels of higher-order thinking with the stages of intellectual development identified by Piaget. The levels of intellectual development progressed
from the concrete (given facts in a text) to the abstract requiring complex interactions involving a variety of operations which were held as ‘schemata’ in the mind. The identification of ‘cause-and-effect’ would be a good example of abstract, higher-order thinking. In Piagetian terms this would be classified as ‘if – then’ thinking which was ‘formal operational’ in nature because it was not directly dependent on ‘concrete’ facts which were given in a text.

The theoretical framework provided by the Piagetian theory of conceptual development, underpinned the rubric structure conferred on it an external validity. It could ensure a possibility of successfully using this method of scoring answers in other studies which were similar in nature to this study.

The reliability of the rubric could not be established by finding a value for Cronbach’s alpha, $\alpha$, a measure of the reliability of a scale. A requirement for using Cronbach’s alpha was that responses had to be recorded in all categories (levels of thinking). This was not possible because the participants would not necessarily achieve all levels of thinking, as identified in the rubric.

5.10.3 Compiling a data sheet for statistical analysis

The data was captured in the following format:

1 denoted achieved that level and
0 meant no score for that level.

<table>
<thead>
<tr>
<th>Question 1 (pre-test) Category</th>
<th>7</th>
<th>6</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
<th>Question 2 (pre-test) etc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant x</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Participant y</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Participant z</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Participant w</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
It was possible for a participant to show evidence of more than one level of thinking, as was the case with ‘x’, who was awarded a total score of 6 for question 1, i.e. 1+2+3=6.

In the case of ‘y’, an alternative answer was also supplied and this was flagged using the category ‘7’. The total achieved for the question was not affected by a category ‘7’ score which was only used to indicate that an alternative had been given which could not be scored. The total was thus 1+2=3.

Zero scores (‘0’) were of importance in indicating possible reasons why ‘incorrect’ answers were given by some teachers (for example caused by certain worldviews held or a lack of knowledge). Both ‘z’ and ‘w’ scored 0, but for different reasons. ‘Z’ gave only an alternative answer (based on an alternative worldview) which could not be scored and ‘w’ provided no answer, which was flagged as category ‘6’ (indicating a lack of knowledge).

Examples illustrating how the following criteria were used to score the answers (thus transforming qualitative data into quantitative data) are given below:

Zero scores (‘0’) were of importance in indicating possible reasons why ‘incorrect’ answers were given by some teachers (for example caused by certain worldviews held or a lack of knowledge). Both ‘z’ and ‘w’ scored 0, but for different reasons. ‘Z’ gave only an alternative answer (based on an alternative worldview) which could not be scored and ‘w’ provided no answer, which was flagged as category ‘6’ (indicating a lack of knowledge).

Examples illustrating how the following criteria were used to score the answers (thus transforming qualitative data into quantitative data) are given below:

The first two categories of the rubric were based on ‘concrete’ information directly given in a text, whereas the third level requires some ‘abstract’ thought and scored as follows:

<table>
<thead>
<tr>
<th>1</th>
<th>specific facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>a link made between two facts</td>
</tr>
<tr>
<td>3</td>
<td>an example given of such a link</td>
</tr>
</tbody>
</table>

- **Example 1** illustrated how these levels of thinking were scored. The answer, given below, was from part of the response by participant 9/1 (post-test) to question 2 of the questionnaire.

**Question 2. Does environmental change drive evolution? Explain your answer.**

*Answer:* 80 Million years ago there was enough forest and the climate was warm dinosaurs were able to survive ...

**Scoring of example 1 was:**

1. 80 Million years ago the climate was warm (fact)
2. ‘enough forest’ and ‘warm climate’ (link)
3 - (because of this) the dinosaurs were able to survive (example)

Total: 1+2+3=6.

In addition, the last two categories of the rubric were based on the ability to use ‘abstract’ thought and scored as follows:

4 - cause – and – effect
5 - complex interaction, multiple causes and effect

- Example 2 illustrated an answer showing all five levels of thinking and also came from a response by participant 9/1 (post-test) to question 1.

Question 1. What can we learn from the evolution of life and the changes that the Earth has undergone in the past?

Answer: Everyday (there) is a change that is made on the earth which brings changes to the environment and to organisms so that they can be able to adapt. Today’s climate is different from that of the past because of the type of life we live. Temperature is higher than before and more of CO₂.

Scoring of example 2 was:

1 - today’s climate different from the past (fact),
2 - no direct link between specific facts (only generalizations),
3 - today’s climate is different (because) of the type of life we live (example),
4 - changes on earth (cause) changes to the environment (effect) and organisms adapt (effect) (cause-and-effect),
5 - change to earth, change to climate, higher temperature, CO₂, way we live and organisms adapt (interaction of multiple causes and effects).

Total: 1+3+4+5=13.

- Example 3 included answers which also showed an ‘alternative’ response to question 1 and came from participant 8/1 pre-test explanation.

*I believe in Creation. *Therefore I believe that everything was created to be able to adapt (to a certain extent) to the different changes they face. Some things are not able to adapt and will therefore become extinct. *This is also necessary to make way for other things. *Everything has it’s order and place
The scoring of the above answer, which included an alternative explanation which could not be measured by the rubric, was:

7 - *alternative explanation

1 - not adapt becomes extinct *(fact)*
2 - adapt … to different changes *(link)*
3 - no example of link
4 - ‘not adapt’ (cause) will become ‘extinct’ (effect) *(cause and effect).*

Total: 1+2+4 =7 + *A.*

Examples which illustrated when a ‘zero’ score was allocated:

0 - no response

0 - incorrect answer to question 2: *living organisms on earth change because of the environment they find themselves in* (participant 1/1 (post-test)). No specific example given, no links, no explanation.

0 - *alternative response to question 2: I agree, because, what happens in certain area(s) influence people’s life style and their belie(fs) eg. Finding bones which may for(e)tel(l) the future w(h)ere as in other areas it might be bad luck* (participant 26/2 (post-test)).

5.10.4 The statistical analysis of data obtained from the answers to questions 1 – 5 of the questionnaire

This involved the following steps:

- preparation of a spread sheet suitable for statistical analysis,
- exploratory data analysis to test for normality or the normal distribution of the data,
- inferential statistical analysis which was based on a skewed distribution of data was non-parametric in nature and involved the following:
  - determining the descriptive statistics such as the median values, and calculating the p, r and z values (discussed in detail in chapter 6),
  - analyzing the ‘between group’ responses (E1 and E2) using the Mann-Whitney U test,
  - analyzing the ‘within group’ responses (either E1 or E2) using the Wilcoxon Signed Rank test.
5.10.5 Data analysis of the responses to the qualitative study

This was obtained from three different sources of information which are discussed below.

5.10.5.1 Data analysis of answers to question 6 of the questionnaire

Two themes evolved from the wording of question 6 of the questionnaire.

(a) Why do you think that the teaching of evolution of life is controversial? (The first theme probed whether the teachers could identify issues involved in the teaching of evolution.)

(b) What can you as a teacher do to address the issue? (The second theme explored what suggestions the teachers make to address these issues.)

The pre-test and post-test responses to question 6 were grouped together to find more general categories such as ‘Criticisms of the theory of evolution’ and ‘Suggested teaching strategies’. The responses given by the teachers were then recorded for each category. Certain participants offered several suggestions and these were all recorded, hence the total number of responses given in each category will not correlate with the number of teachers present in each workshop group.

5.10.5.2 Topics chosen by the teachers for the design of concept cartoons focusing on the issues relating to the teaching of evolution

The worldviews of teachers about ‘evolution’, both as in their personal visions or as they viewed it as appropriate in the classroom, could serve as the basis for a concept cartoon design. The topics chosen by the teachers explored the issues and problems experienced with ‘science and religion’ and the teaching of ‘evolution of life’ in the science classroom. Possible themes were identified which could be used to develop a composite picture of the teachers’ worldviews.

The themes were derived from the work by George (1999) who used worldview theory as the basis of her analyses of some of the traditional practices and beliefs of villagers in Trinidad and Tobago.
Her work was based on Kearney’s concept of ‘world view’ which she saw as useful in generating a ‘general framework for making sense of everyday understandings’ (p. 79). Although she felt that Kearney’s scheme was quite comprehensive, certain aspects of his model such as ‘classification’, ‘relationship’ and ‘causality’ involved more of a ‘process’ approach, whereas notions such as the ‘self’, ‘the other’, ‘space’ and ‘time’ were more conceptual in nature. The construction of the composite picture of the teachers’ worldviews will be discussed further in chapter 6.

5.10.5.3 Narrative construction

The construction of charts, which the teachers prepared for their design of the narrative of their chosen organisms, reflected another facet of the teachers’ worldviews and ability to order knowledge. Their choice of organism, the ability to introduce the notion of ‘cause – and – effect’ into the narrative structure and how they ordered information were all considerations which could be used to explain the effectiveness of narratives as a teaching strategy to encourage higher-order thinking skills.

5.11 SUMMARY

The contribution of different sources of data to the quantitative and qualitative phases of this study is shown in Figure 5.23. The steps involved in analyzing the data are also indicated in this flowchart. (Figure 5.23 serves as a summary of the research design discussed in this chapter.)
CHAPTER 5: RESEARCH QUESTIONS AND RESEARCH DESIGN

**Figure 5.23** The sources of data, data analysis and the mixing of data

- **More effective teaching of evolution**
- **Data mixing**
- **Interventions:** (Quasi)experimental pre-test and post-test format with two experimental groups, measuring the effect of concept cartoons and narratives on achievement of higher-order thinking skills.
- **Issues related to 'Science and Religion'**
  - **Suggestions** on how to address these issues
- **Content Analysis**
  - Themes and Categories
- **Questionnaire**
  - Questions 1-5
  - Knowledge (provided from source material)
    - Evolution of Life
    - Geological History of the Earth
    - Nature of Science
  - **Questionnaire**
    - Question 6
    - Effect of Teaching Strategies
      - Concept Cartoons and Narratives
- **Statistical Analysis**
  - Based on QUAN data
    - Levels of higher-order thinking skills and deep learning achieved
  - Based on qual data
    - Worldviews
    - Charts: Concept Cartoons depicting different worldviews and areas of interest
    - Narratives and the importance of knowledge in worldviews
- **Notes and Reflections by researcher and contributions by teachers**
5.12 MIXING OF THE FINDINGS FROM THE QUANTITATIVE AND QUALITATIVE DATA BASES

The findings derived from the quantitative and the qualitative phases were combined to obtain a more comprehensive insight into research questions 6 and research question 7. The findings were analyzed at different levels. Firstly, at a group level involving generalizations derived from the two experimental groups E1 and E2, which were based on the responses to the first five questions of the questionnaire. Contradictory findings could also be investigated further by drawing on the responses to question 6 of the questionnaire, which generated data used in the qualitative phase of the study.

Secondly, at the level of individual questions of the questionnaire, contradictory and also interesting and unusual results from the quantitative phase could be explored further from a different point of view, using the findings of the qualitative phase. This involved examining the alternative responses and incorrect answers flagged by using the extra categories of the rubric transforming the data. By looking at the statistical analyses of the individual questions of the questionnaire, certain patterns, inconsistencies and interesting observations identified at the group level, E1 and E2, could be investigated further.

At the level of the individual teachers, additional data derived from the various sources of information feeding into the qualitative phase could be useful in probing their personal worldviews. This could contribute to finding explanations for the development of barriers to the understanding of evolution and how the teachers’ conceptual ecologies of evolution contributed to this problem.
CHAPTER 6
RESULTS AND ANALYSIS

6.1 INTRODUCTION

The mixed methods design of this study involved a main quantitative study and an imbedded complementary qualitative study. The quantitative and qualitative results and their analyses are dealt with separately. At the end of the chapter the two data bases, one quantitative and the other qualitative, will be mixed. This gives a more comprehensive picture of the interplay between higher-order thinking skills and teachers’ worldviews of the teaching of evolution, than if the findings reflected by each of the separate data bases were considered separately.

6.2 QUANTITATIVE STUDY

6.2.1 Introduction

In his introduction to the use of statistics, Field (2005, p. 1) explained that ‘we carry out research to find out whether some effect, we are researching, genuinely exists in the real world’. In this study, the effect studied was the achievement of higher-order thinking skills by teachers who attended an intervention in the form of a workshop on ‘narratives’ or on ‘concept cartoons’. Building on these results, it was possible to determine statistically the probability of generalizing the findings to the population of all teachers who teach evolution of life.

Since data from all teachers who constitute this population could not be collected, a sample of teachers was used. The sample was made up from teachers who volunteered to attend Saturday morning workshops on ‘narratives’ and ‘concept cartoons’.

Data, derived from the answers to a questionnaire administered as a pre-test and as a post-test, were used to measure the effect of the interventions on the teachers’ ability to use higher-order thinking skills in answering the questions. The effect was based on the prediction that teachers
would improve their ability to achieve higher-order thinking skills if they were involved in interventions dealing with the construction of narratives or concept cartoons.

In order to test the prediction, the data collected from the answers had to fit a suitable statistical model. An example of such a statistical model could be the ‘mean’, which is a hypothetical value, calculated from any data set (Field, 2005). The statistical model of the ‘mean’ may also be calculated to summarize the data. The mean of the pre-test scores of the group attending the workshop on ‘narratives’, for example, could tell us something about that group’s ability to use higher-order thinking skills.

Furthermore, a test statistic could be calculated to show how much of the variation in the data was caused by the ‘genuine effect’, such as the intervention, and what variation recorded was the result of other factors. These factors could be chance, or perhaps, religious perceptions which interfered with the scientific knowledge structures constructed by some teachers.

The test statistic used in this study was the z-score. It represented a ratio of the variation in the scores caused by the intervention and the variation in scores which could not be explained by the statistical model. The larger the variation in the scores caused by the intervention in comparison to the variation not explained, the greater the value of the test-statistic. If the values of the z-score were greater than -1.969, then it was accepted that the ‘effect’ was genuine and unlikely to have been caused by chance.

It was Ronald Fisher, a statistician, who originally proposed that only when a 95% certainty existed that a result was genuine, that the result could be accepted as a statistically significant finding. It could then be concluded, that the effect was not caused by chance. This percentage value translated into a probability value (signified by p) of 0.050 that the finding was caused by chance.

The criterion of 95% confidence forms the basis of modern statistics, but Field (2005) maintains that it could have been 93% or even 90%. If the probability of the variation in data caused by chance, is less than 0.050 (or p<0.050) then the result is statistically significant (and the null
hypothesis is rejected). Thus in analyzing the results of this study, findings close to \( p = 0.050 \) were also be reviewed and discussed.

If the probability of obtaining the test statistic was greater than 0.050 (\( p > 0.050 \)) then it had to be concluded that the effect was too small to be detected. The result was thus not significant, and the null hypothesis could not be rejected.

**Effect size**, in this instance the size of the impact of the intervention, was also included in the conclusions of this study. Effect size is an objective and a standardized measure of the magnitude of the effect and allows researchers to compare findings across different studies even with different variables. In this study, the Pearson’s correlation coefficient, \( r \), was used.

Hence, \( r = \frac{z}{\sqrt{N}} \) where \( N = \) total number of cases. If this correlation coefficient is used, then 0 means no effect and 1 indicates a perfect effect and the following values of \( r \) signify:

- for a small effect, \( r = 0.10 \),
- for a medium effect, \( r = 0.30 \),
- and for a large effect, \( r = 0.50 \)

(\( \text{Pallant, 2007, p. 223} \))

Referring back to the mean in the initial explanations given, another definition is a ‘simple statistical model of the centre of a distribution of scores’ (\( \text{Field, 2005, p. 738} \)). If the data are distributed symmetrically around this centre, then the distribution is called a ‘normal distribution’. This is a requirement for all parametric statistical procedures.

However, in this study, the responses were not normally distributed but skewed. In figure 6.1, given below, ignoring the first category ‘A’, the scores were mainly in categories 0, 1 and 2. There were very few, if any, responses for levels 3, 4 and 5. The distribution tended towards 0, or the left, and was positively skewed.

(Note: see APPENDIX F for the raw data. See APPENDIX B for the questionnaire.)
Figure 6.1 Frequency distribution of results of the pre-test responses of teachers attending the workshop on concept cartoons

Parametric statistical procedures could not be used because the percentage responses at each level of thinking, did not show a pattern indicating a normal distribution. Instead, non-parametric procedures were adopted, based on the principle of ranking scores. Thus statistically the median, or the middle score of the set of ordered observations, became important rather than the mean.

6.2.2 Research Questions

The first two research questions were necessary to examine the relationship between the use of narratives and concept cartoons (which formed the independent variable) and the achievement of higher-order thinking skills (which constituted the dependent variable). These research questions are given below.

<table>
<thead>
<tr>
<th>Research Question 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>How will the design of a narrative, about how scientists construct the story of the evolution of organisms on Earth, encourage teachers to display higher-order thinking skills?</td>
</tr>
</tbody>
</table>
Research Question 2
How will the use of concept cartoons generate discussion about issues relating to evolution of life, and, of science and religion, encourage teachers to display higher-order thinking skills?

The third research question focused on how the achievement of higher-order thinking skills could be measured and will be considered in more detail first.

Research Question 3
How will the achievement of higher-order thinking skills be measured?

This research question was pivotal in the design of the quantitative phase of the study. Furthermore, it was an important consideration because the initial data were derived from qualitative responses to five open-ended questions of the questionnaire. In transforming the qualitative data into quantitative data, a quantitative measure using a rubric was established to ascertain the levels of thinking (not their factual knowledge) which the teachers utilized to construct their answers.

Factual knowledge about the evolution of life, was a control variable which was built into the design of the interventions. An assumption in the research design was that a basic factual knowledge was necessary for higher-order thinking skills to occur in making sense of evolution. In particular, how facts were linked and how these connections were then built into explanations involving the idea of ‘cause – and – effect’ or causality.

6.2.2.1 The use of a rubric to transform qualitative data into quantitative data

In response to research question 3, a rubric was designed to transform the qualitative data generated by the answers to questions 1 – 5 in the questionnaire, into quantitative data. Provision was also made to record alternative answers which could not be measured using the rubric. Given below are the seven categories of the rubric:
1 - specific facts with no relationships between the facts given
2 - a link made between two facts
3 - an example given of such a link
4 - an explanation of such a link in terms of ‘cause and effect’
5 - an explanation consisting of multiple interactions between ‘cause and effect’

Furthermore, to allow for coding of alternative responses, as well as incorrect answers, the following categories were used:
6 - incorrect answer, or no answer, scored as ‘0’
7 - alternative explanation which could not be measured by the rubric, also a ‘0’ (shown as ‘A’ in the graphs and tables)

**Note**: Most teachers showed evidence of thinking at more than one level. The ‘percentage responses’ reflected at each level of thinking, indicated the number of responses for that specific category only.

### 6.2.3 Frequency distribution of responses and analysis

Because no control group was used in the study, the pre-test responses served as a baseline for comparing the post-test responses. The effect that the intervention had had on the teachers’ ability to achieve higher-order thinking skills was measured by comparing the pre-test and post-test responses.

The teachers’ answers to each of the questions could contain various levels of thinking. Most reflected thinking processes involving only the recall of facts and linking those facts (levels 1 and 2). In the post-test more responses also involved naming an example of such links and introducing the notion of ‘cause – and – effect’ into their explanations (levels 3 and 4). It was only in the answers to question 1 that a score of ‘5’ was achieved, indicating the possibility of multiple causes and effects.

In the pre-test the distribution of responses in the five levels of thinking was skewed, with most of the responses found in levels 1 and 2; and very few were located in level 5. However, comparing the pre-test and post-test responses of the teachers who attended the workshop on ‘narratives’, the
distribution of the bar graphs in Figure 6.2 indicated a shift to levels 3 and 4, with some responses at level 5 for question 1.

**Figure 6.2** A comparison of pre-test and post-test responses to the five questions of the questionnaire by teachers who attended the workshop on ‘narratives’

(The bar graphs show the relationship between the percentage of responses by teachers at each level of thinking to questions 1 - 5) (n=19)

A similar pattern in the distribution of the results was discernable in the pre-test and post-test responses of teachers attending the workshop on concept cartoons, shown in Figure 6.3.

An interesting difference was noted when questions 4 and 5 were compared. Those teachers who attended the workshop on concept cartoons scored higher in the post-test of question 4, whereas those who attended the workshop on narratives scored higher in the post-test of question 5. The group of teachers who attended the workshop on concept cartoons also offered more pre-test alternative answers, as well as post-test alternative answers to questions 1 and 5.
Figure 6.3 A comparison of pre-test and post-test responses to the five questions of the questionnaire by teachers who attended the workshop on ‘concept cartoons’

(The bar graphs show the relationship between the percentage of responses by teachers at each level of thinking to questions 1-5)

(n=15)

By reorganizing the above information into a table of comparison, certain tendencies and differences between the two groups could be examined in greater detail. This is reflected in Table 6.1 on the next page.

The rubric which was used to assess the teachers’ responses was based on the Piagetian levels of operational thinking. The first two levels identified factual knowledge and the ability to link individual facts based on ‘concrete’ sources of information such as written texts. The double line in the table separates levels of thinking which involve ‘concrete operations’ from more higher-order thinking skills using a propositional mode of thinking or ‘abstract’ thinking.
Table 6.1 A comparison of the different levels of thinking, expressed as the percentage responses at each level, achieved by teachers who attended the ‘narratives’ workshop and the ‘concept cartoons’ workshop

‘Narratives’: Pre-test – Post-test (n=19)

<table>
<thead>
<tr>
<th>Levels of thinking</th>
<th>Question 1 (percentage)</th>
<th>Question 2 (percentage)</th>
<th>Question 3 (percentage)</th>
<th>Question 4 (percentage)</th>
<th>Questions 5 (percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test</td>
<td>Post-test</td>
<td>Pre-test</td>
<td>Post-test</td>
<td>Pre-test</td>
</tr>
<tr>
<td>A (alternative)</td>
<td>32</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>0 (incorrect)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>1 (factual)</td>
<td>78</td>
<td>74</td>
<td>63</td>
<td>47</td>
<td>95</td>
</tr>
<tr>
<td>2 (link made)</td>
<td>74</td>
<td>58</td>
<td>74</td>
<td>79</td>
<td>32</td>
</tr>
<tr>
<td>3 (example of link made)</td>
<td>16</td>
<td>32</td>
<td>5</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>4 (cause-and-effect)</td>
<td>5</td>
<td>42</td>
<td>5</td>
<td>37</td>
<td>0</td>
</tr>
<tr>
<td>5 (few causes-effects)</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

‘Concept Cartoons’: Pre-test and Post-test (n=15)

<table>
<thead>
<tr>
<th>Levels of thinking</th>
<th>Question 1 (percentage)</th>
<th>Question 2 (percentage)</th>
<th>Question 3 (percentage)</th>
<th>Question 4 (percentage)</th>
<th>Questions 5 (percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test</td>
<td>Post-test</td>
<td>Pre-test</td>
<td>Post-test</td>
<td>Pre-test</td>
</tr>
<tr>
<td>A (alternative)</td>
<td>20</td>
<td>20</td>
<td>13</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>0 (incorrect)</td>
<td>33</td>
<td>13</td>
<td>33</td>
<td>13</td>
<td>27</td>
</tr>
<tr>
<td>1 (factual)</td>
<td>67</td>
<td>47</td>
<td>53</td>
<td>27</td>
<td>67</td>
</tr>
<tr>
<td>2 (link made)</td>
<td>47</td>
<td>47</td>
<td>33</td>
<td>87</td>
<td>27</td>
</tr>
<tr>
<td>3 (example of link made)</td>
<td>0</td>
<td>20</td>
<td>7</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>4 (cause-and-effect)</td>
<td>0</td>
<td>27</td>
<td>0</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>5 (few causes-effects)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Incorrect answers, in the pre-test, were more numerous in the responses by teachers who attended the workshop on concept cartoons. A decline in such answers occurred in response to all questions in the post-test. Question 5 remained problematic with a comparatively large number of respondents who still gave incorrect answers in the post-test.
Questions 1 and 2 reflected a shift towards higher-order thinking skills in the post-test responses. Interesting was the difference between the responses to questions 4 and 5 when the two groups, attending either the workshop on narratives or concept cartoons, were compared. There was a substantial increase in the number of teachers, attending the concept cartoons workshop, who showed levels of higher-order thinking in the post-test responses to questions 4. The same pattern occurred in the post-test responses to question 5 by the group attending the workshop on narratives.

Question 1 in particular, triggered many alternative responses from both groups. Alternative responses were more frequently offered by members of the group who attended the workshop on concept cartoons. Generally, the number of alternative responses given decreased in the post-test. An exception was the sharp increase in the number of post-test alternative responses to question 5, stated by some members who attended the workshop on concept cartoons.

6.2.4 Inferential statistical analyses

The next step was the statistical analysis of the data. This involved both ‘between groups’ and ‘within the groups’ analyses, in which the pre-test and/or post-test responses were compared. Before proceeding to the statistical analyses it is worthwhile to refer back to the first two research questions of this study because they underpin the statistical analyses.

<table>
<thead>
<tr>
<th>Research Question 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>How will the design of a narrative, about how scientists construct the story of the evolution of organisms on Earth, encourage teachers to display higher-order thinking skills?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Research Question 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>How will the use of concept cartoons generate discussion about issues relating to evolution of life, and, of science and religion, encourage teachers to display higher-order thinking skills?</td>
</tr>
</tbody>
</table>
Building on these two research questions, a series of null hypotheses were constructed to develop the analyses further. To simplify these hypotheses, E1 referred to the results obtained from the answers constructed by teachers who attended the workshop on narratives and similarly, E2 referred to those who attended the workshop on concept cartoons.

### 6.2.4.1 Four null hypotheses which refer to the scores achieved by totaling all five questions of the questionnaire

(Refer to APPENDIX F and G for more information about the statistical results of this section.)

| H01: | There will be no difference between the total scores of the pre-test and that of the post-test responses of E1. |
| H02: | There will be no difference between the total scores of the pre-test and that of the post-test responses of E2. |
| H03: | There will be no difference between pre-test total scores of E1 and E2. |
| H04: | There will be no difference between the post-test total scores of E1 and E2. |

The Wilcoxon Signed Rank test (or the Wilcoxon Matched Pairs Signed Ranks test) was used to test the significance of H01 and H02. This is a non-parametric procedure which is designed to measure the difference between the action of the same participants, measured on two occasions, such as a pre-test and a post-test. The scores are converted into ranks, which are then compared (Pallant, 2007).

The Wilcoxon Signed Rank test revealed a statistically significant increase in the total scores of E1, \( z = -2.681, p = 0.007 \) with a medium effect size \( (r = 0.43) \). The median of the total scores achieved for all five questions of the questionnaire increased to the post-test (Md = 17) from the pre-test (Md = 10).

**H01 was therefore rejected and it was concluded that the use of narratives had had an effect on improving the ability of teachers to achieve higher-order thinking skills as measured by the rubric designed by the researcher.**
Similarly, the Wilcoxon Signed Rank test also revealed a statistically significant increase in the total scores of E2, $z = -2.862$, $p = 0.004$ with a large effect size ($r = 0.522$). The median of the total scores achieved for all five questions of the questionnaire, increased to the post-test ($Md = 13$) from the pre-test ($Md = 7$).

**H02** was therefore rejected and it was concluded that the use of concept cartoons had had an effect on the ability of teachers to achieve higher-order thinking skills as measured by the rubric designed by the researcher.

The Mann-Whitney U test was used to analyze ‘between group’ responses as defined by the null hypotheses H03 and H04. This test is also non-parametric and compares the medians of two groups, rather than the means of two groups used in parametric procedures. The scores are ranked across the two groups and then compared to establish how these two groups differ. (This procedure is based on ranking and not on the actual distribution of scores as required in parametric testing.)

Comparing the pre-test responses between E1 and E2, the Mann-Whitney U test showed a significant difference between the pre-test total scores of E1 ($Md = 10$, $n = 19$) and E2 ($Md = 7$, $n = 15$), $U = 76,000$, $z = -2.083$, $p = 0.037$, $r = 0.362$ (medium size effect).

**H03** was rejected, this showed that the populations from which the teachers were drawn for the workshops on ‘narratives’ and on ‘concept cartoons’, differed significantly.

Comparing the post-test responses between E1 and E2, the Mann-Whitney U test showed no significant difference existed between E1 ($Md = 16$, $n = 19$) and E2 ($Md = 13$, $n = 15$), $U = 109,000$, $z = -0.876$, $p = 0.381$, $r = 0.165$ (small size effect).

**H04** was not rejected, which meant that based on the post-test responses, the teachers who attended either the workshop on ‘narratives’ or the workshop on ‘concept cartoons’ achieved similar levels of higher-order thinking skills, placing them in the same population.
Figure 6.4  A summary of the statistical analyses comparing the two experimental groups E1 and E2

✓ indicates a significant difference - (null hypothesis is rejected)

✗ shows the difference is not significant - (null hypothesis is not rejected)

Building on research questions 1 and 2 further, the following four null hypotheses related to the analyses of each of the five questions of the questionnaire.

6.2.4.2 Four null hypotheses which refer to the scores of each of the five questions of the questionnaire

(Refer to APPENDIX F and G for more information about the statistical results of this section.)

An additional four null hypotheses were constructed to cover the statistical analyses of the five questions of the questionnaire.
H05: There will be no difference between the pre-test scores and the corresponding post-test scores of each of the five questions for the answers given by E1.

H06: There will be no difference between the pre-test scores and the corresponding post-test scores of each of the five questions for the answers given by E2.

H07: There will be no difference between the pre-test scores of E1 for each of the five questions, and the corresponding pre-test scores of E2 for each of the same questions.

H08: There will be no difference between the post-test scores of E1 for each of the five questions, and the corresponding post-test scores of E2 for each of the same questions.

In the tables given below, the results relating to the four above hypotheses were examined for each question. (The subscript to each hypothesis refers to the question being analyzed.)

**Question 1: What can we learn from the evolution of life and the changes that the Earth has undergone in the past?**

**Table 6.2  A statistical analysis of the data from question 1**

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-test</th>
<th>Post-test</th>
<th>n</th>
<th>z</th>
<th>p</th>
<th>Significant</th>
<th>r</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>E1 (Narratives)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypothesis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test:</td>
<td>3</td>
<td>4</td>
<td>19</td>
<td>-1,907</td>
<td>0.057</td>
<td>❌</td>
<td>0.309</td>
<td>medium</td>
</tr>
<tr>
<td>Post-test:</td>
<td>19</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>E2 (Concept cartoons)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypothesis</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test:</td>
<td>1</td>
<td>2</td>
<td>15</td>
<td>-1,162</td>
<td>0.245</td>
<td>✔</td>
<td>0.212</td>
<td>small</td>
</tr>
<tr>
<td>Post-test:</td>
<td>15</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Narratives(pre)</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concept cartoons(pre)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypothesis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test:</td>
<td>3</td>
<td>1</td>
<td>15</td>
<td>-2,029</td>
<td>0.042</td>
<td>✔</td>
<td>0.348</td>
<td>medium</td>
</tr>
<tr>
<td>Post-test:</td>
<td>15</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Narratives(post)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concept cartoons(post)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypothesis</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test:</td>
<td>4</td>
<td>2</td>
<td>15</td>
<td>-1,873</td>
<td>0.061</td>
<td>❌</td>
<td>0.321</td>
<td>medium</td>
</tr>
<tr>
<td>Post-test:</td>
<td>15</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comparing the pre-test responses to question 1 between E1 and E2, the Mann-Whitney U test showed a statistically significant difference between E1 (Md = 3) and E2 (Md = 1), U = 86,500, z = -2,029, p = 0.042, r = 0.348 and a medium size effect.

**The null hypothesis, H07question1, was rejected, which indicated that there was a statistically significant difference between the pre-test responses of E1 and E2 to question 1.**
Based on these responses to question 1 it was highly probable that the two groups, E1 and E2, were derived from two different populations of teachers.

H05question1 revealed $z = -1.907$, a probability of $p = 0.057$, which was very close to the required 0.050 level. Thus, with certain reservations, a tendency was noted for a significant increase in the post-test responses for question 1, which was also shown by E1.

**Question 2: Does environmental change drive evolution? Explain your answer.**

**Table 6.3  A statistical analysis of the data from question 2**

<table>
<thead>
<tr>
<th>Group</th>
<th>Median</th>
<th>n</th>
<th>z</th>
<th>p</th>
<th>Significant</th>
<th>r</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 (Narratives)</td>
<td>Pre-test: 2</td>
<td>19</td>
<td>-1.945</td>
<td>0.052</td>
<td>$\times^*$</td>
<td>0.315</td>
<td>medium</td>
</tr>
<tr>
<td>Hypothesis</td>
<td>Post-test: 3</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H05question2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E2 (Concept cartoons)</td>
<td>Pre-test: 1</td>
<td>15</td>
<td>-2.527</td>
<td>0.011</td>
<td>$\checkmark$</td>
<td>0.461</td>
<td>medium</td>
</tr>
<tr>
<td>Hypothesis</td>
<td>Post-test: 2.5</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H06question2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narratives(pre)</td>
<td>Pre-test: 2</td>
<td>19</td>
<td>-2.373</td>
<td>0.018</td>
<td>$\checkmark$</td>
<td>0.407</td>
<td>medium</td>
</tr>
<tr>
<td>Concept cartoons(pre)</td>
<td>Pre-test: 1</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypothesis</td>
<td>H07question2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narratives(post)</td>
<td>Post-test: 3</td>
<td>19</td>
<td>-1.297</td>
<td>0.195</td>
<td>$\times$</td>
<td>0.222</td>
<td>small</td>
</tr>
<tr>
<td>Concept cartoons(post)</td>
<td>Post-test: 2.5</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypothesis</td>
<td>H08question2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Wilcoxon Signed Rank test showed a statistically significant increase in the post-test scores of E2, with $z = -2.527$, $p = 0.011$, $r = 0.461$ and the concept cartoons intervention caused a medium size effect. The median increased to a post-test (Md = 2.5) from a pre-test of (Md = 1).

The null hypothesis, H06question2, was rejected and it was concluded that the intervention on the use of concept cartoons did have a statistically significant effect on the achievement of higher-order thinking of the teachers of E2.

A similar effect was noticed with E1, where H05question2 revealed $z = -1.945$ and $p = 0.052$ which was very close to the 0.050 level of probability required. Thus, with certain reservations, a tendency was noted towards a significant increase in the post-test responses to question 2, by the teachers of E1 as well.
Comparing the pre-test responses for question 2 between E1 and E2, the Mann-Whitney U Test showed a statistically significant difference between E1 (Md = 2) and E2 (Md = 1), $U = 76,000$, $z = -2.373$, $p = 0.018$, $r = 0.407$ and a medium effect size.

The null hypothesis, $H_0_{question2}$, was rejected and it was concluded that there was a statistically significant difference between the responses of E1 and E2 to question 2. Based on these responses to question 2 it was highly probable that these two groups, E1 and E2, were derived from two different populations of teachers.

Both question 1 and question 2 dealt with a similar topic exploring the relationship between evolution and environmental change or the changes that the Earth has undergone. These topics were presented in the workshop on ‘narratives’ (Figure 6.5) and the workshop on ‘concept cartoons’ (Figure 6.6). The examples given below illustrate how the concepts are dealt with in different ways in these two workshops.

![Figure 6.5 The construction of ‘narratives’ involved the idea of ‘change’ in both the Earth/environment and that of life (p. 250)](image1)

![Figure 6.6 Shows a concept cartoon exploring the relationship between the emergence of new islands and new forms of life (p. 294)](image2)
It is interesting to note that the null hypothesis H03, which dealt with the pre-test total scores of the questionnaire, and the null hypotheses H07_question1 and H07_question2 were rejected. This seemed to indicate that it was mainly the teachers’ responses to these two questions which caused a statistically significant difference between E1 and E2 as predicted by the null hypothesis H03.

**Question 3: What evidence do we have that mass extinctions happened in the past?**

**Table 6.4 A statistical analysis of the data from question 3**

<table>
<thead>
<tr>
<th>Group</th>
<th>Median</th>
<th>N</th>
<th>z</th>
<th>p</th>
<th>Significant</th>
<th>r</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 (Narratives) Hypothesis</td>
<td>Pre-test: 1</td>
<td>19</td>
<td>19</td>
<td>-1,527</td>
<td>0,127</td>
<td>×</td>
<td>0,247</td>
</tr>
<tr>
<td></td>
<td>Post-test: 2</td>
<td>19</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E2 (Concept cartoons) Hypothesis</td>
<td>Pre-test: 1</td>
<td>15</td>
<td>15</td>
<td>-1,831</td>
<td>0,067</td>
<td>×</td>
<td>0,334</td>
</tr>
<tr>
<td></td>
<td>Post-test: 3</td>
<td>15</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narratives(pre) Concept cartoons(pre) Hypothesis</td>
<td>Pre-test: 1</td>
<td>19</td>
<td>19</td>
<td>-0,588</td>
<td>0,607</td>
<td>×</td>
<td>0,100</td>
</tr>
<tr>
<td></td>
<td>Pre-test: 1</td>
<td>15</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narratives(post) Concept cartoons(post) Hypothesis</td>
<td>Post-test: 2</td>
<td>19</td>
<td>19</td>
<td>-0,292</td>
<td>0,770</td>
<td>×</td>
<td>0,050</td>
</tr>
<tr>
<td></td>
<td>Post-test: 3</td>
<td>15</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Question 3 was included in the questionnaire to explore the change in the understanding of mass extinctions dealt with by the narratives of especially the ammonites and the trilobites. Since research deals with the unexpected, surprisingly none of the teachers chose these two options (for further information see Table 6.9).

Some incidental discussion about mass extinctions did arise when dealing with Dr Fickers’ letter about coelacanths (Figure 6.8) and in examining the accompanying concept cartoon on the coelacanth. This may account for the medium effect size recorded when comparing the pre-test and post-test responses of E2.
The story of the trilobites’ and ammonites’ adaptations to new environments and their ability to fill new niches created by the impact of mass extinctions on life, formed an important part of the knowledge necessary to answer the question well (Figure 6.7). The null hypothesis $H_{05\text{question3}}$ was not rejected and the effect size of the intervention was ‘small’, which indicated that the intervention had had little impact on the teachers’ ability to deal with the idea of mass extinctions.

The last two questions of the questionnaire were designed to separate the effect of the intervention dealing with narratives and the effect of the intervention dealing with concept cartoons.
Question 4: Although Darwin was born two centuries ago (1809 – 1881), he is still considered to be a great scientist to-day. Explain why this is so.

Table 6.5 A statistical analysis of the data from question 4

<table>
<thead>
<tr>
<th>Group</th>
<th>Median</th>
<th>n</th>
<th>z</th>
<th>p</th>
<th>Significant</th>
<th>r</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 (Narratives) Hypothesis</td>
<td>Pre-test: 1</td>
<td>19</td>
<td>-0.885</td>
<td>0.376</td>
<td>X</td>
<td>0.143</td>
<td>small</td>
</tr>
<tr>
<td></td>
<td>Post-test: 2</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E2 (Concept cartoons) Hypothesis</td>
<td>Pre-test: 1</td>
<td>15</td>
<td>-2.395</td>
<td>0.017</td>
<td>✓</td>
<td>0.444</td>
<td>medium</td>
</tr>
<tr>
<td></td>
<td>Post-test: 6</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narratives(pre) Concept cartoons(pre) Hypothesis</td>
<td>Pre-test: 1</td>
<td>19</td>
<td>-0.065</td>
<td>0.335</td>
<td>X</td>
<td>0.165</td>
<td>small</td>
</tr>
<tr>
<td></td>
<td>Pre-test: 1</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narratives(post) Concept cartoons(post) Hypothesis</td>
<td>Post-test: 2</td>
<td>19</td>
<td>-1.395</td>
<td>0.163</td>
<td>X</td>
<td>0.242</td>
<td>small</td>
</tr>
<tr>
<td></td>
<td>Post-test: 6</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Wilcoxon Signed Rank test showed a statistically significant increase in the post-test scores of E2, with $z = -2.395$, $p = 0.017$, $r = 0.444$ and the concept cartoons intervention causing a medium size effect. The median increased to a post-test ($Md = 6$) from a pre-test of ($Md = 1$).

The null hypothesis, $H_{06question4}$, was rejected and it was concluded that the intervention did have a statistically significant effect on the achievement of higher-order thinking of the teachers of E2.

Although there was quite a large difference in the median values of the post-test scores of E1 and E2, it must be remembered that the Mann-Whitney U test dealt with the ranking of scores and not only with the comparison of medians.

A small effect size was recorded for intervention on ‘narratives’. This was probably caused by the lack of information about ‘Darwin as a scientist’, although some incidental information arose during the discussion of the investigation on ‘design a beak’ (Figure 6.11 and Figure 6.12 on the next page). The ‘design a beak’ activity was included as an introduction to designing scientific investigations but the workshop materials did refer to Darwin’s observations about these birds and his search for possible explanations to account for the differences he had recorded.
Given below are examples from both the interventions to illustrate the opportunities created in the interventions for encouraging group discussion amongst the teachers about ‘Darwin as a scientist’. Figure 6.9 and Figure 6.10 show the information given about the topic in the workshop on concept cartoons.

![Figure 6.9 The concept cartoon which was used to encourage discussion about Darwin as a scientist (p. 295)](image)

![Figure 6.10 Part of the background information on Darwin as a scientist (p. 306)](image)

**Figure 6.9 The concept cartoon which was used to encourage discussion about Darwin as a scientist (p. 295)**

**Figure 6.10 Part of the background information on Darwin as a scientist (p. 306)**
CHAPTER 6: RESULTS AND ANALYSIS

Figure 6.11 The introduction to the narratives workshop with some incidental discussion about Darwin as a scientist (p. 287)

Figure 6.12 Testing their ‘design a beak’

Question 5: Explain how ‘Darwin’s Finches’ found on the Galapagos Islands, illustrates that evolution is a fact; evolution is a theory; evolution can be a law.

Table 6.6 A statistical analysis of the data from question 5

<table>
<thead>
<tr>
<th>Group</th>
<th>Median</th>
<th>n</th>
<th>z</th>
<th>p</th>
<th>Significant</th>
<th>r</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 (Narratives) Hypothesis</td>
<td>Pre-test: 2</td>
<td>19</td>
<td></td>
<td>-1.910</td>
<td>0.056</td>
<td>X*</td>
<td>0.309</td>
</tr>
<tr>
<td></td>
<td>Post-test: 3</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HO5 question5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E2 (Concept cartoons) Hypothesis</td>
<td>Pre-test: 1</td>
<td>13</td>
<td></td>
<td>-0.587</td>
<td>0.571</td>
<td>X</td>
<td>0.110</td>
</tr>
<tr>
<td></td>
<td>Post-test: 0</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HO6 question5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narratives(pre) Concept cartoons(pre) Hypothesis</td>
<td>Pre-test: 2</td>
<td>19</td>
<td></td>
<td>-0.732</td>
<td>0.464</td>
<td>X</td>
<td>0.129</td>
</tr>
<tr>
<td></td>
<td>Pre-test: 1</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HO7 question5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narratives(post) Concept cartoons(post) Hypothesis</td>
<td>Post-test: 3</td>
<td>19</td>
<td></td>
<td>-2.019</td>
<td>0.044</td>
<td>✓</td>
<td>0.401</td>
</tr>
<tr>
<td></td>
<td>Post-test: 0</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HO8 question5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comparing the post-test responses to question5 between E1 and E2, the Mann-Whitney U test showed a statistically significant difference between E1 (Md = 3) and E2 (Md = 0), U = 86,000, z = -2.019, p = 0.044, r = 0.401 and a medium size effect.
The null hypothesis, $H_{0,\text{question5}}$, was rejected and it was concluded that there was a statistically significant difference between the post-test responses of E1 and E2 to question5.

The null hypothesis, $H_{0,\text{question5}}$, revealed the following values, $z = -1.910$ and $p = 0.056$, which were close to the 0.050 level of probability required for significance. Thus, with certain reservations, a tendency was indicated that the teachers of E1 may well have shown a significant increase in the used higher-order thinking skills in dealing with question 5.

It is only in the workshop dealing with narratives that the nature of science was discussed directly. However, the importance of the nature of science did arise in the discussion of the concept cartoon relating to ‘Charles Darwin – the nature of science and religion’.

Referring back to Figure 6.3, it will be noticed that the percentage of alternative responses recorded for the post-test by the teachers attending the workshop on concept cartoons increased from 0 in the pre-test to 20 percent in the post-test. No alternative responses to question 5 were recorded from the teachers who attended the workshop on narratives.

In the workshop on concept cartoons issues relating to science and religion were discussed. On the other hand, in the workshop on narratives, the nature of science was discussed in terms of how scientists use observations and further empirical data to construct a narrative of the evolution of life on Earth. This could well have been one of the reasons for the difference in the number alternative answers offered by the teachers attending the two workshops. Figure 6.13, on the next page, shows the concept cartoon used to discuss issues relating to Darwin, science and religion. Figure 6.14, also on the next page, reflects a different approach to encouraging discussion about the nature of science which was used in the workshop on narratives.
6.2.5 Findings and answers to research questions 1, 2 and 3

The statistical analyses established that both interventions, the use of narratives and of concept cartoons, significantly improved the teachers’ ability to answer the questions of the questionnaire using higher-order level thinking skills. However, it is worthwhile to re-examine the wording of the first two research questions:

**Research Question 1**
How will the design of a narrative, about how scientists construct the story of the evolution of organisms on Earth, encourage teachers to display higher-order thinking skills?

**Research Question 2**
How will the use of concept cartoons generate discussion about issues relating to evolution of life, and, of science and religion, encourage teachers to display higher-order thinking skills?
In order to answer both questions fully, it was necessary to explain how this was achieved. It was important to establish what was common in both interventions in order to identify a possible explanation why this significant improvement had been achieved by using both teaching strategies. The design of the workshop format and the provision of suitable factual knowledge were control variables of this study. Both these variables could have contributed to the success of the study and will be examined further in chapter 7, where the conclusions and recommendations are made.

In response to the third research question, the statistical analyses showed that the rubric design, used to transform the qualitative responses to quantitative data, had been sufficiently sensitive to ensure the successful identification of the various levels of thinking, including higher-order thinking skills. This is also shown in the spread of responses indicated in Figures 6.2 and 6.3 as well as in Table 6.1.

Lower-order thinking skills also need to be measured because the design of the rubric was based on the Piagetian levels of cognitive development. This included the lower levels of ‘concrete’ thinking which progressed to higher-order or ‘abstract’ thinking. It was the use of the Piagetian levels of cognitive thinking which were important in establishing the validity to the rubric, and which also gave credibility to the results obtained.

6.2.6 A summary of the findings of the quantitative study

1. It must be noted that the findings must be seen in the light of the study’s (quasi)experimental design limitations and hence only tendencies are indicated.

2. The results relating to the achievement of higher-order thinking skills relate only to the levels defined by the rubric and should be interpreted within these parameters.

3. The distribution of responses indicated that

   - most teachers operated mainly on levels 1 and 2 only,
the pre-test results showed that about thirty percent of the teachers from E2 operated without factual knowledge about the evolution of life and the Earth’s geological history.

4. The statistical analyses showed that

- according to the pre-test results based on the teachers' ability to achieve higher-order thinking skills, E1 and E2 were derived from two different populations of teachers, in other words, the two groups were significantly different,

- after the interventions, the post-test results revealed that the teachers were now derived from the same population, based on their ability to think at higher-order levels of knowledge construction, in other words, the two groups were now the same,

- both interventions had had a statistically significant effect on improving the teachers' ability to achieve higher-order thinking skills (with a medium size effect), which answered research questions 1 and 2.

- the responses to questions 1-5 also showed that
  - question 1 measured a significant difference between the pre-test responses of E1 and E2, which could account, in part, for the reason why the null hypothesis HO3 was rejected,

  - question 2 measured the greatest shift to higher-order thinking skills,

  - question 3 measured no change in levels of higher-order thinking,

  - question 4 measured a significant change achieved only by E2, and

  - question 5, measuring understanding of the nature of science, covered concepts most problematic for the teachers.
6.3 QUALITATIVE STUDY

6.3.1 Introduction

The qualitative study was complementary to, and imbedded in the quantitative study discussed in the first part of the chapter. In this section, the focus has now moved from testing theories and examining the relationships between variables to exploring and understanding the meaning individuals, and groups of participants, ascribe to a social or human problem (Creswell, 2009). As a consequence the researcher’s role has changed and in particular, now concentrating on of the meaning that the participants held about issues relating to science and religion and the teaching of evolution. The observations that emerged from this part of the study were descriptive. The interpretations were idiographic, paying attention to the particular realities of the participants, rather than to generating generalizations about the whole population of teachers involved with the teaching of evolution.

Data collection was unobtrusive, which Babbie (2007), described as methods of studying social behaviour without affecting it. There were five sources of data involved in this study:

• answers to question 6 of the questionnaire (pre-test and post-test),
• alternative responses to questions 1 – 5 of the questionnaire (pre-test and post-test),
• documentation of the narratives about the evolution of organisms constructed by the teachers,
• documentation of the concept cartoons constructed by the teachers,
• the reflection and observations about the workshops, written by the researcher.

6.3.2 The two research questions

Research question 4 and research question 5 relate to analyzing the teachers' worldviews about evolution and science and the barriers that could affect the teaching and understanding of evolution.
Research Question 4
How can concept cartoons be used as a tool to analyze teachers’ worldviews about evolution of life, and, of science and religion?

Research Question 5
What barriers can be identified that affect teachers’ understanding of evolution of life and the nature of science and why do these barriers arise?

Before considering the teachers’ worldviews and identifying barriers which affect their understanding of evolution, there were certain aspects identified in the quantitative study which should be explored further.

6.3.3 Were the groups E1 and E2 as different as the pre-test scores indicated?

In considering the observation made in the quantitative part of the study, that the two groups E1 and E2 were originally derived from different populations (as indicated by the difference in their pre-test responses), the following sources of data were examined to find possible explanations:

- qualifications of the teachers and
- the responses to question 6 of the questionnaire.

Table 6.7 A comparison of the qualifications held by teachers in the two experimental groups

<table>
<thead>
<tr>
<th>Experimental Group</th>
<th>Diploma (various)</th>
<th>Diploma and ACE (Advanced Certificate in Ed)</th>
<th>B Ed (various)</th>
<th>B degree and Post grad Diploma</th>
<th>B (Hons) and Post grad Diploma</th>
<th>B Com</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 (n=19) (Narratives)</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>3 (1 B Sc)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>E2 (n=15) (Concept Cartoons)</td>
<td>6</td>
<td>3</td>
<td>-</td>
<td>4</td>
<td>2</td>
<td>-</td>
</tr>
</tbody>
</table>

The table of comparison showed that the spread of different qualifications of E1 and E2 was very similar. The only difference was that E1 was a larger group of 19 teachers and contained four persons who held a B Ed first degree. Thus the qualifications of the teachers did not account for difference between E1 and E2 as the pre-test results indicated in the quantitative study.
However, by comparing the responses to question 6, given below, a different picture arose. (Question 6 was designed to examine the teachers’ worldviews about evolution as a controversial topic and what could be done to address the issue.)

| a) Why do you think that the teaching of evolution of life is controversial?  
| b) What can you as a teacher do to address the issue? |

(See APPENDIX G for all the responses.)

The answers were grouped into several categories, reflected in Table 6.8 below. Some categories showed similar responses and other categories pointed to interesting differences expressed by the two groups of teachers. Most categories were distinct from each other such as ‘View points about God’ or ‘Views about creationism and evolution’. It had to be accepted though that there would be some overlap in views expressed about related topics such as ‘Views about creationism and evolution’ and the ‘Scientific view’ for example. However, when identifying the teachers’ awareness of barriers to the understanding of evolution, categorizing their responses became more difficult if the word ‘barrier’ did not appear in the statement but was implied in the wording. Thus the response by the teacher coded as 20/2, stated ‘address misconceptions between religion and evolution’ which I accepted as implying that the teacher acknowledged an existence of a barrier to the understanding of evolution caused by religious perceptions.

As a researcher, it had to be accepted that some of the responses reflected what the participants chose to share and not necessarily what they really believed. Some teachers were willing to share their points of view more extensively than others did and hence, depending on the richness of their responses, their responses appeared in more than one category. Owing to the variety of responses and resulting categories, Table 6.8 was split and presented on different pages below.

In the first part of the table, on the next page, points of view were examined about ‘Science’, ‘Evolution’, ‘Creationism’, ‘God’ and ‘Barriers to the understanding of evolution’. In some instances the two groups of teachers were similar in the way they expressed their beliefs about ‘Science’ and ‘God’. It was also interesting to note that in both groups the ideas that God was ‘beyond’ Science and ‘cannot be measured’ only appeared in the post-test responses. In the post-test, the notion, that life and the Earth were for ever ‘changing,’ appeared in a few responses of both groups and
Table 6.8  A comparison of the number of responses to each category derived from the answers to question 6 of the questionnaire (See APPENDIX H for complete responses)

<table>
<thead>
<tr>
<th>Category</th>
<th>Narratives (E1)</th>
<th>Concept Cartoons (E2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test</td>
<td>Post-test</td>
</tr>
<tr>
<td>n =19 (E1); n =15 (E2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viewpoints about God (total)</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Supernatural Power</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Made in the Image/Picture of God</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Will of God</td>
<td></td>
<td></td>
</tr>
<tr>
<td>God as the Creator</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Views about God and Science (total)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>God bigger than/above Science</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Science cannot replace God</td>
<td></td>
<td></td>
</tr>
<tr>
<td>God cannot be measured</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Views about Creationism versus Evolution (total)</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Anti-God if believe in Evolution</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Know difference between Science and Religion</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Creation and Evolution 'fight'</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Not address spiritual life</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Scientific View (total)</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Acknowledge facts/Scientific View</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>The world keeps on changing</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Bible as source of information</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Criticisms of the Theory of Evolution (total)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Gaps</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Racist</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Evolution not controversial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problems with the Origins of Life (total)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Humans (in particular)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Life (in general)</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Barriers to understanding of evolution inferred in responses (total)</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Knowledge</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Cultural/beliefs/parents</td>
<td>10</td>
<td>12</td>
</tr>
</tbody>
</table>
implied that a view that knowledge ‘changed’ had been adopted. This development was also apparent in the decrease of the number of teachers who cited criticisms of ‘evolution as a theory’ in their post-test responses. These changes probably arose as a consequence of the discussions, which happened in both the workshops which the teachers attended. Worth noting was that one teacher, who attended the workshop on narratives, commented in her post-test answer that the teaching of evolution was not controversial.

The major differences between these two groups of teachers, however, lay in their ability to acknowledge the impact that religious beliefs had on the understanding of evolution of life. In their pre-test responses, the teachers from E1 articulated a greater awareness of the role played by religion/beliefs in generating controversy in the teaching of the life sciences than those from E2 did. Although there was an increase in the number of responses in the post-test, only about 30% of the teachers who attended the workshop on concept cartoons (E2) indicated such awareness, as opposed to over 70% in the group who attended the workshop on narratives (E1).

It was in the continuation of table 6.8, shown on the next page, that some interesting differences between E1 and E2 became apparent. This involved the categories dealing with ‘knowledge’ and ‘teaching strategies’. If the pre-test responses of E1 and E2 were compared, it showed that more teachers of E1 were involved in and encouraged research about evolution. They also stated more and different teaching strategies which could be used in the teaching of evolution. The teachers of E2 indicated little importance to finding evidence for evolution by doing more research, either by themselves or by their learners. This was also reflected in the lack of different teaching strategies mentioned in their suggestions for how to address the controversies associated with the teaching of evolution. The post-test responses of both groups of teachers showed little change from the pre-test answers.

The only aspects of gathering more knowledge about evolution, which were mentioned in the post-test only concerned ‘different sources’ of information and a single mention of ‘measure and see’. This was surprising because an important focus of the workshop design was to introduce teachers to new teaching strategies which could make them more effective in improving the learners’ understanding of evolution.
Table 6.8  A comparison of the number of responses to each category derived from the answers to question 6 of the questionnaire  (continued)

<table>
<thead>
<tr>
<th>Category</th>
<th>Narratives (E1)</th>
<th>Concept Cartoons (E2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n =19 (E1); n =15 (E2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test</td>
<td>Post-test</td>
<td>Pre-test</td>
</tr>
<tr>
<td>Views about handling the controversy (total)</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Impartial view</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Respect views/ do not change beliefs</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Factual Knowledge about Evolution (total)</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Evidence</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Facts about scientists</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Teacher research</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Learner research</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Measure and ‘see’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Different sources (DVD, concept cartoons)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suggested Teaching Strategies (total)</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Visit places of interest</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Group work</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Debate</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
constituted two different populations in terms of their views about the teaching of evolution and the initial level of their understanding of the topic.

6.3.4 Barriers to the understanding of evolution

The teachers' responses to question 6 indicate the existence of 'barriers' to the understanding of evolution, in terms of knowledge, culture, beliefs, and the influence of parents. This related to research question 5.

6.3.4.1 Contradictory results from the quantitative study

There were five teachers (three from E1 and two from E2) whose responses contradicted the general trend in which there was a significant increase in the post-test scores. Most of these results were caused by abbreviated responses in the post-tests caused by a lack of time to complete the questionnaire at the end of the workshop.

Two teachers' responses however, did illustrate how barriers interfered with the quality of answers constructed. Their responses warrant further examination.

6.3.4.2 Background information on these two teachers

Teacher/participant 33/1 scored a low pre-test with some improvement in the post-test. The answers showed a focus on factual knowledge only and little evidence of higher-order thinking skills. From informal discussions, however, it was apparent that this teacher was very well read and knowledgeable about evolution. The concept cartoon which was designed for the workshop was insightful (see ‘Why do I want to study Evolution’) and indicated that even with 'high knowledge' other barriers such as parental influence and religious beliefs interfered with achieving in-depth understanding of evolution using higher-order thinking skills.

Teacher/participant 26/2 showed no factual knowledge about evolution. As indicated by the pre-test and post-test scores, the intervention on concept cartoons had no effect on this teacher's knowledge about evolution, nor achieving higher-order thinking skills in developing a better
understanding of evolution. There was a great emphasis on ‘beliefs’, whether ‘multi-cultural’ or ‘multi-racial’. Although the teacher was aware of ‘misconceptions’, factual knowledge was based on ‘black and white pictures’ and equating ‘bones’ with ‘fossils’.

6.3.4.3 A summary of the two teachers’ responses

On the following pages are the summaries of these two teachers’ responses including a third teacher’s answers which allow some comparisons to be made.

Teacher/ participant 33/1 who attended the workshop on ‘narratives’ first

<table>
<thead>
<tr>
<th>Pre-test scores: 1+1+1+1+1=5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-test scores: 1+5+1+1+2=10</td>
</tr>
</tbody>
</table>

Question 1: What can we learn from evolution of life and the changes that the Earth has undergone in the past?

Pre-test:
Change is constant

Post-test:
Life is continuously changing

Question 6: (a) Why do you think that the teaching of evolution is controversial?

Pre-test:
It is a scientific view of creation and not religious

Post-test:
It does not allow for religious beliefs

(b) What can you as a teacher do to address the issue?

Pre-test:
Explain to the learners that we have different religious beliefs about creation and the creator. This is a scientific belief and as we are studying Life Sciences we look at what scientists believe. You do not have to believe the same but when answering questions on evolution you are giving scientists’ views.

Post-test:
Teach learners that this is a scientific belief not religious

Field observations:
From observations of discussions, during the workshops, this teacher was extremely well read and factually knowledgeable about evolution. Informal discussions, however, revealed that she felt that the first workshop on ‘narratives’ was a ‘waste of her time’, although she could understand that it was necessary to provide the required background knowledge for the construct the narratives. Her design of the concept cartoon showed great involvement and participation in the discussion indicated her initial distress in having to study evolution at university coming from a family background that did not condone this point of view.

(Figure 6.15 shows the concept cartoon which was designed by teacher (33/1) which focused on a personal experience of ‘Why I want to study EVOLUTION’.)

A different approach to designing a concept cartoon was to represent a general view about ‘Religion versus Science’ (see Figure 6.16) which was constructed by a group in which the second teacher (26/2) was part of.
The second set of responses is from teacher/participant 26/2

**Pre-test scores:** 0+0+0+0+0=0  
**Post-test scores:** 0+0+0+0+0=0

**Aim for attending the workshops:**  
The main aim of attending this workshop is to share ideas with colleagues and present my judgment about the misconceptions I have concerning evolution. Secondly, I wanted to gather information so that I can easily handle and solve learners' problems with confidence. How to present this evolution effectively.

**Question 1: What can we learn from evolution of life and the changes that the Earth has undergone in the past?**  
**Question 1 Pre-test:**  
We can learn that some animals or plants have vanished without trace. It challenges our beliefs and culture about certain things. It tells us about the importance of researchers or scientists about changes that they have brought (about). It never leaves God behind he is our creator.  
**Question 1 Post-test:**  
I have learnt that because of the different beliefs and multi-racial, this topic must be treated with care and should not aim to changing learners' mind. After explaining the sub-topic, not the content, you may ask learners to give their view, according to how they were raised and what they think in relation to other cultures with (due) respect.

The second set of responses is from teacher/participant 26/2 continued

**Question 3: What evidence do we have that mass extinctions happened in the past?**  
**Question 3 Pre-test:**  
There are animals that we only see in pictures (black and white). Geographically changes that take place in stones, erosion.  
**Question 3 Post-test:**  
- Pictures of dinosaurs
- Bones of unknown people
- Plants that were forced out of South Africa

**Question 5:** Explain how 'Darwin's Finches' found on the Galapagos Islands, illustrate that evolution is a fact; evolution is a theory; evolution can be a law.

*Question 5 Pre-test:*
Evolution is a fact – yes.
Things (has) happened in the past and we need to prove them by bringing evidence.

*Question 5 Post-test:*
A fact – Bones, old plants refers to as evidence
A 'law', because their findings must be taught (to) learners (whether) they believe or not, including educators.

**Question 6:** (a) Why do you think that the teaching of evolution is controversial?  
(b) What can you as a teacher do to address the issue?

*a) Because it evoke multi-cultural activities of people.*

*b) I can first ask learners to give their misconceptions about the topic.*

**Question 6 Post-test:**
6 (a) It clashes with what we believe in our country is multi-racial.
6 (b) Allow learners views with respect towards each other.

### 6.3.4.4 A third response for comparison

As a counter balance to the above two examples, a third teacher’s responses has been included to illustrate how good or ‘high’ knowledge can be developed further to ensure higher-order thinking skills and to generate insightful explanations of evolution of life. The following answers were given by teacher/participant 12/1.

**Teacher/ participant 12/1 who attended the workshop on ‘narratives’**

*(Pre-test scores: 3+3+1+2+2=11  
Post-test scores: 3+3+10+2+10=28)*

Answers to some of the questions:

**Question 1:** What can we learn from evolution of life and the changes that the Earth has undergone in the past?

*Question 1 Pre-test:*
Life on Earth is not rigid, changes with time. Life existed millions of years ago.

**Question 2:** Does environmental change drive evolution? Explain you answer.

*Question 2 Pre-test:*
The change in environment affects the physiology of organisms and this has a bearing on genes and heredity in general.
Question 3: What evidence do we have that mass extinctions happened in the past?
Question 3 Post-test:
This evidence in the form of fossils which shows that certain organisms lived during certain period but can not be found after that period, eg. certain layers of sedimentary rocks contain fossil evidence which can only be found in layers(rocks) and not in other layers.

Question 5: Explain how ‘Darwin's Finches' found on the Galapagos Islands, illustrate that evolution is a fact; evolution is a theory; evolution can be a law.
Question 5 Pre-test:
Finches of the ‘same species’ varied according to the environment.
Though the finches varied, it can not be proven that this is purely as a result of adaptation.
Question 5 Post-test:
‘fact’ – the finches show different beaks, adapted to the food available.
‘theory’ – enough evidence exists to support evolution, though ‘gaps’ are available.
‘law’ – the best adapted parts or organisms are likely to survive. Finches which had better adapted beaks would survive and pass genes to their offspring.

Question 6: (a) Why do you think that the teaching of evolution is controversial?
b) What can you as a teacher do to address the issue?
Question 6 Pre-test:
6 (a) Evolution might not be seem as a “Godly” concept, it does not agree with the Bible or some religious and cultural beliefs.
6 (b) State that the aim of evolution teaching is not to convince but to learn. In other words learners should be informed, not to attempt to “erase” their cultural or religious beliefs to accommodate evolution theory, hence the word “theory”.
Question 6 Post-test:
6 (b) Indicate that we learn evolution to be aware of the existence of information as to be scientists.

In addition, it was worthwhile to consider some responses which referred directly to the barriers affecting the teaching and understanding of evolution.

Research Question 5 states:

What barriers can be identified that affect teachers’ understanding of evolution of life and the nature of science and why do these barriers arise?

To identify barriers which could interfere with the teaching of evolution, responses to question 6 of the questionnaire were examined.

6.3.5 Three Teachers' comments about ‘barriers to the teaching of evolution'
The comments have been identified from the answers to question 6 of the questionnaire. (See APPENDIX H.)
Question 6. (a) Why do you think that the teaching of evolution of life is controversial?
(b) What can you as a teacher do to address the issue?

(The barriers referred to are indicated in red.)

Teacher/respondent 5/1 (Narratives workshop)
(Pre-test scores for the questionnaire: 3+2+1+3+3=12
Post-test scores for the questionnaire: 9+5+1+2+3=20)

Pre-test 6(a): Because learners come from different backgrounds eg. other’s religious backgrounds (religious barriers) eg. Christians; or even cultural beliefs become barriers for them to make sense is what is being taught (crossing cultural barriers).
6(b): He must detach himself from the topic which will make it easier for learners to detach their cultural and religious beliefs from the topic. He must also try not to impose his views on the topic. He must derive his topic basing his facts on the facts based by different scientists.

Post-test 6(a): We (teachers?) have to address personal issues and cultural and religious issues first (own, the teachers’, attitudes become barriers).
6(b): Involve learners as much as possible. If they do their own research and findings it becomes interesting and they have also to work as groups and then let the groups debate their findings.

Teacher/respondent 9/1 (Narratives workshop)
(Pre-test scores: 6+2+1+1+1=12
Post-test scores: 13+10+3+3+3=32)

Pre-test 6(a): It is against our belief because we are from the picture of God who has created us. We are not from bacterias as scientist are saying that.
6(b): It can be difficult.

Post-test (a): More educators are not informative and we misinterpret it, comparing science and religion (lack of knowledge).
6(b): Know the difference between science and religion (knowledge about the nature of science).

Teacher/respondent 17/2 (Concept Cartoons workshop)
(Pre-test scores: 0+0+1+1+0=2
Post-test scores: 2+6+3+6+0=17)

Pre-test 6(a): I, for one do not believe in evolution because I am a Christian (religious barrier).
6(b): Evolution should not be done at High School level. It should be done at Tertiary (level) by those who are interested in that study (interest).

Post-test 6(a): Little knowledge about evolution or no knowledge at all (knowledge).
6(b): I will encourage my learners to believe what they believe, but as learners who do Life Sciences, Physical Science and Mathematics they must also know or acknowledge what the scientists do (knowledge about the nature of science).
The following were barriers that some teachers identified and also explained why they arose:

- religious barriers
- cultural barriers
- the teacher’s own attitude towards these religious and cultural barriers
- interest
- lack of knowledge and in particular,
- lack of knowledge about the nature of science.

6.3.6  The role played by interest in influencing the choice of narratives

6.3.6.1  Interest may act as a barrier to constructing knowledge

Interest could act as a barrier, if the choice made by the teachers caused certain organisms not to be included in the range of narratives presented in the workshop, as shown in Table 6.9. Trilobites and ammonites, for example, played and important role in constructing the time line of evolutionary events, yet were not chosen as a topic for a narrative.

Even though examples of fossil of these organisms were examined and discussed in the workshop they were not chosen. These choices did affect the outcome of question 3, which focused on mass extinctions and how knowledge of organisms, such as trilobites and ammonites, assisted in the mapping of such major extinctions in the time scale of the Earth’s history.
Table 6.9 The choice of narratives selected by teachers

<table>
<thead>
<tr>
<th>Narratives</th>
<th>Number selected</th>
<th>Number Showing Cause-effect</th>
<th>Example of a narrative design showing evidence of ‘cause-effect’, extracts from the narratives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stromatolites (used as an example)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Trilobites (fossil examples shown)</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Ammonites (fossil examples shown)</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Dinosaurs (DVD ‘Walking with Dinosaurs)</td>
<td>2</td>
<td>1</td>
<td>Many became specialized (effect) to adapt to the on-going changing (cause) of the Earth’s surface and climate</td>
</tr>
<tr>
<td>Glossopteris (fossil example shown)</td>
<td>1</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Protea (power point presentation)</td>
<td>3</td>
<td>3</td>
<td>…drier climates (cause) = expands distribution of Protea (effect)</td>
</tr>
<tr>
<td>Chimpanzee (no extra information)</td>
<td>4</td>
<td>2</td>
<td>(Ancestors) were small, had large brain size (cause) enabling them to survive (effect) improve memory and identify smells and sounds …</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>6</td>
<td>-</td>
</tr>
</tbody>
</table>

(Note: that although E1 consisted of 19 participants, an additional eight teachers attended this as the second workshop, which accounted for why 10 narratives were presented in total. See APPENDIX J)

The most popular choices were the narratives of the chimpanzee, which Figure 6.17 illustrated, and the Protea, were both conceptually fairly difficult to construct. The reasons for difficulty in conceptualization the narrative stemmed from the fact that there are no fossils of chimpanzees known. The Protea evolved fairly recently during the splitting of Gondwanaland and was affected by a complex series of climate change during the glacial-interglacial periods of the recent past.

6.3.6.2 Interest may encourage in-depth discussion

Table 6.9 also showed that 60% of the narratives presented included the idea of ‘cause-effect’ in the evolution of the organisms studied. This indicated that the higher-order thinking skills focusing on ‘cause-effect’ were considered in the planning and discussion of some of the narratives as shown in Figure 6.18. This could possibly also account for some of the teachers including the notion of cause – and - effect in their answers in the post-test.
Finally, the teachers’ perspectives of evolution and the issues relating to teaching evolution in the classroom were analyzed using the concept cartoons which they designed in the workshop. World view theory originally developed by Kearney in the 1980s was adapted by various science educators, including Coben and George in the 1990s, to serve as a useful framework to analyze the personal views that science teachers held about science.

6.3.7 Using ‘world view’ theory to develop a composite picture of the issues that teachers raised in their design of concept cartoons about the teaching of evolution

According to George (1999) there are seven ‘universals’ which are part of all worldviews. These ‘universals’ can be described as follows:

- The Self (which must survive),
- The Other (all that is not classified as ‘the self’),
- Relationships (ways that people view their interactions with ‘the other’),
- Causality (the nature of cause – effect),
- Classification (ordering phenomena into different categories),
- Space (which is the relationship between the environmental space of a people and their image of it) and
- Time (perceived in different ways).
The issues raised by the teachers in eight concept cartoons, or their designs, were classified according to the above seven ‘universals’ identified by ‘world view’ theory. Most concept cartoons did not include all seven ‘universals’. By constructing a composite picture of all eight concept cartoons the interplay between various issues started to emerge.

The two concept cartoons, shown in Figure 6.19 and Figure 6.20, are used to illustrate how a composite picture, based on the seven ‘universals’ could be developed. Firstly, the statements contained in the concept cartoon were classified according to the seven ‘universals’ outlined in the ‘world view’ theory framework. Secondly, in some instances the statements were appropriate to more than one ‘universal’ and it was at the researcher’s discretion where to place these in the composite picture.

On the left side of Figure 6.21 on the next page, is the universal ‘The Self’, and aspects of this category are indicated in Figure 6.19 above. On the right side of Figure 6.21 are members of the community who may influence ‘The Self’, identified in Figure 6.20 above.
By applying worldview analysis to the topics dealt with by the eight concept cartoons designs, the following picture emerged with respect to the seven universals.

- The Self involved those who were interested in evolution and wished to study fossils and those who felt that evidence was not convincing.

- The Other highlighted various players from the community.

- Relationships indicated interference from some of the members of the community, in particular with respect to different beliefs which they held.

- Causality focused on ‘origins’ and ‘who’ or ‘what’ were responsible.

- Classification highlighted benefits associated with a knowledge of evolution, but also included ‘bones’ and racial issues.

- Time was an important consideration in that it could be interpreted differently in various cultures and included the sense of ‘now’ and also of ‘a long time ago’.

- Space was viewed differently as in the use of ‘caves’ in scientific investigations and for healing.

The composite picture (Figure 6.21) is shown on the next page. It must be pointed out that the classification and interpretation of the content of the concept cartoons may vary from researcher to researcher. For example, the statement ‘I can see evolution around me’ could be interpreted to reflect a personal view (of ‘the Self’) or could be seen in terms of the conception of ‘Time’, as shown in the composite picture.
Figure 6.22 Worldview analysis of eight concept cartoons, designed by teachers on ‘issues relating to the teaching of evolution of life, science and the community’
6.3.7.1 The importance of a connecting factor in ‘world view’ theory

George (1999) also stated that the seven separate ‘universals’ needed to be connected in order to create a holistic picture of the worldviews. A rather ‘tongue in the cheek’ interpretation gave a clue to a possible connecting factor, shown in Figure 6.23.

Figure 6.23 ‘Confusion’ may give an indication of a possible ‘connecting factor’ (p. 338)

When considering all the ‘universals’ there seemed to be a conflict between, for example, ‘evolution’ and the ‘church’, and, ‘science’ and ‘religion’. A possible connecting factor was ‘conflict causes confusion’, which was the interpretation shown by the authors of the concept cartoons shown in Figure 6.24.

‘Conflict and confusion’ may also act as barriers to the understanding of evolution. Linking some of the barriers to the understanding of evolution, ‘conflict’ may then be caused by a lack of knowledge, in particular knowledge of the nature of science.

The ideas of ‘barriers’ and ‘worldviews’ can be linked to show how certain teachers experience difficulty in understanding and accepting the scientific explanations of the evolution of life and the geological history of the Earth. In answer to research question 4, concept cartoons can be a useful tool.
tool in exploring the reasons why there are barriers to understanding and accepting scientific explanations about the evolution of life, and the Earth itself.

In answer to research question 5, Figure 6.25 on the next page, summarizes the effects that barriers may have on the understanding of evolution and why they arise.

<table>
<thead>
<tr>
<th>Research Question 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>What barriers can be identified that affect teachers’ understanding of evolution of life and the nature of science and why do these barriers arise?</td>
</tr>
</tbody>
</table>

6.3.8 The researcher's interpretation of what constitutes 'scientific worldviews'

Scientific worldviews are based on empirical data. The relationships between variables can be used to study causality or the idea of ‘cause - and - effect’. In Piagetian terms, ‘cause – effect’ is interpreted as ‘if – then’ thinking. This is a characteristic of the abstract or propositional thinking. It is also important in dealing with the construction of knowledge and ordered knowledge structures.

For this reason, the ability to weigh up evidence in terms of ‘cause - and - effect’, was included in the design of the rubric used in the quantitative part of this study. In contrast to the notion of 'cause – effect', is the important idea of ‘chance’, which underpins our understanding of statistics and interpretation of results and thus is also part of what constitutes ‘scientific worldviews’.

If the worldviews of a teacher or a learner are similar to that of scientific worldviews, then the barriers to the understanding of evolution will be comparatively easy to overcome. However, when certain worldviews, or aspects of worldviews, differ considerably from that of the scientific worldviews, or even from 'school science worldviews' for that matter, then specific barriers may become difficult to overcome. In some cases, this could result in lack of understanding of the scientific explanations and in other instances it could lead to conflict and confusion and even less understanding and avoidance of the topic evolution.
Figure 6.25 The interplay between different worldviews and the barriers which arise influencing the understanding of the scientific explanations of the evolution of life

Scientific explanations of the evolution of life and the Earth’s geological history

Scientific worldviews

Belief and perception:
- religious
- cultural
- parental influence
- interest
- motivation
- lack of knowledge

Controversy causing:
- conflict and confusion

Origins of:
- Life and humans
- Scientific worldviews of different scientists
- School science worldviews

Nature of science:
- empirical data
- observations
- patterns
- relationships between variables
- laws
- theories

Ordered knowledge structures

Causality:
- (cause – effect)
- Chance

Barriers
difficult to cross

Bars easy to cross

Barriers
difficult to cross

Barriers
easy to cross

Belief and perception:
- religious
- cultural
- parental influence
- interest
- motivation
- lack of knowledge

Note: any of the barriers listed may be difficult or easy to cross

Different worldviews (impossible – discordant)

Border crossing

Scientific worldviews (smooth crossing – congruent)

We use different worldviews in our everyday lives

We use different worldviews in our everyday lives

We use different worldviews in our everyday lives

Different worldviews (impossible – discordant)

Border crossing

Scientific worldviews (smooth crossing – congruent)

Religious worldviews

Worldviews of different groups of friends and peers

Indigenous knowledge worldviews

Personal worldviews
6.3.9 A summary of the findings of the qualitative study

1 Possible reasons why the pre-test results indicated that E1 and E2 were different
   - Qualifications of the two groups were similar, therefore this was not the reason.
   - Responses to question 6 of the questionnaire indicated differences with respect to
     - Knowledge,
     - teaching strategies used in the classroom,
     - the role played by religion in the evolution controversy.

2 Contradictory scores of answers to the questionnaire and comments made by the teachers indicate
   - Barriers to the understanding of evolution were
     - religious and cultural beliefs,
     - teachers’ own attitudes towards beliefs and knowledge,
     - interest and motivation,
     - lack of knowledge, in particular, that of the nature of science.
   - Interest, a lack thereof, could act as a barrier.
   - Interest also encouraged in-depth discussion and hence acquisition or further development of higher-order thinking skills.

3 Concept cartoons were useful tools in analyzing worldviews
   - A composite picture of the teachers’ worldviews indicated
     - a multi-faceted interplay of many factors,
     - conflict and confusion caused by many role players,
     - concern about the explanations of the origin of life and the origin of humans.
   - A further interpretation indicated
     - barriers to understanding the scientific explanation of evolution could be easy or difficult to overcome but
     - this depended on the type of worldview involved.
6.4 A MIXED METHODS STUDY

6.4.1 Introduction

In this concurrent embedded mixed methods study two research questions were addressed. These two questions referred to both the quantitative and qualitative parts of the study. The two questions were different but related. They contained a common ground (thinking skills, deep learning and the factual knowledge relating to evolution and the geological history of the Earth) which was used for comparing and mixing the findings.

Research question 6 addressed how higher-order thinking could be developed by using narratives and concept cartoons.

To what extent will the use of narratives and concept cartoons affect teachers’ ability to achieve higher-order thinking skills and deep learning about the evolution of life, the geological history of the Earth and the nature of science?

Research question 7 referred to identifying barriers that needed to be overcome in the understanding of evolution of life.

In what ways will the worldviews of teachers affect their ability to achieve higher-order thinking skills and deep learning about, and deal with, issues relating to the evolution of life, the geological history of the Earth and the nature of science?

In order to gain a broader perspective, the data from the quantitative and from the qualitative databases are placed ‘side by side’ or, rather one beneath the other, to achieve a composite picture. This is discussed in the next section.

6.4.2 Mixing and combining quantitative and qualitative databases

Please note that the findings for the quantitative and qualitative studies are shown in different fonts.
The effect of the interventions:

**Quantitative Study:** There was a significant difference between pre-test and post-test scores of E1, indicating that the workshop on narratives had a medium size effect on the ability of teachers to achieve higher-order thinking skills.

**Qualitative Study:** The design of the intervention created opportunities for groups to discuss the design and presentation of narratives of the chosen organisms. In 60% of narratives presented there was evidence of ‘cause – effect’ thinking (level 4 of the rubric).

**Quantitative Study:** There was a significant difference between pre-test and post-test scores of E2, indicating that the workshop on concept cartoons had a medium size effect on the ability of teachers to achieve higher-order thinking skills.

**Qualitative Study:** In their design of concept cartoons about the issues affecting the teaching of evolution, the teachers indicated the influence of a variety of role players and the effect of various barriers impacted on the success of teaching evolution in the classroom.

Pre-test scores indicated that there was a significant difference in the ability of teachers from E1 and E2 to use higher-order thinking skills to answer questions about the evolution of life and the geological history of the Earth:

**Quantitative Study:** There was a significant difference between the pre-test scores of E1 and E2. There were also significant differences between the pre-test scores of E1 and E2 when analyzing the teachers’ responses to questions 1 and 2.

**Qualitative Study:** Indicated no difference in the range of qualifications of the teachers, thus showing that the qualifications held by the teachers did not account for this difference. However, by analyzing the responses to question 6 of the questionnaire, it was apparent that there were differences in terms of

- a acknowledging the importance of researching knowledge,
- b teaching strategies used in the classroom, and
- c an awareness of the role played by religion in the evolution controversy.
Post-test scores showed that there was no significant difference in the ability of teachers from E1 and E2 to use higher-order thinking skills to answer questions about the evolution of life and the geological history of the Earth:

**Quantitative Study:** Post-test results indicated that the teachers from E1 and E2 belonged to the same population in terms of their ability to use higher-order skills to explain aspects about evolution.

**Qualitative Study:** Showed that there was a change (increase) in the awareness of teachers from E2 about the role played by science and religion in affecting their understanding of evolution of life. However, the post-test responses to question 6 of the questionnaire still indicated that there was no change in their perspectives about the importance of researching knowledge and use of different teaching strategies in the classroom.

Analysis of individual questions of the questionnaire:

**Quantitative Study:** significant increase in the post-test scores of
- question 2 (both E1 and E2),
- question 4 (E2),
- question 5 (between E1 and E2), and
- no significant change in the post-test scores of question 3.

**Qualitative Study:** With reference to questions 2 and 4, opportunities to discuss and present the narratives of different organisms (E1) and the discussion of concept cartoons, about the coelacanth, the Galapagos Islands and Darwin (E2), could have contributed to the significant increase in post-test scores.

Lack of opportunity to discuss mass extinctions could have contributed to the generally low scores for question 3 achieved by both E1 and E2.

Question 5 was the most difficult and problematic of the five questions because it dealt with the understanding of the nature of science. As shown in the composite picture about the worldviews held by teachers, a lack of knowledge about the nature of science forms a major barrier in understanding of the scientific explanations of evolution of life.
6.4.3 Findings in response to research questions 6 and 7

**Research question 6** dealt with the extent to which the use of narratives and concept cartoons affected the teachers’ ability to achieve higher-order thinking skills and deep learning.

Generally the interventions were successful in encouraging teachers to use higher-order thinking skills. There were five teachers (out of a total of 34 teachers) whose post-test scores were lower than their pre-test scores. In most cases lack of time to complete the questionnaire thoroughly was the main cause. In some instances, the contradictory results indicated that certain barriers had influenced the outcomes.

**Research question 7** dealt with the ways in which the worldviews of teachers affected their ability to achieve higher-order thinking skills and deep learning.

The composite picture of the analysis of the teachers’ worldviews about issues relating to the teaching of evolution, showed various barriers that needed to be negotiated in order to understand the scientific explanations of the evolution of life and the geological history of the Earth.

Deep learning occurred when in-depth discussions encouraged the use of higher-order thinking skills in constructing ordered knowledge structures that helped the interpretation and application of knowledge to new situations.

6.4.4 A summary of findings of the mixed methods study

- Interventions involving the use of narratives and concept cartoons significantly improved the teachers’ ability to use higher-order thinking skills in explaining the evolution of life and the geological history of the Earth. In both interventions, opportunities were created to allow teachers working in groups, to discuss aspects of the construction of narratives or the design of concept cartoons.
• Contradictory results from the quantitative study indicated that some teachers encountered barriers to their understanding of scientific explanations of evolution of life and the geological history of the Earth.

• The barriers to the understanding of evolution were identified by analyzing the concept cartoons designed by the teachers as well as the responses of some teachers to the questionnaire administered as both the pre-test and the post-test.

• Concept cartoons were a useful tool in exploring the worldviews of teachers. The closer the teachers’ worldviews were to scientific worldviews, the easier it was to negotiate these barriers and to understand how scientists explained the evolution of life and the geological history of the Earth.
CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

This is a fairly extensive study which is based on a mixed methods design. The study focuses on aspects of the professional development of teachers as well as on the conceptualization of macro-evolution and probing the understanding of the nature of science. The main question of the research examines how a complex topic such as the evolution of life, may be taught more effectively by employing teaching strategies involving the use of narratives and concept cartoons which develop higher-order thinking skills. The effectiveness of these teaching strategies on improving the understanding of evolution is measured by using a rubric based on the Piagetian levels of concept development. In the process of developing a better understanding of evolution, higher-order levels of thinking will be necessary, which are linked to achieving deep learning and concept development.

7.1.1 A brief outline of the research design

One of the reasons for choosing a mixed methods research design, was possible to compare the results of the study in terms of both generalizations and contextual perspectives. The quantitative part of the study established whether the interventions had had an impact on the participants’ abilities to use higher-order thinking skills in dealing with the open-ended questions about evolution. The qualitative, or embedded part, explored possible reasons why certain barriers interfered with the outcome of specific participants’ responses, and generally probed the worldviews held by the participating teachers.

Two separate interventions underpinned the study. Firstly, a workshop was presented, based on the use of narratives in constructing a story of the evolution of certain organisms. Secondly, another workshop focused on the use of concept cartoons in the teaching of evolution. In the
design of these workshops careful attention was given to the format of each intervention and to keep as many variables constant as possible. Hence, the time allocation, for activities which involved discussion of workshop materials and in the design of the narratives and concept cartoons; the information necessary for the success of these activities; the way in which the workshops were presented; and the time allowed for the completion of the questionnaires; were similar. All of these were part of the control variables of the study.

The independent variable constituted the type of intervention used, whether this was based on narratives or concept cartoons. The dependent variable in this quantitative study was the level(s) of understanding of evolution achieved by the participants, who were teachers of the life sciences. Non-parametric statistical procedures measured the relationship between these variables in order to establish whether there were any significant tendencies discernable.

7.2 EFFECTIVE USE OF NARRATIVES AND CONCEPT CARTOONS

The effectiveness of these two teaching strategies was measured in terms of whether the participants, or teachers, showed an improved ability in using higher-order thinking skills in explaining open-ended questions. A questionnaire was administered both at the beginning and at the conclusion of the workshops. In the quantitative part of the study, the effectiveness of teaching evolution was linked to the ability to use higher-order thinking skills. In the qualitative part of the study, effectiveness was measured in terms of how a greater awareness about the complexity of knowledge, and the role it plays in the generation of conceptual ecologies of evolution which teachers hold.

7.2.1 Conclusions based on the teachers’ abilities to use higher-order thinking skills

In both interventions there was a significant increase in the level of understanding of evolution between the pre-test and the post-test. This was measured by a rubric, the criteria of which were based on the Piagetian levels of concept development. These Piagetian levels, in turn, were based on a model that described universal stages for concept development, which are mostly independent of content knowledge. Although Piaget was criticized for not focusing on the
importance of contextual factors, such as the impact that various worldviews may have on concept development, his model was useful in identifying the manner in which learners, and teachers, go about to understand a topic such as evolution.

The study explored how higher-order thinking skills may be used in making sense of evolution and was based on the idea that evolution may be interpreted at different levels, discussed by Dempster and Hugo (2006). These authors interpreted the levels of understanding of biology as being on the lowest rung, ‘the what’ or descriptive part of biology, then ‘the how’, which was the functional part examining causation and finally, the highest level which concerned ‘the why’ of biology which focused on the history and the evolution of life. Teaching strategies based on the use of narratives and concept cartoons can challenge the teachers to consider incorporating these higher levels of thinking into the teaching of the life sciences/ biology, and encourage more creative thinking and the inclusion of new ideas into existing knowledge structures.

An improvement in the ‘understanding of evolution’ could be viewed as a better factual knowledge of the topic, which is easily measured by the increased number of facts given by the learners. The reward could be a good symbol achieved in an examination. This may not, however, necessarily be indicative of the ability to use higher-order thinking skills effectively or, that any deep learning has occurred. Deep learning concerns a wish to understand according to Goodyear and Zenois (2007). Low-level thinking skills, on the other hand, are used when learning is perceived to be only important in terms of completing a task as quickly as possible, in the least demanding way, and by using a more superficial approach to learning. A challenge faced by many teachers who teach the life sciences in the FET, or further education band. They are pushed to show improved results, which may not necessarily indicate that better conceptualization and understanding have been achieved, let alone the development of higher-order thinking skills necessary in creativity and for problem solving.

Examining the pre-test responses, shown in figure 6.2 and figure 6.3, it is apparent that most of the teachers answered the questions using only level 1 (facts) and level 2 (linking two facts) of the rubric. There was little evidence of higher-order thinking skills such as incorporating ‘cause – and – effect’ into their explanations or the ability to think in terms of complex interactions between
multiple causes and effects. The pre-test scores were thus mainly concentrated in the categories of ‘zero’, ‘1’ and ‘2’. This showed a skewed distribution for the groups of teachers of this study, instead of the more accepted ‘normal’ distribution which would have included more responses in the categories of ‘3’, ‘4’ and ‘5’.

With reference to table 6.1, most of the ‘alternative explanations’ were recorded for question 1 of the questionnaire. In addition to the ‘alternative’ responses to question 1, twenty percent of the teachers who attended the workshop on concept cartoons also offered such explanations in response to question 5, which examined their understanding of evolution as a ‘fact’, ‘theory’ or ‘law’. This was done rather than giving a scientific explanation of what is meant by a fact, theory or law. Most of the ‘alternative’ responses to the open-ended questions of the questionnaire included mainly religious perceptions. Because these responses were not considered to be biological explanations, they were scored as zeros. Surprisingly, there were also a number of zeros based on an absence of any relevant biological facts in the answers. The group of teachers who attended the workshop on concept cartoons also scored double the number of zero responses to the questions in comparison to those who attended the workshop on narratives.

The statistical analyses of the pre-test results also showed that the group, which attended the workshop based on the use of narratives, was significantly different from the one which attended the workshop on concept cartoons (the null hypothesis HO3 was rejected). This was a matter of concern because the results therefore indicated that the participants were derived from two different populations and that the use of parametric statistical procedures could not be justified. However, non-parametric statistical procedures involving the ranking of ‘paired responses’, i.e. the pairing of the pre-test and post-test responses of each individual or group, allowed for some very useful findings to be made.

In the post-test scores there was a significant improvement in the ability of the participants, of both groups, to use higher-order thinking skills in their answers. Results reported in the literature, such as by Zohar (2006) about similar research, indicate that single interventions are not sufficient to bring about such significant changes. It is thus assumed that the teachers already had developed some of the higher-order thinking skills before attending the workshops, but had not deemed it
necessary to use them in answering the questions of the pre-test. During the workshops, however, they had been challenged into using these higher-order thinking skills, both in interpreting the source materials as well as in designing and presenting the narratives and concept cartoons. Once an awareness had been created in the workshops that knowledge could be constructed beyond a purely factual level, the ability of many of the teachers to use such higher-order thinking helped them to appreciate the importance of deep learning as opposed to a superficial approach adopted in merely ‘completing the task’.

In the process of designing the narratives and concept cartoons, the teachers had had to incorporate ‘new’ knowledge into their existing knowledge structures. They also became aware of ‘different points of view’ expressed not only in the source materials but also reflected in their discussions with their peers and fellow teachers. These experiences also emphasized that there were multiple sources of information available about the evolution life and that most of the participants did not necessarily have the same points of view, nor did they show the same understanding of the topics being discussed. All these factors were conducive to improving understanding and the incorporation of new information into existing knowledge structures as discussed in chapter 4, with particular reference to the work by Garton (2004).

7.2.2 Comparing the effectiveness of the use of narratives and concept cartoons

The questionnaire used in this study was designed not only to explore the level of understanding of certain aspects of evolution, but also to probe any differences that the use of narratives and concept cartoons could have had on the teachers’ ability to use higher-order thinking skills in answering certain questions. The first two questions were more general in nature, by looking at whether the teachers could explain the influence of ‘cause – and – effect’ on the diversity of life on Earth. The choice of macro-evolution for the first two questions was most suitable for probing an understanding of the idea of ‘cause – and – effect’ and also explanations based on the interaction of multiple factors influencing the diversity of life.

Both questions 1 and 2 were based on the idea of macro-evolution but the responses to these two questions were different. Although the validity of these questions was verified by five experts, it can
only be assumed that the wording had had an effect on these outcomes. When comparing the ‘between groups’ pre-test scores using the Mann-Whitney U test, it revealed a significant difference between the responses from those who attended the workshops on concept cartoons and narratives (null hypotheses HO7\text{question1} and HO7\text{question2} were both rejected). The pre-test results thus indicated a significant difference between the two groups’ responses to questions 1 and 2. This could account for one of the reasons why the two groups were significantly different in their overall pre-test totals. This also supported the assumption that they had been derived from two different populations.

These discrepancies were probed further by comparing the ‘within group’ pre-test and post-test response to questions 1 and 2 using the Wilcoxon Signed Rank test. A significant improvement in the level of answers constructed in response to question 2 only, was found for those who attended the workshop on concept cartoons (the null hypothesis HO6\text{question2} was rejected). For the group who attended the narratives workshop, the statistical analyses showed an improvement close to the required 0.050 level of significance, for both question 1 and question 2, with a medium effect size.

The analyses of the pre-test and post-test answers of the group of teachers who attended the workshop on concept cartoons, revealed a different pattern, in that there was no significant improvement regarding question 1 (with a small effect size) but a significant increase recorded for question 2 (with a medium effect size). The different responses from these two groups seemed to verify the above observation that they were derived from different populations, giving further explanation why the null hypothesis HO3, which stated that there would be no difference in the pre-test responses between the two groups, was in fact rejected.

In their explanations of question 2 in the post-test, a significant change was thus revealed in the ability of the teachers to use higher-order thinking skills in answering the question, particularly, by those who attended the workshop on concept cartoons, and to a lesser extent of those who attended the narratives workshop. Thus analyzing the effect of both interventions it can thus be assumed that there had been a positive change in the teachers’ abilities to use higher-order thinking skills but that a greater change had occurred in the group who attended the workshop on
concept cartoons. This seemed to indicate both teaching strategies were effective in encouraging higher-order thinking.

In the overall design of the interventions, a comparison of the effectiveness of the two workshops was included. Question 3, about mass extinctions of life, and question 5, about the nature of science, had been designed to measure more specifically the effect that the workshop on the use of narratives could have on higher-order thinking skills of the participants. Question 4, on the other hand, concerned ‘Darwin as a scientist’ and was covered in greater detail by a specially designed concept cartoon. This activity was included, specifically, to determine how well concept cartoons could impact on the teachers’ thinking abilities in comparison to the use of narratives.

In the design of the questionnaire it was assumed that if a topic was not discussed in the workshop, then the pre-test and post-test responses would not differ significantly. Specifically, the null hypothesis HO5question3 was indeed not rejected, showing that there were no significant changes between the pre-test and post-test for those who attended the workshop on narratives. The teachers who attended the narratives workshop did not choose to design narratives about the evolution of the trilobites and ammonites. As a consequence, opportunities could not be created to allow for discussions about why these organisms were instrumental in the construction of explanations, by scientists about how mass extinctions affected the diversity of later life on Earth.

In the workshop on concept cartoons, the occurrence of mass extinctions only arose in the discussion of the concept cartoon based on the ‘coelacanth’. The post-test results for this group also showed that there was no significant increase in their ability to use higher-order thinking skills. Comparing the effect size of the interventions however, a medium effect size was recorded for the group using concept cartoons in contrast to the small effect size recorded for the group who did the narratives. The role played by social interaction and discussion in encouraging the teachers to use higher-order thinking skills could well be a possible reason why this happened. This will be discussed further in the next section.

In the literature there are several studies, such as by Rutledge and Warden (2000); Sinatra, Southerland, McConaughy and Demastes (2003) and Trani (2004), which emphasize the
importance of the role played by a sound knowledge of the nature of science in understanding the processes used by scientists to interpret evidence about the evolution of life. In my study the importance of an understanding of the nature of science was approached in two different ways. Firstly, in the workshop on the design of narratives, a section was included on the various techniques used by scientists to explain the ‘story’ of evolution of life on Earth. Explanations were also included in the workshop materials of what is considered to be a scientific theory, a law and a scientific fact. Secondly, for the workshop on concept cartoons a special concept cartoon was designed to explore ‘Darwin as a scientist’. The idea of why Darwin is still to-day considered to be an outstanding scientist was also included in the materials. This examined aspects of Darwin’s life, as well as looking at Darwin as a scientist in the context of what we believe to be the nature of science to-day. This idea was also explained in chapter 3 which dealt with the conceptual framework of this study.

In analyzing the responses to question 4, the null hypothesis HO6question4 was rejected, indicating that the group which discussed the concept cartoon about Darwin as a scientist, showed a significant improvement in their ability to answer question 4 at a higher level of conceptualization in their post-test responses. This was not the case with the group attending the workshop on narratives, which had not examined the idea of Darwin as a scientist directly in their discussions. In this instance the null hypothesis HO5question4 was not rejected, indicating that there had been no significant increase in their ability to deal with question 4. They had, however, considered the nature of science in greater detail than the other group dealing with concept cartoons had done. This was reflected in the post-test responses of the group who attended the workshop on narratives, which achieved an improvement close to the 0.050 level of significance for their answers to question 5. This indicated that where there had been opportunities to examine the information in the source material and to discuss certain ideas about what were the characteristics of a good scientist or what was the nature of science, which the teachers were able to use in dealing with the question 5 in the post-test.

Question 5 was rated as the most difficult question to conceptualize by the experts who validated the questionnaire. This is not surprising, because the question required both a knowledge about ‘Darwin’s Finches’ (covered in both workshops) and a good knowledge of the nature of science.
Gregory and Ellis (2009) found in their survey of post-graduates that the understanding of what a scientific theory was considered to be, was even problematic amongst many of their participants who were all science post-graduates. It is not unexpected therefore, that being able to justify why evolution is a scientific theory, is a difficult task.

Based on the above conclusions both the use of narratives and concept cartoons encouraged the participating teachers to use higher-order thinking skills in answering the open-ended questions of the questionnaire. Teaching strategies involving both the use of narratives and concept cartoons can be effective in improving the understanding of evolution. The answers to the first two research questions cannot be given in full unless what is similar between these two teaching strategies is examined further.

The similarities between the design and format of both workshops highlighted the availability of information provided by the workshop materials. Further similarities involved the importance of social interaction, the quality of talk and discussion that happened during the design and presentation of both the narratives and the concept cartoons. In both workshops the source materials were designed to provide sufficient factual information on which the participating teachers could base their discussions. This was one of the ‘control variables’ of the intervention and was introduced to ‘control’ for a lack of ‘previous’ knowledge. A lack of suitable knowledge could have interfered with the teachers’ abilities to complete successfully the activities of the workshops and hence also have affected the quality of their responses to the post-test questionnaire. Another ‘control variable’ was the format of presentation of the workshops by the researcher. Particular attention was paid to the time allocation of the various activities, such as answering the questionnaire, the discussion of the source materials, and most importantly, the time spent in discussion about the design and presentation of the narratives or concept cartoons (this was dealt with in the discussion of chapter 5).

7.2.3 The importance of social interaction and talk

In both workshops the participants worked in groups and were involved in much peer discussion
about the source material relevant to their choice of topic and the construction of the design of their narratives and/or concept cartoons. Goodyear and Zenois (2007) identified that in the process of such social interactions, the participants could be involved in gathering information, constructing knowledge by contributing to the discussions, formulating and clarifying opinions, remembering things by reinforcing learning and also comparing themselves with each other. They would also become aware of different points of view and interpretations presented in the group discussions.

Goodyear and Zenois (2007) also described four conceptions of learning which could happen during social interaction involving discussion. These occurred when: the participants checked that their ideas were correct; deciding on ways of how to collect ideas such as by brainstorming; they challenged and improved their own ideas and, finally, when they challenged ‘ideas and beliefs in order to arrive at a more complete understanding’ (p. 361). The last two categories of learning could be seen as involving deep learning.

Deep learning could thus be interpreted as a process in which the quest for new knowledge would be intrinsic. If superficial learning occurred, on the other hand, there would be a greater concern for what the other peers of the group would think of the individual’s contribution, and the reward would then be interpreted as being extrinsic. The importance of considering discussion as part of social interaction between participants thus played an important role in the establishment of the teachers’ conceptual ecologies of evolution.

In this discussion a constructivist approach has been assumed in interpreting the findings. Firstly, participants interacted socially in the learning process but constructed their knowledge personally (Taber, 2006). This accounted for the fact why participants, working in the same group with the same source materials and involved in the same discussions, gave different responses to the questions of the questionnaire. A Piagetian interpretation of social interaction has been preferred to a Vygotskian approach. In essence, the teachers operated as ‘peers’ in the learning process and the social interaction was not seen to be that of ‘expert’ and ‘novices’ finding a mutual solution.

According to Piaget, a conflict in perceptions generated useful discussions in which different points of view were acknowledged, justified and even defended. This process required social skills
involving tolerance and insight into how others construct knowledge. Garton (2004) quotes the study by Kruger, who found that the greatest gains were made when the participants could not only come to some agreement on the solution of a problem such as the choice and presentation of a narrative, but also could justify why other solutions had been rejected.

Talk was also considered to be important when participants working in groups, were able to express their thoughts and suggestions about how to solve the problem, as well as the procedures to be followed. They scored higher than when these processes had not happened. Even when individuals worked on their own, they did better if they could ‘talk through’ possible ways of finding an answer by verbalizing how they went about finding a solution (Garton, 2004).

7.3 CONCLUSIONS BASED ON THE FINDINGS OF THE QUALITATIVE PART OF THE STUDY

Using a mixed methods research design affords possibilities to compare quantitative and qualitative findings about the same topics under investigation. An example of the possibility of comparing the outcomes of the quantitative and qualitative part of the study involved the increase in the number of teachers who used higher-order thinking skills to answer the post-test after attending the workshop on narratives. Analyzing the number of groups of teachers who built ‘cause – and – effect’ explanations into their narratives designs, it showed that 60% of the groups had indeed done so. This indicated that there had been opportunities to discuss the narrative designs in which the idea of ‘cause – and – effect’ had been introduced into the construction of the stories of the evolution of certain organisms. This could be interpreted as a possible reason why some of the post-test responses included answers involving an awareness of ‘cause – and – effect’ (level 4 of the rubric).

Another example deals with the worrying results from the quantitative part of the study concerned the fact that the pre-test responses from the participants of the two groups showed that these two groups were statistically different and had to be interpreted as belonging to two different populations. When analyzing the qualitative responses to question 6 of the questionnaire, there were several clues as to why this was indeed the case. These are discussed in the next section.
7.3.1 Attaining higher-order thinking skills and epistemological belief systems

Although the qualifications of both groups were similar, it was their responses to what sources of information could be used to help address the perceived controversy between evolution and religion which was of interest. Members of the group who attended the workshop on narratives, stated various sources of information that could be used, and some felt that research by the teacher as well as the learners should be encouraged. They also cited educational visits, group work and debate could be used as ways to address the controversy as shown in table 6.8.

This was not the case with the group of teachers who attended the workshop on concept cartoons who indicated little awareness of different sources of information that they, as educators, could use. Instead, many felt that their religious beliefs should serve as sources of information (as recorded in APPENDIX H). Analyzing the number of ‘alternative’ responses, instead of biologically correct explanations, given by these teachers in their pre-test and post-test answers showed no decline for question 1. In comparing the responses given in the pre-test and post-test of question 5, a worrying increase by twenty percentage points of alternative responses was noted for the group which attended the workshop on concept cartoons. Question 5 probed an understanding of the nature of science and its application to concepts dealing with evolution (see Table 6.1 for information about levels of thinking in response to questionnaire). The teachers who attended the narratives workshop, had acknowledged the importance of multiple sources of information, however, showed a sharp decline in all post-test answers that made references to alternative responses.

There was also a difference in the awareness of an existence of controversy between science and religion. Again, in the group of teachers who attended the workshop on narrative construction, about 50% cited such awareness in their pre-test responses, whereas in the other group only 30% of the participants registered such feelings in their answers. This changed with the post-test findings, when 80% of the teachers of the latter group (who attended the concept cartoons workshop) recorded concern about the conflict that evolution posed with religion. This was probably due to discussions of the concept cartoon about ‘Darwin – science and religion’ and, also the construction of their own concept cartoons about the controversy between science and religion.
Constructing a composite picture of the worldviews expressed by the teachers who designed their own concept cartoons, a conflict between science and religion arose in almost all universals used to probe and record the various points of view held by the teachers. This seemed to verify the reasons for the above observation, that there was an increase in the awareness of conflict between personal worldviews and that of science in the post-test responses, of those who attended the workshop on concept cartoons.

One of the major differences between the two groups of participants was how they viewed the importance of various sources of information for the teaching of evolution of life. This also related to their willingness to consider different teaching strategies which involved debate, research and group work. Hence the quantitative finding, which indicated that the two groups were statistically different in their pre-test results, was substantiated by analyzing the teachers’ points of view as reflected by their answers to question 6 of the questionnaire, on how to deal with the controversy between evolution and religion.

In the statistical analyses, the null hypothesis $H_0^4$ was not rejected, which showed that the post-test scores of both groups indicated that there was no difference between the groups in terms of their abilities to answer the questions using higher-order thinking skills. However, the post-test responses of the group which designed the concept cartoons, indicated little change (an increase from one response in the pre-test to three in the post-test) in the participants’ views about consulting various sources of information which they as educators could use to address the controversy between evolution and religion. The group who attended the workshop on narratives gave a very different response in that eleven out of the nineteen participants stated that they considered the use of multiple sources of information important in dealing with evolution (see Table 6.8). Hence it seemed as if two different but related issues were involved in interpreting the teachers’ responses. The first issue related to the ability to use high-order thinking skills in answering open-ended questions. The second issue was about knowledge and the importance of different sources of information.

In their study about how effectively students dealt with different texts about the characteristics of light, Mason, Gava and Boldrin (2008) commented on the role played by epistemological beliefs in
the outcome of their research. Their classification of the approaches to the origin of knowledge ranged from a view that knowledge is absolute and stable to a belief in knowledge as complex and evolving. Thus if knowledge were seen as absolute, it would consist of discrete facts that were unchanging and that the source of knowledge lay vested in an ‘authority’, which could be interpreted as the bible, or a textbook, or a handbook, or a figure of authority such an ‘expert’. The knowledge would be externally derived from an ‘authority’ and reside ‘outside’ the person. It seemed likely that many of the teachers who attended the workshop on concept cartoons held an epistemological view that knowledge was absolute and based on a single source of information such as the bible or the textbook which they used in class.

When given the opportunity to discuss various points of view in the workshop on concept cartoons, many teachers did demonstrate an ability to use higher-order thinking skills, based on multiple sources of information. However, in their post-test responses most did not include teaching strategies involving the use of multiple sources of information such as further research and group work as possible ways to address the perceived controversy between science and religion. Generally, this was not the case with most of the teachers who attended the workshop on constructing narratives, who maintained that they should encourage their learners to do research and consider various sources of information.

The Piagetian levels of thinking used in the rubric design, were based on the interpretation that concept development was universal and not dependent on factual knowledge or epistemological beliefs. Although capable of using higher-order thinking skills this did not mean that some of the teachers saw it necessary to do so or chose to incorporate teaching strategies that would challenge them to use these skills in problem solving or presenting good scientific arguments. This was particularly the case with some of the participants who attended the workshop on concept cartoons. However, it must be borne in mind that in the conceptual ecologies of evolution which are held by these teachers, higher-order thinking skills form only a part of a much larger picture of how knowledge is constructed to deal with the everyday problems of life both inside and outside the school classroom.
It seemed that an important barrier in teaching evolution of life effectively in the classroom concerned the teachers’ epistemological beliefs, a part of their conceptual ecology of evolution. These ideas could be developed further by looking at what worldviews these teachers held about the controversy between science and religion and what barriers they were prepared to acknowledge as possible stumbling blocks in teaching evolution of life effectively in the classroom.

7.3.2 Barriers identified by teachers

When answering the post-test question about what could be done to deal with the controversy between science and evolution, some teachers had had some time to reflect on what had been discussed during the workshops. Their comments were insightful in that some admitted that, they, as the teachers had a hand in creating the controversy. It is not surprising that Demastes, Settlage and Good (1995) also indicated that not only should the students’ or learners’ worldviews be recorded during research, but also those of the instructors and teachers involved in a study of the acceptance of evolution.

The teachers also identified other possible barriers in the acceptance of evolution, such as the role perceived to be played by culture, lack of knowledge, both on the part of the teacher as well as the learners, interest, influence of parents and motivation. There was little reference to the importance of evolution in the understanding the processes of biology at different levels. This supported the comments made by Dempster and Hugo (2006) about the danger of teaching of biology at only a ‘recall’ level without an appreciation of the importance of the ‘whys’ of the subject.

A few teachers did indicate that it was desirable to stress to the learners the importance of understanding how scientists make sense of the world, but mainly as a means of how to pass examinations in the life sciences. Little reference was made to the role played by the nature of science in understanding how scientists deal with information. No correlation was made between the understanding of evolution and the nature of science. This was surprising because in the literature, most studies conducted about the understanding and acceptance of evolution, had shown a positive correlation between understanding evolution and the understanding of the nature of science.
By identifying the barriers which they felt interfered with the teaching of evolution, the teachers showed the importance of considering not only the ‘facts’ of evolution, but also to be aware of other factors that influenced their teaching. Trani (2004) concluded in his study of teachers in Oregon in the USA, that there existed a danger of succumbing to claims of religious perceptions acting as barriers to the teaching of evolution. In fact, the real reason had more to do with a lack of knowledge about the subject and lack of will, or even an unwillingness, to understand the nature of science.

Another approach, which could be adopted to deal with barriers that interfere with the teaching of science, was discussed by Aikenhead and Jegede (1999). This will be examined in relation to the effects that teachers’ worldviews have on their ability to cope with teaching of science.

**7.3.3 Worldviews and border crossings**

The worldview analysis of the teachers’ own designs of concept cartoons, which could be used to explore ‘science and religion’ in their own classrooms, was based on the work by George (1999). A composite picture of the worldviews held by the teachers was constructed using the ten concept cartoon designs which they brainstormed and constructed during the workshops and is shown in figure 6.22. The underlying theme, or logico-structure of the composite worldview, revealed that conflict occurred between science, society and, or, religion as highlighted in figure 6.23.

The ‘self’ could be seen as ‘being interested in fossils’ or unsure as how to handle the controversy generated from the input from ‘other’ members of the community: a minister of the church, parents and the ‘learned people’. The ‘relationships’ between the ‘self’ and the ‘other’ again indicated a tension between ‘science’ and ‘religious’ expectations. Interesting points of view were also raised about a fossil australopethine called ‘Mrs Ples’, whether ‘she’ (or ‘he’) was black or white, and her age as part of the universal ‘classification’. ‘Space’, as a universal, was seen in terms of ‘caves’ which could be used as an area for healing and worship of ancestors, as well as a space excavated by scientists to find fossil remains of the ancestors of present day humans.
Aikenhead and Jegede (1999) used the idea of conflict in explaining the dilemma faced by many teachers and learners when their personal worldviews were in conflict with the requirements of what the authors term ‘school science’. In particular, adopting an approach based on the nature of science in dealing with the problem. These authors explained that if the worldviews of the learners were similar to the worldviews held by scientists, then the border crossings between these two worldviews would happen relatively smoothly. If, on the other hand, the worldviews were different then the border crossings became more difficult to negotiate. If the worldviews of the learners and the worldviews required by ‘school science’ were so dissimilar that the border crossing became almost impossible, then the learners would either drop out of the subject or resort to rote memorization.

Anderson (2007) described a similar situation when dealing with border crossings between worldviews associated with the nature of science and worldviews underpinning religious beliefs. The first of the two ‘approaches’ which Anderson identified, dealt with the worldviews in which science and religion were in ‘conflict’ with each other. This is also shown in figure 6.22 highlighting that a conflict in views causes confusion. The second, related to a compartmentalization of these two worldviews so that there was little or no contact between them. Statements made by teachers shown in APPENDIX H confirm this point of view. In both approaches the border crossings between science and religion were ‘hazardous’ and difficult to negotiate. In the analysis of the teachers’ responses to the controversy between science and religion, these two approaches described by Anderson were prevalent. There was little or no evidence of the latter two approaches, discussed by Anderson, involving ‘dialogue’ and ‘integration’, where common ground was found between science and religion.

By examining the responses of the teachers from the quantitative study, it seemed that many of the teachers’ epistemological belief systems centred on knowledge as absolute and unchanging. It was therefore not surprising that conflict existed between their beliefs and that of the nature of science, based on the premise that knowledge is tentative and evolving. Some teachers indicated the importance of keeping science and religion separate or compartmentalized, in order to avoid such conflict.
However, Aikenhead and Jegede (1999) also indicated that there were some individuals who had been able to negotiate even the most difficult of border crossings. When considering what characteristics made it possible for them to make such border crossings, the authors discovered that collateral learning was part of the process. This meant that these persons were capable of thinking and were at ease in handling at least two different worldviews, either simultaneously or separately. Thus when scientists from an African background worked in a laboratory or in an observatory, they operated and thought as scientists. When visiting their families they could operate in a different domain of beliefs and would feel comfortable in doing so, but would be aware of the fact that they had crossed borders between different worldviews. George (1999) in her conclusion about the study in ‘Seablast’ recommended the importance of such persons serving as role models for aspiring scientists. They faced problems of how to handle multiple worldviews with regard to their indigenous knowledge and the world of science. A good example would be Thebe Medupe, an astronomer who has written a book about the ‘Astronomy of Tibuktu’ in which he ‘does not simply account of what these ancient Muslim scholars discovered’, but explored the topic in general – by including ‘some of the European astronomy of the time, showing the parallel investigation of the subject on two different continents.’ (Anonymous, 2011, p. 48)

For successful border crossings to happen, an adventurous spirit was needed, a quest for new knowledge, meeting different types of people and visiting various new places. Thus a certain degree of ‘playfulness’ was recommended by Jegede (Aikenhead and Jegede, 1999). The ‘playfulness’ referred to an ability to ‘play’ epistemic games which define the ways in which knowledge is constructed within certain cultures, and certain worldviews (Goodyear and Zenois, 2007. In fact, many teachers would have to break away from the notion of the absoluteness of knowledge, and the certainty and stability this was thought to bring, and adopt a willingness to accept the uncertainty that knowledge is evolving. This, indeed, will be a challenge that many teachers will need to reflect on in order to teach evolution effectively.

7.4 LIMITATIONS OF THE STUDY

Sample size may generate problems if volunteers only are used for the study. This was the case with this study where 34 participants volunteered, making the sample a bit small to allow for any
general conclusions to be made. Thus the recommendations were based on tendencies and patterns discerned in the study, and should also only be interpreted within certain specified parameters. One of these parameters involved the allocation of teachers to the two treatment groups. This did not happen randomly and hence caused the two interventions to be presented to groups that were at the beginning of the intervention statistically significantly different, based on their pre-test results. The pre-test responses also indicated that that the scores were not normally distributed but skewed toward the lower-thinking levels used by the teachers. This made it difficult to generalize the findings to the overall group of teachers of the life sciences, assumed to be normally distributed in their abilities to use lower- and higher-order thinking skills.

It must also be accepted that the time interval between the administration of the pre-test and the post-test was about three hours and that a further post-post-test should have been given at a later stage to establish the effect of the workshops over a longer period of time. This was not possible within the design of the study.

It is accepted that the findings should be interpreted within the parameters of the study only in terms of the conceptual ecology of evolution of life and may not necessarily be relevant to other topics and conceptual ecologies until further investigations are conducted. The rubric that was used to identify the levels of thinking was based on the assumption of universality, according to a Piagetian interpretation. The rubric worked well in distinguishing the different levels of thinking, and was content free which avoided the possibility of a lack of ‘previous knowledge’ to interfere with the outcome of the research.

The reliability of the rubric could not be established using a statistical measure such as the Cronbach α, because of an absence of scores in each of the categories of the rubric for every participant. The study thus needed to be repeated in order to establish its reliability. However, the rubric was based on the premises of an accepted and tested theory of concept development which gave it not only its validity but also assured a good possibility of repeatedly giving the same measurements, a criterion for its reliability.

7.5 CONCLUSIONS AND RECOMMENDATIONS
7.5.1 Higher-order thinking skills and how teachers view knowledge

This study has indicated that many teachers are capable of using higher-order thinking skills but do not seem to see the necessity for doing so. Lower-order thinking skills involving the memorization of facts give answers that are easily assessed, and can reflect large improvements of factual knowledge, but in many instances occur without any in-depth understanding. This is a superficial approach to learning, which is often mistakenly seen as the improved conceptualization of a topic instead of as the consequence of rote memorization. This may also point to a danger within our ‘matric’ examination system when claims of increases in pass rates in fact do not necessarily indicate a better understanding of the subjects thus passed.

Various educationists, including Dempster and Hugo (2006) have expressed alarm about the poor results South African learners achieved in tests such as in the international studies of mathematical and scientific literacy. In many instances higher-order thinking skills are necessary in order to be creative and offer solutions to problems. This may well be one of the contributing factors to the poor showing of our learners in these international studies. Furthermore, the study also seems to indicate that many teachers view knowledge as ‘absolute’ and unchanging, and resides outside the learner. In other words, it is not accepted that knowledge is constructed by the learners themselves, and that knowledge is indeed tentative and may evolve further with positive experiences that reinforce a pleasure derived from handling scientific challenges confidently.

7.5.2 Teachers as agents of change: critical reflection about epistemological beliefs and the nature of science

One of the recommendations arising from this study, is to acknowledge that many of our teachers are good, creative and capable thinkers. But, that the time has come for many teachers to reflect on their own views about how knowledge is constructed both within themselves as well as in the learners in their classrooms. They need to think deeply about their own dispositions towards knowledge and adopt a willingness to act as positive role models in demonstrating that border crossings into the world of science are possible and important for encouraging a younger generation of scientists to develop. Indeed, to be effective, teachers need to act as agents of
positive change and not merely look for soft options which involve only one source of information, such as the use of one textbook.

7.5.3 Border crossings between worldviews and the encouragement of future scientists

Border crossings between different worldviews, even when seen as almost impossible, can be overcome if some calculated risk taking happens, associated with a will to acquire new knowledge. Most importantly, that insights and solutions to problems involve higher-order thinking skills and that situations need to be created to allow this to happen in the classroom. This study has shown that teaching strategies such as the creation of narratives about the story of life and the use of concept cartoons, do encourage the use of such higher-order thinking skills and could be useful in the classroom to effect deep learning and concept development.

One of the greatest problems faced by South Africa is a lack of persons who have scientific and technological skills. Mthuli Ncube, chief economist and vice-president of the Tunisian based African Development Bank (AfDB), stated that even in Africa, South Africa with 0.6% of the adult population being graduate scientists and technologists, was far behind countries such as Tunisia (5.6%), Botswana (2.7%) and Kenya (2%) (Business Report, The Star, 2011). It is possible that the lack of scientific and technological skills should not only be addressed at a tertiary level as Ncube suggested. It is necessary to consider ways and means of encouraging far younger learners to feel confident enough to embark on problem-solving activities which involve scientific and/or technological approaches in their own ‘backyards’ and schools. The encouragement of learners to become involved in such activities has already happened in projects such as ‘eco-schools’ and in their participation in ‘Expo Young Scientist’.

Many studies mentioned in the literature, such as by Rutledge and Warden (2000); Trani (2004) and Deniz, Donnelly and Yilmaz (2008) correlate the acceptance of evolution with not only the understanding of evolution but also with the understanding of the nature of science. Hence the seemingly unwillingness of teachers to teach evolution may well be related to a lack of understanding of how scientists construct knowledge rather than to a rejection of evolution on the basis of religious perceptions. In many instances, the rejection of evolution seems to be based on an absolutist view of knowledge which contradicts the tentativeness of science.
In a corporate report issued about the Department of Science and Technology (Innovation is the way, 2011, May 27), the deputy-minister Derek Hanekom stated that learners should be able to ‘touch’ science in order to be encouraged to take up a scientific career. Likewise in teaching evolution effectively, it is important that the teachers of the life sciences should also ‘touch’ science and come to understand the nature of science. This understanding could help them to inspire their learners not to be afraid to cross into the world of science, even if initially it seemed to be a daunting experience.

7.5.4 The danger of viewing knowledge as being absolute

Supplying multiple sources of information such as libraries, the internet and laboratories will not be effective in solving problems if the source of knowledge is seen by many teachers as absolute, related to an authority ‘outside the classroom’, and as a single source of unchanging facts. This, indeed, presents a great challenge that our country’s science education planners need to take seriously.

7.6 CONTRIBUTION OF THIS STUDY TO RESEARCH

This study deals with the increasingly more complex area of research which focuses on the conceptual ecology of teaching evolution, rather than on the mere acquisition of knowledge about evolution. As a consequence of this development in the perceptions of how evolution of life should be taught effectively, a wide range of sources of data, some discussed in the preceding chapters of this thesis, have become available and are open to a variety of different ways in which the data thus generated can be analyzed. Hence the perceptions and worldviews recorded in this study, the design and methodology and its analysis of data and conclusions could make a valuable contribution to make the teaching of evolution of life more effective.

7.6.1 Mixed method research methodology

An embedded and concurrent mixed methods research design was used to measure both the level of conceptual thinking as well as the teachers’ worldviews about the controversy concerning the
teaching of evolution of life. The teachers’ responses were gathered during one workshop and reflected their understanding of aspects of the evolution of life. At the same time, information was also collected about their perceptions concerning the controversy associated with the teaching of evolution. Data thus gathered arose from various sources, but all contributed to a clearer picture and better understanding of the conceptual ecology of evolution held by the participants of the workshop.

7.6.1.1 Designing a rubric to transform data

A rubric was designed to transform qualitative data, generated from open-ended questions, into quantitative data. This data could then be analyzed statistically to identify possible patterns and trends about the teachers’ abilities to use higher-order thinking skills in answering open-ended questions about evolution. The rubric was based on Piagetian levels of conceptual development and consisted of hierarchical categories which could be rank-ordered, similar to an interval scale. Associated with the quantification of the responses, another category was included in the rubric to record ‘alternative’ responses which did not meet the requirements of the rubric. However, these answers did contain useful information about the participants’ worldviews which influenced the responses given to the questions. Thus one set of data offered more than one way of analyzing and interpreting the information.

A mixed methods approach is useful in research where diverse data and different sources of information are used to explore a complex area of study such as the conceptual ecologies of evolution that teachers have. A cautionary note needs to be added, however, because with increasing complexity of the area of research comes the demand that the researcher needs to be acquainted with both quantitative as well as qualitative methods of research design. In addition, the researcher should also have a ‘feel’ for data and understand what the data can and cannot reveal.

7.6.1.2 Interventions, the design and presentation of workshops

This study has demonstrated that ‘once-off’ workshops can be effective. The design and also the presentation of the workshops should involve the participants, to generate discussion about topical
issues and encourage the use of higher-order thinking skills.

Although not sufficient time may be available to master many skills, a ‘once-off’ workshop can be used to stimulate interest in a topic, plant a seed for future use and can create awareness in the participants about issues in education. However, a realistic expectation of what can be achieved in a short period of time should also underpin the design of an intervention based on the use of workshops.

Workshops need to be planned carefully with the study's research questions in mind. Time allocation is an important factor in achieving the success of such workshops both in terms of the positive response from the participants and also in data collection.

7.6.2 Contribution to pedagogical content knowledge

The pedagogical content knowledge (PCK) of teachers is determined by their content knowledge, or (CK) of the subject, and their ability to transform such knowledge in order to make it accessible to the learners. A good knowledge of the different types of pedagogical skills (pedagogical knowledge, or PK) is also necessary. Pedagogical content knowledge is unique to the teaching profession (Shulman, 1987). It constitutes an area of research which is found only in the teaching profession.

In this study the conceptual ecology of evolution held by teachers was an important area of research and should contribute to the PCK of practicing and future teachers. Conceptual ecologies are fairly complex areas of investigation and involve not only the construction of knowledge but also the contextual factors which affect the formation of such knowledge structures.

The inclusion of conceptual ecologies into PCK is a fairly recent occurrence and requires a range of different research techniques to study this idea, exemplified by the research by Abd-El-Khalick, and Akerson, (2004). The work by Deniz, Donnelly, and Yilmaz, (2008) attest to the challenges faced by researchers who have examined the conceptual ecology of evolution held by teachers.
7.6.2.1 Content knowledge (CK) about evolution

In this study the teachers were provided with up to date source material about the evolution of life on Earth derived from multiple resources such as from the latest publications, from the internet and also from DVDs clarifying recent findings and interpretations by scientists. In the source material concerning the ‘narratives of the evolution of life’ a clarification was also offered about the scientific techniques used by scientists to study not only how evolution happens but also the changes of the environment in the Earth’s history, which was linked to the importance of understanding the nature of science. This information was not readily available to the teachers, and required many hours of research, but provided valuable information to make lessons about evolution more interesting and relevant.

7.6.2.2 Pedagogical knowledge (PK)

Pedagogical knowledge is important in implementing teaching strategies involving the use of concept cartoons and narratives of the evolution of life. Encouraging the use of higher-order thinking skills in learners can be challenging, especially if teachers usually refer only to a textbook in the classroom. However, once the teachers become aware of a diversity of strategies, such as the use of concept cartoons and narratives, a range of thinking skills involving analyzing information, problem solving, formulating an argument and creative thinking may be developed. With an improvement in the quality of thinking by both the teachers as well as the learners in the life sciences classroom, it could translate into the learners being more knowledgeable and confident about choosing careers in the sciences and technology.

However, to achieve such quality of teaching would require teachers to become more reflective and critical about themselves as ‘agents of change’ (Gravett and De Beer, 2010). The teachers, who experienced the workshops about concept cartoons and the use of narratives, found that it was possible to incorporate higher-order thinking skills into their teaching. This experience has given many of the teachers a different insight into the world of their own classrooms and what can be achieved by using such teaching strategies and the importance of implementing such pedagogical knowledge. One of the workshop participants achieved an ‘educator of the year’
award for using innovative teaching strategies in his teaching, which included the use of concept cartoons and narratives.

A further challenge faced by many life sciences teachers is to understand and justify the importance of a good knowledge about the nature of science in their teaching. Incorporating higher-order thinking skills into their lessons, the teachers will be able to create opportunities for learners to examine information critically, develop arguments and design investigations probing certain ideas. In the process both the teachers and their learners should be able to ‘touch science’ as expressed by the deputy minister of science and technology, Derek Hanekom (Innovation is the way, 2011, May 27). They should also become aware of the tenets of the nature of science such as the tentativeness of knowledge and that science also has boundaries within which is at its most effective.

7.6.3 Areas for future research

This study has focused on two complex areas of research. A mixed methods research design, and, that of the pedagogical content knowledge of teachers and their conceptual ecologies of evolution, in particular. Many opportunities for future research may arise, which could include:

- Feedback from one of the participants indicated successful implementation of both the use of concept cartoons and narratives in the classroom. With a focus on innovative teaching strategies that add value, in terms of developing higher-order thinking skills in learners, applicants for teaching positions who have such experience, may also have an advantage over other colleagues applying for the same position.

- The design of follow-up activities in the classroom, based on the implementation of concept cartoons and narratives, should also provide an interesting opportunity for teachers who are involved in action research.
• The further investigation of the components of conceptual ecologies, the dynamic relationships between these components, and the construction of models to explain such relationships.

• Probing the worldviews held by learners and teachers about the nature of science, why some avoid science; examining the possibilities of establishing border crossings between world views; and hence the ability to overcome problems associated with avoidance of science and technology as a career.

7.7 CLOSING COMMENTS

In this exploratory mixed methods study various factors were identified which could influence the effective teaching of evolution of life. These factors were reflected in the problem statement initially given in chapter 1. It is worthwhile to revisit this problem statement and the research questions generated from it.

What strategies can be used in the professional development of teachers to encourage them to further their knowledge about the evolution of life and the nature of science and to use higher-order thinking skills in addressing issues relating to the teaching of evolution of life?

Four clusters of factors emerged from the above statement: the use of teaching strategies in the professional development of teachers, their knowledge about evolution and the nature of science, higher-order thinking skills and issues relating to the teaching of evolution of life. The first two research questions related to the introduction of new and innovative teaching strategies, i.e. the use of narratives and concept cartoons in the professional development of teachers.

The third research question was pivotal in the research because it dealt with the measurement of higher-order thinking skills. Indeed, in dealing with this research question the gap between qualitative and quantitative research methods was challenged by designing a rubric to transform qualitative data into quantitative data. The quantitative data thus derived could then be subjected to inferential statistical procedures to identify trends and patterns of the teachers’ thinking abilities in dealing with the topic on the evolution of life. Additional insights derived from such quantification of
qualitative data underpin a new approach to research which has been initiated only recently in other fields related to business economics, nursing and the health sciences, for example.

Research questions four and five were designed to probe why many teachers did not teach evolution effectively. This dealt with the teachers’ individual perceptions and their conceptual ecologies of evolution. The construction of concept cartoons by the teachers, themselves, reflected their personal perceptions on the issues about teaching evolution.

Two additional research questions were formulated in accordance with Creswell’s view (2009) that these research questions should reflect both the quantitative and qualitative nature of a mixed methods design. Thus included were the notion of ‘to what extent’ will the use of teaching strategies affect the teachers’ ability to use higher-order thinking skills and the identification of ‘different ways’ in which in which individual worldviews could influence the outcome of the study.

No studies have been reported in the literature on the combination of the use of higher-order thinking skills, and teaching strategies involving concept cartoons and narratives with specific reference to the teaching of evolution of life. In this instance the research is new. However, there have been publications about the use of concept cartoons based on a range of topics, and the development of higher-order thinking skills (Naylor and Keogh, 2000). There have been several publications on the importance and use of higher-order thinking skills discussed in this thesis (Dempster and Hugo, 2006; Zohar, 2006; Goodyear and Zenois, 2007) and the development of conceptual ecologies of evolution by, for example, Demates, Good and Peebles (1995). All these publications have contributed towards a framework, discussed in chapters 2, 3 and 4, against which the results and findings of this study may be interpreted and evaluated in terms of its contribution to research.

Although the exploratory nature of this study and the fact that it focused on the teaching of evolution of life only, may make it difficult to propose any generalizations about the professional development of teachers as a whole, this does not preclude it from its contribution to improving the effectiveness of teaching evolution of life. The trends and patterns identified in this study about the effective use of concept cartoons and narratives in encouraging the use of higher-order thinking
skills of teachers also may serve to open the door to innovative research in other topics and aspects of professional development of teachers.

What this study has highlighted is the complex and dynamic interplay between many factors involved in the professional development of teachers. This allows for challenging and innovative research to happen not only into the study of effective teaching of evolution and the conceptual ecologies that teachers hold, but also involving other topics in the life sciences and different subject areas.

7.8 SUMMARY

Many teachers are capable of using higher-order thinking skills but do not seem to see the necessity for doing so. Lower-order thinking skills involving the memorization of facts, give answers that are easily assessed, and can reflect large improvements of factual knowledge. Thus impressive increases in the pass rate of a subject such as the life sciences can be achieved without improved understanding.

Knowledge is viewed by many teachers as ‘absolute’ and unchanging, and ‘resides’ outside the learner. It is not generally accepted that knowledge is constructed by the teachers and the learners themselves. The tentativeness of knowledge and the fact that it evolves further as more information becomes available, is not easily accommodated within the worldviews held by some teachers.

Insights and solutions to problems involve higher-order thinking skills and situations need to be created to allow this to happen in the classroom. Teaching strategies, involving for example, the creation of narratives about the story of life and the use of concept cartoons, do encourage the use of such higher-order thinking skills.

Border crossings between the learners’ worldviews and that of science, even when seen as almost impossible, can be overcome if some calculated risk taking happens, associated with a will to acquire new knowledge.
Supplying multiple sources of information such as libraries, the internet and laboratories will not be effective in solving problems concerning the effective teaching of a topic such as evolution, if the source of knowledge is seen by many teachers as absolute, related to an authority ‘outside the classroom’, and as unchanging facts. This, indeed, presents a great challenge that our country’s science education planners need to take seriously.

The contribution of this study to research involves the methodological research design of a mixed methods approach, the design of a rubric which transforms qualitative data into quantitative data which can be used for statistical analyses, and the design of interventions involving the successful presentation of ‘once-off’ workshops. In terms of the study’s contribution to knowledge, the importance of pedagogical content knowledge is highlighted in achieving effective teaching of evolution and the nature of science with an emphasis on teachers as ‘agents for change’.

Areas for future research could include investigating further the ecology of evolution that teachers have; the implementation of teaching strategies developing higher-order thinking skills in the classroom; and probing the worldviews of teachers and learners about the nature of science in order to establish why careers in the sciences are avoided.

This is an exploratory study and its contribution to research may be difficult to establish because little research has been published in terms of the combination of all the factors addressed in the research (i.e. professional development of teachers, effective teaching of evolution of life, innovative teaching strategies involving the use of narratives and concept cartoons, higher-order thinking skills and deep learning). However, the complex dynamic between these factors has been highlighted and opens a window to innovative and challenging research in the future.
REFERENCE LISTS


Charles Darwin Trust: [www.charlesdarwintrust.org](http://www.charlesdarwintrust.org/)
[www.ucmp.berkeley.edu/geology/tectonics.html](http://www.ucmp.berkeley.edu/geology/tectonics.html)
[www.nature.nps.gov/geology/usgsnps/animate/pltecan.html](http://www.nature.nps.gov/geology/usgsnps/animate/pltecan.html)
REFERENCE LIST – WORKSHOP ON CONCEPT CARTOONS

Letters:


Journal articles and books:


APPENDIX A: LETTER OF CONSENT

Letter of Consent

Welcome: to two workshops that will be interesting and thought provoking.

Thank you for attending these workshops and volunteering to be part of this research project.

In order to safeguard your ethical integrity as a volunteer and my ethical integrity as a researcher, the University of Johannesburg requires that you made aware of the following considerations before signing the ‘letter of consent’ provided.

Research background and rationale for presenting the workshops

Central to the design of this investigation is the following question: What strategies can be used in the professional development of teachers to encourage them to further their knowledge about evolution of life and the nature of science and to use higher order thinking skills in addressing issues relating to the teaching of evolution of life?

The two strategies are the ‘use of narratives’ and ‘concept cartoons’, each covered in a workshop of about four hours.

Five research questions arise from the above rationale
1. What knowledge do teachers require to know or be able to access in order to make links between concepts such as geological time, mass extinctions, climate change and the future of life on Earth?
2. What explanations can be built into the design of the narrative about the evolution of life?
3. How can concept cartoons be used to assess the quality of links made, and hence how much deep learning has occurred, and how effective are they in measuring the deep learning that has occurred?
4. How can teachers be empowered to introduce higher order thinking skills into their teaching and assessment of learning?
5. How are teachers’ attitudes and beliefs about the teaching of evolution of life influenced by the ‘community’ according to the model based on the Cultural-Historical Activity Theory?

Data Collection
The research design is based on a pre-test; post-test (in workshop1 on ‘narratives’) and a post-post-test (which will occur at the end of workshop2 on ‘concept cartoons’) format. The questionnaire consists of open-ended questions and your answers will be assessed using a rubric.
The intervention also involves the construction of a concept cartoon as a group activity, which will be recorded by a scribe. This information will be used to analyze aspects of the group’s beliefs about ‘science and society’ and religious ‘world views’.

Owing to the design structure of the investigation, the data and interpretations can only be discussed after the study has been completed. These will be made available to the participants if so requested. The data will be stored for five years after the research has been completed.

**Benefit of the research to you the participant**

Participants will be given source material not previously accessible to teachers. Partly, because this is original research and new concept cartoons have been created specially for the workshops. The information contained within the workshop handouts, is derived from over thirty sources researched over a lengthy period of time.

With exposure to higher order thinking skills, teachers will also be able to include these ideas in their teaching, the setting of assignments and projects and in examination questions.

**General**

Participation in this research is completely voluntary. You are free to withdraw from the research without stating reasons. You may also request that your data no longer be used in the research. However, you are requested not to withdraw from the research without careful consideration, since this may have a detrimental effect on the research’s validity and statistical reliability.

By agreeing to be part of the research, you are also giving consent for the data that will be generated to be used by researchers for scientific purposes. However, it must be stressed that confidentiality will be guaranteed and that your name will not be linked to any of the data.

There are no known risks associated with this study. No names of participants will be used during the publication of the research findings. The data will be used sensitively and confidentially. Anonymity is guaranteed and where applicable, pseudonyms will be used.

Kindly complete the ‘Letter of Consent’ at the beginning of workshop1.

Your contributions are important and valued as part of an important research project.

Thank you: Maria van der Mark (tel. no. 011-447-2707), mariasworkshop@iburst.co.za Dr Josef de Beer: Promoter (tel. no. 011-559-2765), josefdb@uj.ac.za
LETTER OF CONSENT

I, the undersigned ____________________________________________________
(full names and surname – please print clearly)
have read all the conditions as outlined in the preceding explanations in
connection with the research and have also heard an oral discussion thereof,
declare that I understand these conditions.

I declare that my participation in the research is voluntary.

With this declaration I give consent, for my responses to the questionnaire
and written input in the workshops, to be used for research purposes and
publication of the findings, by the researcher, Maria van der Mark.

_______________________________ signed on this

date __________________________

witnessed by _______________________
(full names and surname – please print clearly)

_______________________________ signed on this

date __________________________
APPENDIX B: QUESTIONNAIRE

DATE:__________________

CONTACT NUMBER:______________

Please supply the following information.

1. Qualifications:

2. Teaching Experience:
   Life Sciences
   Natural Science

3. Have you attended other workshops (Life Sciences/Natural Science) in your own time?
   YES      NO
   If YES, please describe briefly.

4. Briefly describe your reasons for attending this workshop.

Please turn over.

PLEASE answer as fully as possible.
1. What can we learn from the evolution of life and the changes that the Earth has undergone in the past?

2. Does environmental change drive evolution? Explain your answer.
3. What evidence do we have that mass extinctions happened in the past?

4. Although Darwin was born two centuries ago (1809 – 1881), he is still considered to be a great scientist today. Explain why this is so.
5. Explain how ‘Darwin’s Finches’ found on the Galapagos Islands, illustrate that

- evolution is a fact,

- evolution is a theory,

- evolution can be a law.

6. Why do you think that the teaching of evolution of life is controversial?

What can you as a teacher do to address the issue?
APPENDIX C: WORKSHOP 1 - Narratives

THE STORY OF EVOLUTION OF LIFE
AND THE EARTH’S GEOLOGICAL HISTORY -
AS TOLD BY SCIENTISTS

PRESENTED by MARIA VAN DER MARK
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INTRODUCTION

Workshop 1: Narratives – ‘A Story of the Evolution of Life and the Earth’s Geological History - As told by scientists’

For FET teachers of the Life Sciences

Knowledge Area: Diversity, Change and Continuity.

The aim of the workshop is three fold:

- present ideas on how to construct Life Sciences Knowledge by using narratives,
- open a window to the Nature of Science by highlighting Science in Action,
- create opportunities for critical-thinking and problem-solving.

There are four strands in the preparation of the narratives.

1. A framework of knowledge built using certain scaffolds.
   Firstly, relating to change, diversity of life, mass extinctions and evolution of the living world.
   Secondly, with regard to change of the environment in terms of tectonic plate movement, ‘drifting’ continents and climate.
2. The nature of science in reconstructing the past using scientific data; and the value of scientific laws, scientific theories and use of computer generated models.
3. Data collection tools scientists use to help them find more information (for example radiometric dating, use of different isotopes, stratification and paleomagnetism).
4. Thinking ‘outside the box’, innovation and creativity in stimulating interest in what is the most challenging and controversial part of the curriculum.

Two workshops are part of research into the construction of knowledge in the Life Sciences and higher order thinking skills involved in deep learning.
NARRATIVES

An example of a Narrative: Television ‘Soap Operas’

The successful television series called ‘Walking with Dinosaurs’ is a good example of a narrative. The series illustrates how stories of the Earth’s distant past can be used to stimulate greater curiosity about the sciences and even appeal to an audience not usually that interested in Biology and the Life Sciences.

The introduction to the book ‘Walking with Dinosaurs’, p7, sets the scene to the television series.

No period on Earth has gripped the human imagination more than the time of the dinosaurs. For over 150 years dinosaurs have fascinated scientists and lay people alike – perhaps because they seem so completely alien to anything currently to be found on Earth, and yet they were frighteningly real. Their very size and power tempt us to try and picture them. But how can we imagine such a different world?

To begin with, visualize the changes in the landscape you would see in front of you should you go back in time; get rid of all the houses and roads, and then all the fields and hedgerows. That just touches the surface. Now replace grass and open ground with ferns and low, palm-like cycads. Convert any trees you can see into conifers – not the familiar plantation-pine types but older species like monkey puzzles – and space them out over the landscape. Pull the birds out of the air, change the noise the insects make and turn up the temperature. Finally, place a herd of enormous, loud reptiles in front of you and watch as groups of alarmingly fast predators stalk them. This book attempts a similar mental exercise, conjuring up the world of dinosaurs. It is not intended to be an encyclopedia, it is an experience.

The trouble is that we are separated from these prehistoric scenes by a staggering long time. Millions and millions of years have passed during which the remains of these magnificent creatures have been scattered, eroded and buried. While mountain ranges have come and gone and oceans have risen up and drained away, a few of these remains became locked in the rocks and turned in stone.

What is a narrative?

Narratives tell a story. In our case it is a story of how scientists have pieced together the evidence from rocks and fossils. It is a scientist’s perspective, built up from layer upon layer of information to construct a scientific model of the Earth’s past.
WORKSHOP ACTIVITY

Planning Narratives: ‘The story of the evolution of different organisms in the Earth’s history - As told by scientists’

There are seven narratives we’ll consider in this workshop:

The story of Stromatolites
The story of Trilobites
The story of Ammonites
The story of Dinosaurs
The story of Glossopteris
The story of the Chimpanzee
The story of the Protea

Additional information is provided on p26 – p39

Consider the following in planning the narrative:

The Earth is in a state of constant change – changes in climate, the atmosphere, the Earth’s crust, vegetation, fauna and flora ….

The ‘arrow of time’ can only move forward; we cannot move back in time or reverse things in the past.

Each happening in the Earth’s history is caused by a unique combination of things that will most likely not happen again.

In preparing for your presentation:

1. Choose one of the seven narratives listed above.

2. Work in a group and decide the format of the presentation – only one speaker, or a group effort. Remember you’ll be telling a story. Elect a scribe who will record the main points, or scaffolds, on a large sheet of paper.
3 Refer back to the introduction of ‘Walking with Dinosaurs’, to give you some ideas on how to construct the narrative.

4 Quickly scan the source material to identify the scaffolds relating to
   • the nature of science,
   • tools scientists use,
   • write down these scaffolds,
   • let each member of the group select scaffolds that they will read about and then briefly explain the information to the rest of the group.

5 Scan the information about
   • the organism that you have chosen,
   • the geological time scale to identify what is relevant.

6 Select the information you’ll use to make the presentation interesting, short and to the point:
   • Think ‘outside the box’ and be innovative.
   • You’ll notice that I have not highlighted any ‘scaffolds’ in the section on ‘additional information about selected organisms.’
   • When preparing your narrative, identify the scaffolds and use them as part of the framework of your presentation.

7 You must also include the following:
   • Explanations of the questions posed in the section on additional information about the organism(s) that you have chosen.
     • What was the Earth like when these organisms lived?
       - where were the continents situated,
       - what was the climate like?
       - how high was the sea level?
       - what did the ‘terrestrial/ land environment’ look like,
       - what other organisms were present.

8 Each group, in turn, will present their narrative and contribute to the ‘Story of the Earth and how Life evolved’.
THE NATURE OF SCIENCE – WHY IS IT IMPORTANT TO INCLUDE THIS IN THE NARRATIVE?

Scientists unlock clues held in fossils and rocks to construct a story of the Earth’s past and how Life evolved.

This is an interesting story, challenging and thought provoking. Knowledge of the nature of science can give us an insight into the processes used by scientists to find out more about what happened in the Earth’s past.

Understanding the nature of science involves, amongst other things, the importance of facts, scientific laws and theories. Therein lies the power of science, but also its limits.

In science we deal only with facts that result from observations about things in the material world that we can see, hear, touch, smell and taste. These facts can be in the form of numbers, words or drawings and diagrams. There are many things that cannot be observed in this way, for example, ‘beauty’ or ‘faith’ which fall outside the scope of science.

Scientific laws are useful in science because they describe a pattern of behaviour and the relationship between things that are being investigated. The pattern is consistent and helps scientists to calculate and derive further facts.

Theories are constructed to explain observations and why things happen the way they do.

What inspires scientists to want to know more?

Here is a suitable example for this workshop:
Walking up a hill you notice a different coloured layer of rock, which contains fossilized sea shells. The fossilized shells look similar but are not quite the same as shells which you found at the sea. Somehow something is strangely different. Furthermore, you now see other similar bands of fossilized shells present in rocks further away.

This is strange, you wonder: ‘How old are these fossils and what are they?’

Scientists use various tools to help them find answers to questions such as ‘how old are these fossils?’

**Radiometric dating** is a tool which scientists use to find the age of rocks and fossils.

### In radiometric dating scientists use the fact that radioactive isotopes decay and form new elements at a known rate.

**Radioactive isotopes decay at a constant rate (with time).** (This is a scientific law based on the fact that all radioactive isotopes show the same pattern of decay – a constant rate of decay.)

Radioactive isotopes of uranium, uranium-235 and uranium-238, decay to form lead-207 and lead-206. This process takes a long time, in the case of uranium-235, it takes 7.1 hundred million years for half the uranium to change into lead. For uranium-238 it takes 4.5 billion years for this to happen.

Certain rocks contain uranium, such as sedimentary rocks which have zircon crystals in them. (You may know zircon/zirconium as gems in jewellery, which are used as substitutes for diamonds.) When these rocks were formed, uranium was incorporated into the zircon crystals, but lead was excluded in the process. At time of rock formation, the crystals contained uranium but no lead.

As time progressed, the radioactive isotopes of uranium started to decay and formed lead which was trapped inside the zircon crystals. By measuring the amount of lead present in the zircon crystals and knowing how long it takes for uranium to decay, the age of the rock can be calculated. Thus, if only a little lead is present, it means that only a small amount of uranium has decayed and the rock is comparatively young in age.

Unfortunately, not all rocks contain zircon crystals, so isotopes of other elements (such as potassium which decays to form argon) are used in the same way to help find the age of the rock.

In order to check the accuracy of dates of the rocks, the information is compared with other methods used to find the age of rocks. This could be looking for the presence of certain types of fossils in the rock or examining at the ages of rocks found above or below the layer tested.

**Older rocks** contain fossils of organisms that lived earlier in the Earth’s history. More **recently formed rocks** contain fossils of organisms of more recent ages in the Earth’s history.
Usually the older rocks are at the bottom with the newer rocks formed on top of them. So the position of the fossils and the rocks with respect to other layers tells us something about their ages. This is another ‘tool’ that scientists use to determine the age of rocks, which is called **stratification** (the geological time scale of the Earth is largely based on this).

Thus an answer to the question about the age of the fossils you saw in the strangely coloured rock is: **by using radiometric dating these rocks are 206 million years old.** The fossils are **identified as ammonites**, ancient snail-like creatures living in the sea.

There may be many more questions about the fossil ammonites:

**Why are these fossils on land and not in the sea?**

**Was the sea level much higher than it is to-day?**

**Was it hotter than it is to-day?**

**What was the climate like?**

**Has the Earth changed or does it look the same as it did many millions of years ago?**

In order to answer these questions we now accept that there is a **complex interaction** between the evolution of life and the change of habitats on Earth. On a global scale this would involve the changes that happen to the climate, the oceans, the continents and the Earth’s crust and how these impact on the evolution and diversity of life.

**Discovery about life in the past involves finding out about prehistoric climate which in turn includes studying the changes that have happened to the Earth’s crust.**

*Jastrow and Rampino (2008) explain this in the following manner:*

‘The **evolution and distribution of life** on Earth is **linked** to the **changing face** of our planet. The idea that the **continents are not fixed in place**, but can **drift** across the Earth’s surface seems as strange now as it did when it was first proposed. Since the 1960s much geological and geophysical information has accumulated to provide clear evidence that the continents move. The **theory of plate tectonics** explains the major features of the Earth, and the history of the Earth’s crust over billions of years. **As plates separate, move and collide, they also affect the oceans and atmosphere. On timescales of millions of years, plate movement is a major cause of climatic change, which in turn has greatly influenced the history on Earth.’ (p 196)
Continents are not fixed in one place but drift across the Earth’s surface.

The theory of plate tectonics assumes that the Earth has a constant surface area. The surface of the Earth is divided into sections called plates. These plates form the outer shell of the Earth’s crust and are on an average about 100 km thick. The moving plates carry the continents with them.

At the boundaries, where the plates move apart, or collide – with one of the plates usually plunging beneath the other plate; earthquakes and volcanic activities happen. In the past, over many millions of years, smaller continents have moved together and even collided, forming a large super-continent. Then split and moved apart again to form smaller different continents. These changes have had a great effect on global climate and life on Earth.

To-day we measure the movement of these plates by using a satellite tracking system, which is very precise. On an average the plates move less than 10 centimetres a year. (Satellite tracking systems are also tools which scientists use in studying the movements of continents.)

The movement of tectonic plates greatly influences the carbon dioxide levels of the atmosphere.
When there is a lot of tectonic plate movement and the ocean floor spreads quickly, caused by volcanic activity at the mid-oceanic ridges, then more carbon dioxide is released.

The amount of carbon dioxide in the atmosphere in turn affects the greenhouse activity of the Earth and how much global heating or cooling will occur.

**How hot or how cold was it in the past?**

| There is a complex interaction between global heating and cooling; the formation of ice sheets at the poles and the global sea levels:  
| low levels of carbon dioxide cause global cooling which in turn causes ice sheets to develop at the poles; and sea levels drop;  
| higher levels of carbon dioxide cause global warming which in turn causes the poles to become free of ice, even forests growing there; and sea levels rise. |

**How do we know this?**

The above pattern emerges when we use **computer generated models** based on evidence from **volcanic activity** (which adds carbon dioxide to the atmosphere) and the formation of calcium carbonates in rocks and shells of marine creatures (removing carbon dioxide from the atmosphere) which happened at specific times in the Earth’s history. (The use of computer generated models is another example of tools available to scientists.)

The graph shown below is based on a computer designed model. The estimates of carbon dioxide content of the Earth’s atmosphere are based on geological information about volcanic activity releasing carbon dioxide and the formation of calcium carbonates removing the gas from the atmosphere. The clear area on the graph shows the range in readings obtained, (from Jastrow and Rampino (2008) p 233).
How much land above sea-level?

The amount of land (terrestrial environment) present would depend on how high the global sea-levels were at a specific time in the Earth’s history. If the sea levels were low then much more of the land and the continent would be exposed to the atmosphere. If the sea levels were high then less land would be visible above the sea. This would usually indicate that the land could be easily flooded by the sea and wetlands and swamps were present.

Fossil shells can tell us about ocean temperatures.

At the moment scientists are involved in drilling for rock samples found beneath the ocean floor. By studying fossils shells in these rock samples, scientists can start to piece together the history of these oceans. They are particularly interested in what fossils are found in which rock layers, giving them an idea about the climate when these rocks were formed.

Certain sea organisms lived in warmer water, others lived when there were ice sheets present and in colder water. What makes this research interesting is that the oxygen isotopes, found in the calcium carbonate that makes up these shells, also tells a story about the Earth’s climate. (Note: the use of oxygen isotopes is another tool scientists use.)

There are two isotopes of oxygen: oxygen-16 and oxygen-18. The presence of more oxygen-16 than oxygen-18 indicates that the shells were formed in warmer sea water. More oxygen-18 present indicates that the sea water was colder with more oxygen-16 locked in the ice sheets.
From this information, it is highly likely than the deep ocean temperature, for example, at the time of dinosaurs roaming the world in the Cretaceous period, was nearly 20 degrees Celsius warmer than it is today at nearly zero degrees.

**How do we know where our continents were situated on the Earth in the past?**

**Paleo-magnetism or ‘fossil-magnetism’** is a useful tool in locating the position of continents in the past. Rocks formed in the past have information about the Earth’s past magnetic fields locked into them.

New rocks, part of the Earth’s crust, form as the tectonic plates move apart at the mid-oceanic ridges. Volcanic activity on land, also gives rise to lava which will solidify into new rock.

As the lava cools, the rocks that form become magnetized showing where the Earth’s magnetic north and south poles were at that time in the geological history of the planet. Rocks formed in the Earth’s past will show magnetic north and south poles pointing in a different direction to where these magnetic poles are today. The age of the rocks and the position of the Earth’s magnetic poles at the time of the rock formation, can be used as part of a computer model to establish the position of the continents at a specific time in the Earth’s history. You’ll see various examples of these computer models in the next section on the geological time scale of the Earth’s history.

Interesting computer generated models of continental drift can be seen on:

- [www.ucmp.berkeley.edu/geology/tectonics.html](http://www.ucmp.berkeley.edu/geology/tectonics.html)
- [www.nature.nps.gov/geology/usgsnps/animate/pltecan.html](http://www.nature.nps.gov/geology/usgsnps/animate/pltecan.html)

**As new data becomes available more and more layers of information can be constructed to build a clearer picture of the Earth’s history and diversity of Life.**

This involves the complex interplay of many different types of information relating to identification of fossils, finding the age of rocks, developing models about the movement of continents and the changes in climate.

**Powerful computers** and **modern technology** have made it possible to develop models of what we think the Earth looked like and how life evolved and diversified in the past.
CONSTRUCTING LIFE SCIENCE KNOWLEDGE

The Geological Time Scale is a time scale of the Earth’s history.

This time scale was already established in the 1800s by William Smith, a geologist. He noticed that when rocks were excavated, certain fossils occurred in specific layers of sedimentary rock. He concluded that if the same fossils were found elsewhere, those rocks, though occurring in different locations, would have been formed at the same time.

This insight allowed him to compare the relative ages of rocks and fossils in different parts of Great Britain (older at the bottom and younger rocks at the top). Geologists then used this information to construct a geological record of the Earth’s history, although they had no idea of how many millions of years the record spanned. It was only when data from radiometric dating became available in the next century, that the time span of the Earth’s history could be established.

The geological time scale is divided into sections, using mass extinctions as their boundaries.

Background Extinction and Mass Extinction

Benton (2003) pp135-6 explains:

‘Extinction is normal. Species do not last forever. Indeed, the average lifespan of a species is perhaps 5 million years, with a range from 100 000 years to 15 million years, depending on what you are, whether a microbe or a flowering plant. Species come and go and, even though the overall diversity of life still seems to be increasing, there is a steady rate of background, or normal, extinction. The background rate of extinctions may be only 10 to 20% …’

Three things happened in all the mass extinctions of the past:

• many species became extinct, generally more than 40 to 50%,
• the species that became extinct belonged to a range of ecologies, including marine; plant and animal forms, microscopic and large organisms,
• extinctions all happened within a short time, related to a single cause or a cluster of linked clauses.

The geological time scale of the Earth’s history

The major divisions of the geological time scale are called eons. The first three eons are grouped together as the Precambrian time which includes 90% of the Earth’s history.
All of the Earth’s history after the Precambrian comprises the Phanerozoic eon – the time of ‘visible life’.

**The Precambrian time is divided into:**

- **Hadean** time meaning ‘hellish’ (4 500 – 3 800 million years ago)
  This starts with the formation of the Earth about 4 500 million years ago. It was so hot that the oceans only formed towards the end of this eon.
  There is little information available about this time in the Earth’s history.

- **Archaean** Eon meaning ‘old’ (3 800 – 2500 million years ago)
  Almost as soon as the earth had cooled enough to allow water to become liquid, the oceans formed. **The Earth was mostly covered by oceans.**
  Life in the form of early bacteria must have started quickly. These were organisms that could survive extreme environmental conditions, such as hot environments, high pressure and salinity.
  Archaebacteria, ancestors of modern bacteria evolved.
  There was little oxygen in the Earth’s atmosphere.
  The earliest forms of life were anaerobic.
  A time of biochemical evolution must have happened, but invisible in fossils.

- **Proterozoic** Eon of ‘earlier life’ (2 500 – 540 million years ago)

Note: volcanic activity, hot and barren land, and shallow seas in which stromatolites grew during the Proterozoic Eon.
The continents began to form.

The diagrams above show what the Earth must have looked like about 650 million years ago.

During the Proterozoic Eon, the African continent and Europe (Laurentia) were in the southern hemisphere. There was a large and growing ice sheet over the South Pole. Only a small amount of land was above sea level (part of it included South Africa).

Oxygen gradually accumulated in the atmosphere and eukaryotic cells developed.

Then multi-cellular organisms such as seaweeds evolved.

By the end of the eon the concentration of oxygen in the atmosphere was similar to to-day.

The Phanerozoic Eon follows (540 million years ago – to-day)
This includes the evolution of all complex organisms that were related to modern plant and animal groups.
There are three eras:

- **Paleozoic era** of ‘ancient life’ (540 – 250 million years ago)
  Animal life proliferated in the sea.

  In the beginning of this era the land was barren.
  At the end of the era the Earth was covered with extensive forests, but no flowering plants yet.

  On land, amphibians and reptiles had evolved.

  The end of the era is marked by the Permian mass EXTINCTION, in which 95% of all species died.
• **Mesozoic era** of ‘*middle life*’ (250 – 65 million years ago)
  On land, **flowering plants evolved**.

  The **dinosaurs** were the largest and most diverse group of vertebrates.

  **Birds and mammals had evolved**.

  The Mesozoic era ended with another **mass EXTINCTION**, when a giant asteroid hit the Earth and 76% of all species died.

• **Cenozoic era** of ‘*recent life*’ (65 million years – to-day).
  A **cooler and drier** Earth was dominated by **flowering plants**.

  **Mammals** were the largest group of vertebrates.
  There have been several ice ages.

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**The Paleozoic era consists of six periods, described below.**

1. **Cambrian period** (540 – 510 million years)
   **Climate**: all life lived in water only.

   **Continents**: no continents near the poles, so ocean currents could circulate freely. No significant ice sheets near the poles.

   **Marine life**: arthropods were represented by trilobites. The first vertebrates were jawless fish. Single-celled and multi-cellular protists, such as seaweeds were the basis of the marine food chain.

   **Life on land**: the continents consisted of bare rock, sand, silt and clay – no evidence of life on land.

2. **Ordovician period** (510 –to 440 million years ago)
   **Climate**: oceans warm around equatorial continents but cool around the southern continents.

   **Continents**: oceans separated the northern continents from the southern continents of Gondwana.

   **Marine Life**: almost all organisms lived in the oceans and freshwaters. Caused by specialization, the diversity of marine animals more than tripled. It was also partly due to the development of the first reefs, formed by sponges creating new habitats to be filled. Most species were invertebrates and the most abundant
group were arthropods, in particular the trilobites. The fossil record also indicates the presence of two groups of molluscs, the Gastropods (snail-like forms such as ammonites) and the Cephalopods (such as the nautilus and squid). The only vertebrates were fish, jawless descendants of earlier fish.

**Life on land:** no clear evidence.

**Extinctions:** the first mass extinction of life happened at the end of this period and 60% of genera and 85% of all species died. Because this mass extinction happened against a background of rapid evolution, it is suspected that a type of global catastrophe (such as volcanic eruptions or an asteroid impact) must have happened.

3  **Silurian period** (440 – 410 million years ago)

**Climate:** of the continents generally warm and moist, except for land masses directly over the South Pole. Some of the southern ice sheets melted and raised the sea level.

**Continents:** continents of Gondwana near the South Pole, the other land masses near the equator.

**Marine Life:** aquatic animals expanded from shallow marine waters into deeper waters and into freshwater. Fishes continued to evolve both jawless and the first fish with jaws.

**Life on Land:** fishes adapted to freshwater habitats. The most noticeable advance was onto dry land. A few invertebrates lived in mud and very small plants (only a few centimeter tall) grew from the mud into the air.

4  **Devonian period** (410 – 360 million years ago)

**Climate:** regions near the equator were warm and wet whilst the southern continents over the South Pole were cold. There is evidence that the oxygen level in the atmosphere rose to 35% (higher than to-day’s 21%). This could have been caused by the extensive growth of plants, producing oxygen. The fossil record indicates that insects in particular, grew very large in size.

**Continents:** there were three continental areas – what is now Europe and North America near the equator, much of it covered by shallow water. To the north was what is now Siberia and to the south Gondwana(land) composed of South Africa, Antarctica, Australia and India.

**Marine Life:** many invertebrates such as trilobites and a great diversity of fish, including lobe-finned fish such as lungfish, a few descendants still live in tropical rivers to-day. The Devonian is described as the AGE OF FISHES.

**Life on Land:** during the Devonian plants evolved from small structures to large
trees up to 10 metres high. In part this was possible because of the presence of vascular tissue that reinforced the stems. These were seedless plants, such as club mosses and ferns, reproducing by spores not seeds. The first leaves evolved. Plants filled the wet areas and for the first time in the Earth’s history, land surfaces became green.

Living between the small plants in the wetlands, were arthropods such as scorpions and spiders. Later, insects, millipedes and centipedes evolved. Amphibians made an appearance in these swamps, having developed from ancestors similar to lobe-finned fish.

**Extinctions:** at the end of the Devonian the second mass extinction happened removing 57% of the genera and 83% of all species died out. The mass extinction happened against a background of ongoing extinction, indicating that changes in climatic conditions (and tectonic plate activity) were the cause.

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This is how the early Devonian landscape looked like.

Carboniferous period (360 – 290 million years ago)
Climate: in the northern hemisphere it was very warm and wet, extensive swamps and shallow seas. To the south Gondwana experienced cold polar conditions.

The Carboniferous continued

Continents: near the equator was Laurasia, consisting of what is Europe and North America to-day. Gondwana(land) was near the South Pole. In the late Carboniferous, Laurasia and Gondwana collided to form a super-continent called Pangaea.

Marine Life: all modern groups of marine organisms existed.

Life on Land: large tree now up to 30 metres high became abundant. In drier upland areas seed plants evolved. Insects such as beetles and dragonflies were abundant. Many were larger than the insects alive to-day which could indicate that the oxygen levels were higher as well. The insects were predators and herbivores that ate plant material were rare. The shortage of herbivores may have contributed to the great accumulation of plant material that finally
became **coal**. The first reptiles appeared.

5 **Permian** (290 – to 250 million years ago)

*From: Jastrow and Rampino (2008), p316.*

**Climate:** was cooler and drier, especially in the interior of Pangaea. Glaciation occurred in the southern part of Gondwana. Then global warming was triggered by volcanic eruptions at the end of the Permian. This was one of the factors that contributed to the mass extinction at the end of this period.

**Continents:** all the continents collided to form a super-continent called **Pangaea**.

**Marine Life:** had reached its greatest diversity to that time. Reefs were common but the trilobite numbers had started to decline. Many species of fishes had evolved in both marine and freshwater environments, including bony fishes, sharks, lungfishes and coelacanths.

**Life on Land:** the tree sized spore-producing club mosses and horsetails that had characterized the coal swamps were now almost extinct. They were
replaced by seed-producing seed ferns and conifers. The drier conditions also encouraged the diversification and spread of reptiles. There were no dinosaurs. There were two groups of reptiles. The diapsids became the ancestors of most of the reptiles we know to-day, as well as the dinosaurs and also the birds. The second group, the synapsids, had mammal-like characteristics like specialized teeth, hair and whiskers – and they were the ancestors of mammals. A nearly complete set of synapsid transitional forms has been found between these ‘mammal-like’ reptiles and mammals.

**Permian mass extinction:** caused the disappearance of 82% of the genera and 95% of all species died out. Geological information about the boundary between rocks formed in the Permian and the next period, the Triassic, is found in China, the Karoo Basin of South Africa and in Russia. This indicates that the mass extinction happened worldwide. However, it required teams from Russia, America and China to work together to obtain precise radiometric dating readings to establish whether these boundary rocks had all been formed at the same time (in fact, 251 million years ago).

Evidence from rocks that show a black coloured band, indicate a lack of oxygen in the atmosphere. (Estimates show that the oxygen level dropped to 15% - from a high of 35% in the Carboniferous period). The ratio of isotopes of oxygen-16 to oxygen-18, also acts as a permanent record of temperature. The worldwide drop in oxygen levels seemed to have been coupled to massive global warming, with an increase in temperature averaging sixteen degrees Celsius.

There was also a shift in the carbon-12 to carbon-13 ratios, indicating a worldwide decrease in plant growth. Fungal spores were very abundant at this boundary, indicating that something killed the plants and that fungal moulds were growing all over them.

During the early Triassic ‘recovery period’ pollen reappeared, from small plants such as club mosses. This period of recovery seemed to have lasted for about twenty million years. Stromatolites, layers of cyanobacteria common in the Precambrian, also reappeared in the fossils record. This suggested that aquatic grazing animals that destroyed the stromatolites in the past had died.

Several causes have been suggested for this catastrophe including severe climatic changes, caused by the collision of continents; an asteroid impact and volcanic eruptions.

McCrae (1999), p142, comments:

‘In the immediate aftermath of the End-Permian Extinction, terrestrial landscapes everywhere must have appeared awfully bleak. Plant and animal life had been truly decimated. Not many species of plant, insect and tetrapod survived this
crisis but those that did found a world of opportunity, a world of emptied niches to exploit.’ He explains further: (I have highlighted the next statement in bold.) ‘A general evolutionary law that seems to hold is that the greater the extinction, the greater the radiation of life thereafter. Indeed the Triassic saw a renewed explosion of terrestrial life forms perhaps unequalled in any other geological period.’

The Mesozoic era is the second of the Phanerozoic Eon and consists of three periods.

1 **Triassic period** (250 – 210 million years ago)

Note: the super-continent Pangaea stretched from the North Pole to the South Pole.

*Climate:* because the super-continent of Pangaea was so large, the middle part of the continent became dry and arid.

*Continents:* by the end of the Triassic the super-continent Pangaea started to separate into a northern part called Laurasia and the southern part Gondwana.

*Marine Life:* the Permian extinction had eliminated some groups and reduced the diversity of other groups. It took many millions of years to recover but then triggered the evolution of many new forms.

*Life on Land:* because of the Permian extinction, there were only a few but common species present on land. The drier interior created opportunities for seed bearing plants, such as *Glossopteris*, to dominate vast forest areas. Vertebrates were small including the early dinosaurs.

*Extinctions:* 53% of genera and 80% of species disappeared. This happened against a background of ongoing extinction caused by climatic changes.

2 **Jurassic period** (210 – 140 million years ago)
**Climate:** with a mild climate, swamps and shallow seas covered vast areas.  
**Continents:** Laurasia and Gondwana moved further apart.  
**Marine Life:** all modern groups of marine life existed. There were large aquatic reptiles in the oceans.  
**Life on Land:** gymnosperms dominated the forests. Dinosaurs, some large, flourished. Fossil records show early birds and a few small mammals.

From: Dawkins (2004), p238.

The Earth in the Upper Jurassic about 150 million years ago, showing how the super-continent of Pangaea had fragmented into Laurasia to the north and Gondwana to the south.

3 **Cretaceous period** (140 to 65 million years ago)

**Climate:** the mild climate continued with swamps and shallow seas covering widespread areas. As the continents drifted further apart, the climate became cooler.

**Continents:** Africa and South America split apart, allowing the southern part of the Atlantic Ocean to form. India split from Gondwana to form a separate continent. The geographical isolation of plants and animals on these newly formed continents increased the evolution of new species in each of these separate areas.

**Marine Life:** all modern groups of marine life existed except for marine mammals such as whales. However, very large aquatic reptiles did exist.
**Life on Land:** flowering plants appeared and angiosperm trees evolved in the tropical areas displacing most of the gymnosperms towards the colder polar and montane areas. This affected the distribution of dinosaurs, particularly those that relied on gymnosperms for food.

Many dinosaur groups started to decline in this period but new types of dinosaurs also evolved indicating changes in habitat and food availability. Mammals were small and only represented by a few species.

**Extinctions:** about 47% of the genera and 76% of the species disappeared at the end of the Cretaceous. Not the greatest mass extinction, but because it occurred comparatively recently, a well documented fossil record is available about this event.

Part of the problem of explaining the Cretaceous mass extinction is that not all groups of organisms suffered the same rate of disappearance. All the dinosaurs and marine reptiles became extinct. Most groups of mammals, amphibians, crocodiles, turtles, insects and land plants survived. The ammonites became extinct but the nautiloids, with a similar ecological role, survived. Extinction rates were far higher on land (about 90% of species) than in freshwater (about 10% of species).

**Was the extinction caused by a gradual decline or by a catastrophe?** The fossil record indicates that at the end of the Cretaceous ferns and their spores were very numerous. Ferns often live in areas where larger vegetation has been removed by a disturbance. This could have indicated a collapse in the food chain. The animals that survived could probably hibernate until food became available again. Plants could have survived adverse conditions as seeds or rootstocks.

In 1980 a proposal by physicist Luis Alvariz suggested that an extraterrestrial impact was the cause of the Cretaceous extinction. The impact itself would have caused dust high into the atmosphere and ignited fires causing smoke, blotting out the sun. The shock to the crust could also have set off volcanic eruptions and tsunamis (tidal waves). Some scientists believe that as the asteroid collided with the Earth, life was wiped out within days. Others estimate that such an impact could have influenced the climate for tens of thousands of years.

Evidence seems to indicate that an interplay of several causes triggered the extinction of life.
The Cenozoic era (of ‘recent life’) is the third era of the Phanerozoic Eon.

It is now divided into the **Paleogene** period (65 – 23.5 million years ago) and the **Neogene** period (23.5 million years ago – to-day).

**Climate:** warm and moist conditions allowed extensive forests to grow even near the North Pole during the Paleogene. During the Neogene the climate became cooler and drier and this caused grasslands and deserts to develop. Periodic ice ages then started.

**Continents:** continued to move apart with the sub-continent of India colliding with the Eurasian continent forming the Himalayas.

**Marine Life:** all modern groups of marine life already existed, including the first aquatic mammals such as whales.

**Life on Land:** the Cretaceous extinction left a world in which many organisms had died, causing many niches (including new niches) to be filled. Not only had the dinosaurs become extinct, but also many types of birds, reptiles and mammals. The conifer forests now occurred in mainly in the colder and nutrient-poor mountain areas of the Earth.

Great diversification of flowering plants made the angiosperms the dominant vegetation. This also resulted in the diversification of insect groups such as
bees, butterflies and flies as they co-evolved with the new species of flowering plants appearing.

As the Earth became drier in parts, grasses spread to these regions giving rise to the vast grasslands that we see in Africa for example.

Mammals evolved into many specialized forms. Certain groups developed into large body forms such as giant rodents, sloths and elephants, for example the mammoths and mastodons. Even some birds were larger than any that exist to-day, with carnivorous birds as tall as 2 metres. These are all extinct to-day. Grazers evolved as the grasslands appeared, taking advantage of new niches that had grass as a food base.

**Extinctions:** towards the end of the Pleistocene epoch (1.64 million –to 10 000 years ago) of the Neogene period, many large mammals became extinct in various parts of the Earth. Though controversial, these extinctions coincide with the arrival of humans in about 50 000 years ago in Australia and 11 000 years ago in North and South America. The large mammals were prime targets for hunters. Smaller mammals suffered lower extinction rates.

Scientist have concluded that a combination of climate change and overhunting caused the extinction of these large animals.

‘As the Earth enters into what many scientists consider the sixth of the mass extinctions, as a result of human activity, the lessons of the Pleistocene extinctions may be essential. Now, as then, it is not necessary to kill many animals in order to drive them to extinction. At the end of the Pleistocene, climate change reduced their habitats and made them vulnerable to hunting. To-day, habitat destruction for agriculture and human habitation is the principal threat to the survival of most threatened species’. (Rice (2007) p 318)
STROMATOLITES

From McCarthy and Rubidge (2005), p115
Fossils of ‘dome’ shaped stromatolites that lived about 2 650 million years ago, in a shallow ‘inland’ sea near Johannesburg.

From: McCarthy and Rubidge (2005), p172.
Stromatolites found in some of the world’s oldest rocks near Barberton, about 3 500 million years ago.
Note the thin layers of rock packed on top of each other.

The environment was probably similar to the coral reefs that we find in our oceans today. However, remember that coral had not evolved yet. Instead that niche was occupied by cyanobacteria or ‘blue green algae’. These bacteria photosynthesized by extracting carbon dioxide from the sea water and releasing oxygen into the water. They formed a ‘slimy mat’. Calcium carbonate, in sea water, then became trapped in the bacterial mat, forming a layer. (How do we know that cyanobacteria were present in the layers?)
With time, layer upon layer formed to give rise to dome-like structures. These ranged from one metre high in shallow waters to about 100 metres in deeper water where there was enough light for the bacteria to photosynthesise. The stromatolites grew to form reef-like structures tens to hundreds of kilometers wide.

Not surprising that so much oxygen was formed over millions of years that the composition of the atmosphere changed.

Most stromatolites disappeared when the cyanobacteria became the food of marine gastropods or snails (check to see when they evolved.)

Stromatolites appeared briefly after the Permian extinction (can you explain why?) Cyanobacteria and their associated stromatolites still exist to-day, apparently unchanged since the Archaean Eon. To-day they only occur where it is too salty for sea snails and other grazing marine animal to survive. Shark Bay in Western Australia is one place where stromatolites still grow.


These cushion-like structures are living stromatolites, which are still found in Shark Bay Australia. They indicate what stromatolites looked like in the past.
TRILOBITES


Trilobites range from the early Cambrian until they faded at the end of the Permian. They were marine arthropods. Although they have been described as 'cockroaches of the ancient seas', they are more closely related to arachnids than insects.

As their name suggests, their body consisted of three lobes. A unique feature of trilobites was the fact that the lens of the eye was made of the mineral calcite, as was their exoskeleton.

They developed different ways of obtaining food. Some were predators, eating annelid worms, others were eaten by early fish and molluscs. Some were scavengers and even filter feeders.

Trilobites were abundant for more than 200 million years of the Earth’s history. They provided a window into the evolution of early life. The fossil record is particularly rich in trilobites because they lived mainly on the sea bed which was a perfect environment for fossilization.

Trilobites were very numerous and ranged in size from a few millimetres to 50 centimetres. Different species evolved a range of body shapes, some smooth and others spiny.

There were thousands of species that appeared and disappeared at various times in the 200 million years the fossil records indicate they existed.
Because they were so plentiful and occurred over a long period of time, they are useful in revealing evolutionary transitions and indicate how speciation occurred. So where speciation occurred, even in small localized areas, the chances were particularly good in locating fossils of many intermediate forms.

Some species of trilobite were wiped out as a consequence of two mass extinctions. (Which are they? And how did this affect the diversity of the trilobite species after the events?)

**AMMONITES**

The coiled shells of the ammonites go back to the fossil records of the Ordovician. They are molluscs, and were closely related to squid and the nautiloids. In the ancient seas they were predators and scavengers, similar to the niches occupied by fish to-day.
The ammonites were abundant and showed a great diversity of thousands of species over a long period of time up to the end of the Cretaceous. In many species there were larger and smaller forms, representing females and males. Such differences in size in living cephalopods is associated with complex courtship rituals, (so what could you conclude?). Ammonites also laid numerous small eggs which hatched into ‘ammonitella’ only a few millimetres in diameter. Their small size suggests that they were part of the plankton living in the surface waters of the sea (how do you think scientists know this?).

The adults of most species had shell diameters from 10 to 60 centimetres, but some could reach the size of 2 metres in diameter.

The habitats in which the ammonites lived, shallow and surface waters, made them vulnerable to mass extinctions (explain why you think this is so). The close relative of ammonites, the nautilus, on the other hand lived in deep water, could tolerate low levels of oxygen, fed on carrion and laid only a few large eggs. It did not become extinct when the ammonites finally disappeared (can you speculate why this is so?).

Many of the species only existed in the fossil record for a short time. Ammonites are widely used as markers for specific rocks belonging to certain periods of the geological history of the Earth.

The ammonites were particularly abundant during the Triassic and Cretaceous. A quarter of the known genera of ammonites evolved during the Triassic but these were reduced to almost extinction at the end of that period. They then evolved rapidly in the next two periods prior to their extinction (which periods and why do you think this happened?).

**GLOSSOPTERIS**

The early land plants such as ferns and club mosses reproduced by means of spores. These plants lived in mostly swampy areas. The first seed-bearing plants appeared in the Devonian but it was during the Permian when the world became drier, that the advantages of bearing seeds instead of spores became apparent.

The seed-bearing plants had an advantage because their method of reproduction allowed them to grow in drier areas. The seed was protected by a strong outer seed covering and a built-in ‘food-store’ for the embryo was also present. This means that the seed could remain dormant during dry periods and then germinate when it rained. Under similar conditions the spores of ferns, for example, would dry out and fail to grow. A further advantage of seeds, was the fact that the stored food gave the seedling a better chance of surviving the first few weeks of its life.

The disadvantage, however, was that these seeds were highly nutritious and were eaten by a number of plant-eating reptiles and insects. Groups of plants developed various ways of increasing the possibility of surviving periodic drying out and preventing all their seeds from being eaten. A group of seed plants, called the cordaites, grew into fairly large trees developed wooden cones that housed the seeds. This group of plants gave rise to the conifers.

About 300 million years ago what is now South Africa started to drift northwards from the South Pole. As the ice sheets melted and disappeared, plants started to colonize the newly exposed land, previously covered by ice.

One such group was the glossopterids. They dominated Gondwana for about 60 millions years. They appeared in the early Permian (about 280 million years ago), diversified and became extinct in the early Triassic (check the effect of extinction on the environment).

Glossopterids occurred in Gondwana only. Fossils records show them to have been present in Antarctica, South America, Australasia, Africa and India.

Glossopterids growing in swampy areas contributed greatly to thick layers of undecomposed organic material that developed in these wetlands. With time these layers turned into coal.


The study of fossilized plant material is complicated.

It is unusual to find a complete tree or even a smallish plant that is fossilized in one piece. Usually leaves are shed periodically and seeds are only formed and shed occasionally to become fossilized. As a result fossils of different parts of the plant are given different names. Thus Glossopteris refers to the different varieties of tongue-shaped leaves, the roots of the same plant belong to another ‘genus’, Vertebraria and the male and female reproductive organs have been assigned to various genera. Unless various parts are found together in one fossilized plants, they are treated as separate entities.
DINOSAURS

The earliest dinosaurs lived during the Triassic when the super-continent of Pangaea stretched almost from North Pole to the South Pole. The single continent Pangaea was situated in the middle of a large ocean covering two thirds of the Earth’s surface. Remember the animals and plants at the beginning of the Triassic were survivors of a mass extinction that had wiped out 95% of all species.

Fossils of the earliest known dinosaurs show that they were small and agile, not the enormous animals that we usually associate with the name ‘dinosaur’. Their bones were strong but light; that they had an upright posture and tails to assist with balance. Thus these early dinosaurs were bird-like in appearance, but with the long tail of a lizard. A jaw with a wide gape, and many sharp teeth completed the picture.

Some controversy exists as to when exactly and how dinosaurs appeared. Generally it is accepted that the first dinosaurs were small, two-legged carnivores appearing around 235 million years ago in the mid Triassic.

Vegetation would have been ferns in wet areas but primitive conifers, including yellow woods (that we find in South Africa) became widespread, eventually forming large forests. Initially, there were no flowering plants so the dinosaurs’ world would be that of greens and browns. Only towards the end of the dinosaurs’ reign did flowering plants appear in the mid Cretaceous. Palms were some of the earliest groups to develop around equatorial regions.

From: Dixon and Matthews (1992), p73
Note; Ankylosaurs from the late Cretaceous of North America. Forest in the background is that of conifers and palms.
During the Jurassic the continent of Pangaea started to break up. However, large herds of herbivorous sauropods, such as *Diplodocus* and *Brachiosaurus* could still wander from the northern parts of Africa to Australia, continents part of Gondwana.

By the end of the Cretaceous groups of unique dinosaurs had started to develop on different fragments or new continents that formed as Pangaea disintegrated. This explains why dinosaurs, such as ‘*Tyrannosaurus rex*’ (which was a late comer appearing at 70 million years ago) are not found in Africa but only in the northern countries such as the United States of America.

**Why were the dinosaurs successful?**

For approximately 135 million years they dominated the Earth. During this long interval of time the Earth’s climate was warm and most of the world had a tropical or sub-tropical climate. Sea levels were up to 200m higher than they are to-day causing large areas of the continents to be submerged beneath shallow seas. Increased volcanic activity caused large amounts of carbon dioxide to form. This means that the carbon dioxide levels were ten times greater than to-day, increasing the greenhouse effect and warmer climate.

Unlike to-day, there were no high mountains present. The air could circulate freely between the equatorial and polar regions. This accounts for the fact that there were no ice sheets at the poles and forests even flourished in these areas.

**The end of the dinosaur reign**

About 80 million years ago the environment started to change again with the rate of sea floor spreading slowing down. The sea level dropped and the shallow seas flooding the land drained back into the deeper oceans. The exposure of more land caused the climate to become cooler and less tropical. The dinosaurs’ habitat was changing. Some scientists believe that at the end of the dinosaurs’ reign many had become too specialized to adapt to the ongoing changes of the Earth’s surface and climate.


*Tyrannosaurus rex* at the end of the reign of the dinosaurs.
THE CHIMPANZEE

The success of mammals
Mammals were well adapted to the cooling world of the Cenozoic Era. One reason could be that they were warm-blooded and better able to survive cooler climates than dinosaurs could. Mammals evolved from mammal-like reptiles, which originated in the Permian. Mammal-like reptiles were the casualties of the mass extinction at the end of the Triassic. For about 200 million years early mammals and dinosaurs lived side by side.

An early nocturnal shrew-like mammal, about 80 million years ago.


A cat-sized early primate active at night and probably also during the day.


The first true mammals were small and nocturnal animals. The night offered safety and food when the dinosaurs were less active. Because mammals were active at night, they were forced to memorize a map of their surrounding as well as identify smells and sounds that could help them find their way around. Larger brain size improved powers of memory and consequently the ability for mammals to survive better. This is an example of the process of natural selection in action.

The evolution of monkeys and apes
Early tree dwellers or prosimians, first appear in the fossils record about 55 million years ago. The prosimians were common for about 20 million years. To-day only a few survive as for example the lorises of Africa and Asia, which are active at night and do not compete with monkeys that evolved later.

Ancestral monkey-like creatures lived in the forests about 35 million years ago. The earliest apes seemed to have appeared at the same time. However, fossil remains of these early apes are scarce.
At about 20 million years ago the fossil record shows a great increase in the diversity of modern-type apes, living in vast and widespread forests.

About 10 million years ago the forerunners of all modern branches of apes (though some of these are now extinct) were present. These ranged from the gibbons (which had refined the arm-swinging mode of travel common in more ancestral apes); the orangutan (larger and heavier than the gibbon, but still primarily a tree dweller) to the chimpanzee (curious and spending much time on the ground, though also at home in trees).

**A dilemma of fossil records**

The fossil record is incomplete. It represents a ‘sample’ of the diversity of life that occurred in the past. A good example is the chimpanzee – no fossils have been found of this ape. A reason could be the habitat of these animals, which is not conducive to fossil formation.

Phylogeny is another source of information which can be used in conjunction with the fossil record. This method uses distinguishing characteristics of specific groups of organisms to construct ‘evolutionary trees’ to show how closely related these organisms are.
Molecular phylogeny is based on the idea that large molecules such as proteins or nucleic acids undergo changes at a constant rate. This is the principle on which the ‘Molecular Clock’ is based. In determining how closely related two primates are for example, the nucleotide sequences of certain parts of their DNA are compared. The fewer the differences in their nucleotide sequences the more closely they are related (or the shorter the time it took for them to diverge from their common ancestor). In effect, this is another biological law which scientists can use to help them understand how life evolved.

From: Krukonis and Barr (2008), p 253.
The relationship between humans and apes.

The two chimpanzee species (Chimpanzee and Bonobo) have a most recent common ancestor (each diverged from this ancestor about 2 – 3 million years ago). These two species are more like each other than any other ape.

Humans, have a most common ancestor with the chimpanzee lineage that we do not share with any of the other apes.

Humans and the chimpanzees separated from this ‘most common ancestor’ between 6-9 million years ago. (Did humans develop from chimpanzees?)
THE PROTEA

The earliest fossils of the *Protea* family appear at about 95 million years ago. Although Gondwana was already splitting up, the *Protea* is found in all the southern hemisphere continents, including India, part of Asia and Central America. This seems to suggest that dispersal of seed must have happened across the relatively narrow seas between the diverging landmasses (why does the Proteaceae not occur in most of the northern countries?).

From: Anderson (1999), p94.

At the end of the Cretaceous the climate was mild, uniformly moist and subtropical. There were subtropical forests present in what is now the ‘fynbos’ region of the southern Cape. These forests consisted of both angiosperm and gymnosperm trees (such as the yellow woods which we still find in this area to-day). There were no ice sheets present over the South Pole.

There has been much fluctuation of climate between wetter and drier and cooler periods in the Cape region (can you suggest why this happened?– the clue is found in glacial and inter-glacial periods). This affected the distribution of forests and the drier fynbos vegetation found in the southern part of the Cape to-day.
About 35 million years the climate became drier and cooler which meant that the forests gave way to drier woodland, containing proteas and other members of fynbos such as ericas. There were several cycles, both of cooler and then warmer climatic conditions, which affected the distribution of proteas. Thus the distribution of proteas expanded when drier climates occurred and then contracted again as subtropical forests were re-established during warmer times. (Why is the identification of pollen in different layers of rock important?)

At about 5 million years ago the fynbos vegetation, including proteas became dominant. There was the first evidence of burnt fossil bones indicating that frequent fires swept through the fynbos vegetation, much as we know it to-day.

The fossil record also indicates that in the last few million years, the animal population in the fynbos area has changed from forest dwellers to grazers such as zebras and various antelope, for example, the springbok (can you suggest why this happened?). A summer-dry, Mediterranean-type climate had been established. The fynbos species including proteas proliferated and diversified.

(Note: Australia has more genera and species of the Proteaceae family than Africa has. However, the genus *Protea* is African, with the majority of species found only in South Africa and, specifically, in the fynbos region of the Cape.)

From: Cowling and Richardson (1995), p7

*Protea cynaroides* – the ‘king protea’.

p50: Without doubt, the onset of recurring fire made possible the development of a summer-dry or Mediterranean-type climate about five million years ago, was the most important impetus for the replacement of forest by fynbos.
WORKSHOP ACTIVITY

With the bi-centenary of Darwin’s birth to commemorate, here are two investigations relating to his voyage around the world and his subsequent development of the theory of evolution by natural selection.

**Darwin’s Finches - ‘Design a Beak’**

You’ll find out more about ‘Darwin’s Finches’ in workshop 2. (Finches are sparrows or ‘mossies’).

The Galapagos Islands which Darwin visited in 1835, are situated near the equator and close to South America. There are many islands, and the flora and fauna are similar, but slightly different on each island. On some islands only one finch species occurs, on other islands more than one species live together. (The species are evolving further even today. Several researchers have studied these birds in the past sixty years.)

Darwin commented in his book ‘the Voyage of the Beagle’ published in 1845:

‘the remaining land-birds form a most singular group of finches, related to each other in the structure of their beaks, short tails, form of body and plumage: there are thirteen species… The most curious fact is the perfect gradation in the size of the beaks in the different species of *Geospiza*...Seeing this gradation and diversity of structure in one small intimately related group of birds, one might really fancy that…one species had been taken and modified for different ends.’ (p361)

![Image of finch beaks]


The original ancestor or ‘one species’ probably migrated from South America Darwin reasoned, and then diversified to give rise to different species.
DESIGN AN INVESTIGATION

Work in a group.
You are provided with

• polystyrene trays
• a pair of scissors
• an assortment of mixed seeds.

Decide on the size and shape of the (‘original’) beak. (Called the original ancestor.)
Draw the outline of the beak in the block below.
You need to cut out two polystyrene ‘beaks’ which you’ll use to pick up the seeds.
Modify (as happens in natural selection) the ‘original’ beak so that each person in the
group has a ‘unique’ beak to work with. Draw these in the block as well.

Organise a ‘feeding competition’ and decide on the rules.
• Is one trial enough, or do you need to repeat the competition?
• Decide on the time allowed – suggest about 30 seconds.
• Decide how you will record the results.

**Your results:**
Record your results in the block below.

Imagine that there is a drought and most plants die. Only these seeds remain. What will happen now?
Test your ideas. What did you find?
Critical thinking:
Why is this investigation an oversimplification of what really happens when natural selection occurs?

Are beak size and shape the only reasons why some birds survive on certain islands?

What about the environment and the availability of different types of niches?

A good reference to consult is:

In studying the process of evolution of life on Earth both the living and non-living components affect the outcome of natural selection.

A second investigation relates to Darwin’s problem in explaining how plants came to colonize the islands of the Galapagos. (This is also covered in workshop 2.)

Darwin had a hunch that seeds were transported by the ocean currents from the South American mainland to the Galapagos Islands. Some seeds survived the salty seawater and germinated to colonize the islands. Many of Darwin’s friends were skeptical.

Darwin set out to show them that this was possible. Fortunately, a formula for making seawater had already been devised (mainly for the use in seawater aquaria).

He soaked various seeds in seawater for different periods of time. He then tested the seeds to find out if they would still germinate.

Also see the following website of the Charles Darwin Trust: www.charlesdarwintrust.org/ and all his publications on www.darwin-online.org.uk

An interesting project.

Again, there are pitfalls to negotiate.
Consider why the use of ‘controls’ would be very important here.
Be careful, it is very difficult ‘to prove’ anything in science.
References


APPENDIX D: WORKSHOP 2 - CONCEPT CARTOONS

1. Coelacanth — a fish out of water?

What do YOU think?

© University of Johannesburg and Tanya van der Walt

2. Galapagos Islands — and Darwin’s Finches

What do YOU think?

© University of Johannesburg and Tanya van der Walt

3. Charles Darwin — a unique scientist

What do YOU think?

© University of Johannesburg and Tanya van der Walt

4. Charles Darwin — the nature of science and religion

What do YOU think?

© University of Johannesburg and Tanya van der Walt
1. Coelacanth – a fish out of water?

We have proof that the coelacanth crawled out of the sea.

Missing links do not live today!

It is the ancestor of tetrapods such as amphibians.

Not a missing link because it is not an air-breathing lung fish.

What do YOU think?
© University of Johannesburg and Maria van der Mark

Workshop 2: Concept Cartoons
Doctoral Research by Maria van der Mark
University of Johannesburg
2. Galapagos Islands— and ‘Darwin’s Finches’

Living things change if the islands where they live change.

Birds with different beak shapes live on different islands.

Only the finches adapted to the different islands— that’s why they are called ‘Darwin’s Finches’.

New islands make new animals and plants.

What do YOU think?

© University of Johannesburg and Maria van der Mark

Workshop 2: Concept Cartoons
Doctoral Research by Maria van der Mark
University of Johannesburg
3. Charles Darwin - a unique scientist

Darwin was an unconventional scientist.

Careful observations will give you all the answers.

Only Darwin’s note-taking was important.

Darwin was an acknowledged scientist - that’s why we accept his theories.

What do YOU think?
©University of Johannesburg and Maria van der Mark

Workshop 2: Concept Cartoons
Doctoral Research by Maria van der Mark
University of Johannesburg
4. Charles Darwin – the nature of science and religion

Evolution of life is the view of scientists only.

Darwin believed in a Creator.

Evolution proves that God does not exist.

I feel I need to know more about evolution.

What do You think?
©University of Johannesburg and Maria van der Mark

Workshop 2: Concept Cartoons
Doctoral Research by Maria van der Mark
University of Johannesburg
APPENDIX E: SOURCE MATERIAL ACCOMPANYING THE CONCEPT CARTOONS

Workshop 2 - Concept cartoons

ISSUES RELATING TO THE TEACHING OF EVOLUTION OF LIFE, SCIENCE AND THE COMMUNITY

PRESENTED by MARIA VAN DER MARK
Content

Introduction

1. Coelacanth - fish out of water?
   Source material Concept cartoon

2. Galapagos Islands - 'Darwin's Finches' Source material Concept cartoon

3. Charles Darwin - a unique scientist Source material Concept cartoon

4. Charles Darwin - the nature of science and religion Source material Concept cartoon

5. Issues - teaching evolution and the community Design your own concept cartoon

Appendix
Introduction

Concept Cartoons

There are four concept cartoons in this set, the fifth concept cartoon you'll design yourself:

1. Coelacanth - a fish out of water?
2. Galapagos Islands - 'Darwin's Finches'
3. Charles Darwin - a unique scientist
4. Charles Darwin - the nature of science and religion
5. Issues - the community and teaching evolution.

The design of concept cartoons

To interpret a cartoon you need

- knowledge about the event,
- to identify and understand different things shown in the cartoon,
- think about why these things were included in the cartoon.

Concept cartoons show a group of people discussing a topic. Each person offers a comment, an opinion or idea. These are shown in the speech bubbles.

The statements in the speech bubbles are usually open-ended.
You may agree with the statement or disagree in part.
Or, you may feel that you need more information because the statement is too tentative to allow you to make up your mind.

Discuss this with your group members, giving reasons for your comments.

Source material is provided to give you background information. Use this as a reference.

At the end, decide how you will respond to each of the statements shown in the concept cartoon. Include explanations to support or clarify your responses.
1. Coelacanth - a fish out of water?

The source material is based on three letters written to 'The Sunday Independent' newspaper in response to an article on the coelacanth.

Firstly, read the letter written by Dr Bernhard Ficker titled 'Something fishy this way comes'.

**Identify the questions he poses.**

Divide the questions among the members of the group.

Now refer to the other two letters written in response to Dr Ficker's letter (see Drs Miller and Ackermann: *Metaphor mischief about coelacanth article* and Dr Whitehead: *Coelacanth definitely not the 'missing link').

See whether you can find explanations in terms of the questions Dr Ficker raises.

Note carefully what type of argument is presented in all the letters. Who do you think is a creationist and who do you think is an evolutionist?

Now look at the concept cartoon and examine the conversation shown in the speech bubbles.

Finally, decide how you would respond to the statements shown in the speech bubbles and then answer the question posed in the title.

**References**


1. Coelacanth – source material

Read the letter below first.

Something fishy this way comes

I found the article “70 years of ‘Old Fourlegs’” (December 28) both intriguing and contradictory.

It reports that the coelacanth’s fossil record “stretches back 380 million years” and “it was assumed that the fish had been extinct for 65 million years”. Who has determined that the coelacanth lived between 65 and 380 million years ago and what measuring techniques were used? These dates seem highly speculative and assumptive to me.

Clarke states that “the coelacanth represents a missing link”. It can no longer be a missing link, as it has now been found. How can it be a ‘missing link’, or a transitional form, when it is exactly the same now as it was 380 million years ago? If it is still living today, it cannot be a transitional form, as transitional forms are supposed to be just that, in transition and no longer in living existence!

If the coelacanth “belonged to a family of fishes that crawled out of the sea”, as Clarke states, why are they no longer crawling out of the sea but living in the outermost caves, canyons and depths of the ocean? What proof does anyone have that they ever crawled out of the sea?

If the fish’s four “legs” represent an evolutionary leap, as Clarke states, why are they no longer doing “evolutionary leaps” with their “legs”?

The coelacanth is now called a “living fossil”. Why is it singled out to be a “living fossil” when there are numerous other living entities that also appear exactly the same in the fossil record?

The article makes reference to Stephan J Gould, the famous evolutionist. Gould himself never described the coelacanth as a transitional form or missing link. He was honest enough to admit in his book The Panda’s Thumb that “The extreme rarity of transitional forms in the fossil record persists as the trade secret of paleontology. The evolutionary trees that adorn our textbooks have data only at the tips and nodes of their branches; the rest is inference, however reasonable, not the evidence of fossils.”

I do not have enough faith to believe that the coelacanth “is our ancestor” as Clarke states and that I evolved out of nothing into a bacteria, and then to what I am now. This is inference and unsubstantiated speculation. This whole coelacanth report strikes me as a very “fishy” story!

Dr Bernhard Ficker
Somerset West

Now read the other two letters on the next pages.
Coelacanth definitely not the ‘missing link’

I agree with Dr. Bernhard Ficker (Letters, January 4) that labelling the coelacanth the “missing link” (Letters, December 28) is rather misleading.

First of all, the link between fish and amphibians had to be descended from air-breathing lung fish – such a fossil, appropriately named in Eskimo-speak to Tiktaalik, was described in 2004 to 2006 from more than 300-million-year-old late Devonian sediments uncovered on Ellesmere Island in the Canadian Arctic, which was once, apparently, in tropical climes.

This proto-amphibian with a robust ribcage had lungs as well as gills and its fins, with basic wristbones and fingers, were supported by muscular structures that enabled it to move on land. Its head and neck, with spiracle holes above the eyes, resemble that of a crocodile rather than a fish. The mixture of fish and tetrapod features prompted Neil Shubin, one of its discoverers, to call the Tiktaalik a “fishapod”.

Marjorie Courtenay-Latimer’s amazing coelacanth, a much more primitive animal still, does not really fit the mould of a would-be amphibian, although it does possess stubby lobes. The question to ask is why have the coelacanth and the crocodile remained relatively unchanged over millennia? The answer: because, it could be said, they both — like the amoeba — perfectly fit their environment.

Dr. DL Whitehead
Cape Town

(A picture of a coelacanth by Alan Taylor)
Metaphor mischief about coelacanth article

Dr. Archer is being mischievous in his criticism (Letters, January 4) of James Clark’s journalistic article on the coelacanth (December 28). The coelacanths comprise a very long-lived group of bony fish, with numerous different species, all but one extinct.

The modern coelacanth is not exactly the same as the one caught in 1938, but it is remarkably similar in ancient, extinct species, particularly in having lobed fins.

It is in this sense that the one known extant deep-water representative is called a “living fossil.” The coelacanth is not unique in having such a designation, as consulting any paleontological textbook will reveal.

Lobed fins are widely believed by those professional paleontologists whose life’s work consists in studying such things, to be the evolutionary precursors to limbs like ours. In this sense, fossil coelacanths represent a “missing link” or “transitional form” between fish and tetrapods. Living coelacanths, are not ancestral to tetrapods, of course, but are similar to and descend from the group of fish that were ancestral.

The fossilised coelacanths lived in a variety of environments, both fresh water and marine. Paleontologists can determine past environments from the nature of the rocks containing the fossils, and can date rocks with a variety of methods, the most common being through the radiative decay of elements such as uranium, thorium, and potassium in their constituent minerals. Of course, there are religious fundamentalists who don’t believe that radiometric dating is valid, but it is based on the same physics as atomic bombs and nuclear power stations, so it manifestly works.

Metaphor allows a journalist to write that coelacanths “belonged to a family of fishes that crawled out of the sea.” There is no direct evidence that any coelacanth species actually colonised land, but lobed-finned fish represent a well-documented step in the evolution of articulated bony limbs that made such colonisation possible (see the journal Nature: December 4, 2008 for a detailed description of just such a transitional form).

Selective quoting of Stephen (not Stephen) J. Gould’s The Panda’s Thumb to misrepresent an important model for interpreting patterns of palaeontological diversity (Punctuated Equilibrium) is just naughty. Anyone seriously interested in understanding the complexities of evolutionary theory should read Gould’s The Structure of Evolutionary Theory before venturing a personal opinion.

Dr. Duncan Miller and Dr. Rebecca Ackermann
Cape Town

(an unidentified researcher measuring a coelacanth caught at a depth of about 100m off Nungwi, northern Zanzibar in July 2008). See a transcript in the appendix.

Note: see a transcript of the letter at the end of this appendix.
2. **Galapagos Islands - 'Darwin's Finches'**

**How did the name 'Darwin's Finches' originate?**

David Lack chose the title 'Darwin's Finches' for his book written in 1947. He introduced the idea of 'Darwin's Finches' to describe how a group of 13 species of finches evolved on the Galapagos Islands. (Note: 'finch' as in the Afrikaans word 'vink').

The finches have developed specialized beaks and this illustrates the fact that evolution is an ongoing process in terms of speciation and adaptive radiation. Darwin collected many different birds, including examples of some of the finches when he visited the Galapagos Islands in 1835.

**The origin of the Galapagos Islands**

The islands lie on a tectonic plate, named the Nazca plate, close to Ecuador in South America. They also lie just south of the Galapagos Rift in the Pacific Ocean. This is an area where new oceanic floor is formed by volcanic activity. New islands arise in the process. It is believed that the finches were original colonizers of the present islands of the Galapagos about three to five million years ago. They must have come from the South American mainland, more than a thousand kilometres away. The islands, not all formed at the same time, were originally made of barren rock and lava and became progressively populated by plant and animal life. The islands themselves are not fixed and steadily move towards the southeast as the tectonic plates change in position.

**Distribution of animals and plants on the Galapagos Islands**

It is interesting to note that not every plant or animal is found on all the islands of the Galapagos. Depending on chance arrivals of animals and plants and the specific habitats present on each island, there is great variety in the distribution of different species found on these islands. Darwin had noted in 1835 that different islands within sight of one another had slightly different looking birds, and in particular the shape of their beaks and their feathers. This was also true of the body shape and size of the giant tortoises found on different islands.

However, most finch species live on more than one island but none live on all islands. No island has its own unique species of finch. The finches have undergone a process of adaptive radiation in two ways. Firstly, by evolving on different islands and secondly, by specializing on different food resources. Different species of finch can live together only if they avoid competition by eating different types of food. Hence they developed various shapes and sizes of beaks.

Today researchers consider both competition and environment are important in the evolution of finch species.

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Workshop 2: Concept Cartoons
Doctoral Research by Maria van der Mark University of Johannesburg
Darwin and the Galapagos Islands

Darwin visited the Galapagos Islands rather late in his five year journey around the world on HMS ‘The Beagle’. Having visited other islands first, he saw a recurring pattern developing in terms of the origin of the island inhabitants. Animals and plants found on oceanic islands in different parts of the world were most similar to those occurring on the closest mainland. The specimens he collected on the Galapagos Islands substantiated this observation. His theory of 'origin of species' came later.

In the 'Voyage of the Beagle' Darwin writes

Seeing this gradation and diversity in structure in one small, intimately related group of birds, one might fancy that from an original paucity (shortage) of birds in this archipelago, one species had been taken and modified for different ends (P361).

Darwin the creationist turned evolutionist

When Darwin started his voyage on The Beagle in 1831 he was a creationist, who believed that species were specially created by a deity (God) and were unchanging with time. This view was called 'special creation' and was widely held in his time.

The evidence that Darwin collected during his voyage, convinced him that species were not fixed and unchanging. However, it was only in 1844 that he started to develop this idea further, leading to the publication of 'On the Origin of Species - By Means of Natural Selection' in 1859.

References


Workshop 2: Concept Cartoons
Doctoral Research by Maria van der Mark University of Johannesburg
3. **Charles Darwin - a unique scientist**

There are many sides to 'Darwin the Scientist'.

**Skills of a scientist**

Keith Thompson (2007) comments

'Not only did Darwin master the skills of observation, description and classification common to all natural history, he applied his gift of critical intelligence to almost every animal and plant group. More than anyone else, he also extended that work into deep analysis and theory.' (p. 267)

As Darwin approached his seventieth birthday, he wrote some notes to his children to tell them what he had done in his life time and who he was (Aydon, 2008 p. 260).

'On the favourable side of the balance, I think that I am superior to the common run of men in noticing things which escape attention, and in observing them carefully ... From my early youth I have had the strongest desire ... whatever I observed, - that is, to group all facts under some general laws. These causes combined have given me the patience to reflect ... for any number of years over any unexplained problem... ,'

**Darwin an acknowledged scientist**

Darwin spent eight years studying barnacles, a group of marine crustaceans. Examining them in minute detail he was surprised to note such variation that the barnacles showed. This lead him to study and describe 10000 varieties of barnacles. He published his classification of barnacles in three volumes. His scientific peers gave him great acclaim and he was awarded the Royal Society's Royal Medal for his work on barnacles. This gave him the credibility and authority as a recognized scientist.

Darwin also established a network of correspondents (to-day we would see this as a scientific community) who supported him as a scientist.

In his correspondence with his cousin, William Fox in 1855 Darwin commented:

'I mean with my utmost power to give all arguments & facts on both sides. I have a number of people helping me in every way', (Aydon, p. 260).

**Darwin as an acknowledged author**

In preparing the three volumes on the classification of barnacles, Darwin developed a writing style reflecting clear and accurate descriptions as well as an ability to craft his hypotheses in a way that was 'modest with tactful common sense' (Stott, p. 253).

His unique contribution to the theory of evolution, was not the idea but the explanation of how evolution works.

Darwin's writing skills were such that he could make his ideas accessible to all who read his books. His book, *On the Origin of Species by Natural Selection*, is almost unique in that he presented a new and revolutionary idea in such a way that it could be understood.
and read for pleasure by those who did not have a background in science. Not surprising that all copies of the first printing were sold on the first day of publication.

Darwin wrote for the general reader of his time. He wrote at a time when there was an educated audience interested in the 'big issues of science'. As Ridley (2005, p3) notes

*Earlier scientists tend to be lost in history. More recent scientists are lost in specialization and technicality.*

**Darwin asked many questions and devised extensive experiments**

*Can seeds survive in seawater and still germinate?*

In March of 1855 (four years before the *Origin of Species* was published) Darwin decided to investigate whether various types of seeds could survive exposure to seawater and still germinate. This was important, because he suspected that the plants on the Galapagos Islands originally came from South America. He wanted to understand how the plants had spread from continent to continent, from island to island by wind, seawater and even on the bodies of birds.

In their discussions about the unique flora and fauna found on the Galapagos Islands, Sir Joseph Hooker, Darwin's close friend questioned whether seeds could survive long periods in seawater and still germinate in new places such as on islands. Darwin set to find out if seeds could survive in seawater and still germinate. He devised a series of experiment no one had ever attempted. His whole household, including his wife and children became involved. (It was most fortuitous that a chemical formula had been developed for making artificial seawater, which Darwin could use in his investigations.)

*His findings confirmed his suspicions about the ancestors of flora on the Galapagos Islands*

They investigated the germination of cabbage, radish and even bird seeds in small bottles, saucers and tanks, filled with the artificial seawater. Everything was labeled carefully, temperatures recorded in various rooms in the house utilized. Darwin supervised the careful daily observation and note-taking made by his the children. Despite the foul smell almost all the seeds germinated between seven to fourteen days, Darwin noted to his disbelieving friend Joseph Hooker.

Darwin also compared his results with those of Miles Berkley, a clergyman and botanist, who had found that one set of seeds still germinated after 56 days. Seeds could travel considerable distances in 56 days they concluded. Thousands of seeds would probably not germinate after such a long spell in seawater, but against all odds a few would and then colonise new shores and islands, such as the Galapagos Islands.
Additional information about some of Darwin's experiments: from *Darwin - His Life and Times*, pp 266-7. (I have highlighted parts in bold).

*When he returned from his voyage, one of the very first papers he presented to his scientific peers had been one that he had read before the Geological Society, entitled 'On the Formation of Mould'. He had maintained his interest in the subject ever since, and after forty years of note-taking and experiment, he had enough material in the portfolio marked 'Worms' to form the basis of one last book. He had no idea whether anyone would want to buy it, but it was a labour of love, and he settled down with pleasure to the task of describing the part that these tiny creatures played in the economy of nature.*

*He tackled the subject in the only way he knew, exhaustively. Worms were animals, and he wanted to know how their abilities and sensations compared with those of other animals. As always, his questions and his experiments went far beyond what would normally be regarded as the appropriate course of scientific investigation. He brought worms into the house and had Emma (his wife) play the piano to them, and Frank (his son) play the bassoon, to see if they responded to music. He shouted at them, blew tobacco smoke over them, and threatened them with a red-hot poker. He went into the garden after dark, and shone red and blue lights into their faces. He offered them salads to see whether they preferred red cabbage to green cabbage, and he eavesdropped on them, studying their sexual behaviour. He tested their intelligence: offering them leaves of different shapes and sizes, and observing the way they solved the problem of manouevring them into burrows. To anyone who did not understand what he was up to, his behaviour would have appeared certifiable. But by the time he had finished he was an honorary worm himself, with an insight into their abilities and their instincts which enabled him to explain for the first time the huge contribution which worms made to the well-being of humanity.*

*The result was a little gem: The Formation of Vegetable Mould. through the Action of Worms, with Observations on their Habitats. It was a publishing phenomenon. Within two years of its publication it had sold 8000 copies (a large number for those days).*

*It was his swan song, and the book summed up the man. It displayed all the qualities that had made him the scientist he was: the total commitment to a problem that had caught his interest; the patience to carry an investigation to a successful conclusion years after it had first been embarked upon; there refusal to be confined by any narrow definition of how a scientific enquiry should be conducted; the ability, amounting to genius, to frame questions, and to make the connections that led to answers.*

**References:**


4. Charles Darwin - the nature of science and religion

I have included various extracts from the references listed below.

Comments from biographers

The Life of Darwin
(From: 'Darwin - A life in Science " pp. 2-3.)
When Darwin conducted his pioneering work, the theory of evolution was ripe for discovery and had been postulated by many others, but this should, in no way, demean the man's achievement. In Darwin, all the factors necessary to develop the idea of evolution came together - a combination of experience aboard the Beagle, imagination, freedom to work and, perhaps most significantly, the influence of a strong family tradition of scientific interest and ability.

Darwin was raised a Christian, trained as a cleric ... Yet, his theory of evolution does not dispute Christianity at its deepest level. Although it certainly destroyed fundamentalist principles and naive Creation myths, evolution is not an atheist doctrine as some would like to imagine.

(From: 'Charles Darwin - His Life and Times', p. 259.)
There was one matter he had never written about in any of his books, and seldom talked about to his friends. This was the nature of his religious beliefs. He had never felt any great need to talk about such matters, because religion had, in truth, never meant very much to him.

(From: 'Darwin's Origin of Species: A Biography', p. 55.)
Tragedy struck in the midst of this quiet domestic activity. No Victorian was ever immune but death in the family hit Darwin and his wife (Emma) deeply. Their second child, the daughter they called Annie, died in 1851 of an unidentified fever, aged ten. She was the apple of Darwin's eye .... Annie's death may have tipped Darwin finally into disbelief. The doctrines of the Bible in which Emma took comfort were hurdles that he could not jump. In a short memoir that he wrote for his and Emma's eyes only, in which he praised Annie's sunny nature, the despair can easily be read. How could a caring, beneficent creator extinguish an innocent child? How could God make a child suffer so?

(From: 'Charles Darwin: His Life and Times', p. 179.)
After her death, he still walked to church with his family every Sunday morning. But he left them at the church door.

(From: 'Darwin's Origin of Species: A Biography", p. 45 and p. 84.)
In 1838 Darwin noted 'Being well prepared to appreciate the struggle for existence ... it at once struck me that under these circumstances favourable variations would tend to be preserved, and unfavourable ones to be destroyed. Here, then, I had at last got a theory by which to work.
This was the essence of Darwin's theory, scarcely to change except in one major point until it was published twenty years later in *Origin of Species* ...

For the moment, (in 1838) Darwin kept this theory secret. He realized the need to be cautious. It may have struck him as too sudden, too dangerous and unorthodox, too much in need of fuller and further reflection. He saw no need to rush into print.

**Controversy**
The tidal wave of comment began almost immediately. Despite all Darwin's carefully amassed evidence, and his repeated invitations to the reader to consider the issues impartially, Victorians found it nearly impossible to accept the idea of gradual change in animals and plants, and equally hard to displace God from the creative process. Yet this volume, and the ensuing debate, placed the issue of evolution before the public in a form that could not be ignored. The essence of Darwin's proposal was that living beings should not be regarded as the carefully constructed creations of a divine authority but as the products of entirely natural processes. As might be expected, there were scientific, theological and philosophical objections from all quarters, often mixed up together .... Should science be allowed to address questions that up until then were the business of theologians?

**Comments by a Scientist and Christian**
(From: *Finding Darwin's God*, pp. 221-2 and p. 292.)

Many of my scientific colleagues would think me crazy to write anything about God.

The world has many religions but just one science, and that tells us something about both. I do not mean, of course, that all scientists agree all the time on all issues. Science thrives on controversy and disagreement. But there is one science, worldwide, in the sense that scientific issues can be addressed by a common set of principles. All scientists use experiment, observation, and analysis to settle scientific issues, and ultimately all subscribe to a final test of their theories in the reality of nature ... This isn't even remotely true for religion ...

What kind of God do I believe in? ... the answer is in the final sentence of *The Origin of Species*:

The grandeur in this view of life; with its several powers having originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed laws of gravity, from so simple a beginning endless forms most wonderful and most beautiful have been, and are being evolved.

Miller concludes: 'I believe in Darwin's God'.

**Comments by prominent science educationists**
(From: Colburn (2006) p. 438 who states:)

Distinguishing between evolution and creation. Similarly, we also distinguish between evolution-organisms changing through time-and the creation of life. Although scientists continue to study possible physical mechanisms for the origin of life, it still remains a separate area from evolution via natural selection.
idea is considerably stronger than that for any idea about the origin of life.

*Distinguishing evolution from historically perceived implications of evolution.*

... people have cited evolution as being an idea supporting atheism as well as evidence supporting God's involvement in the observable world. Our suggestion to readers is to be aware of scientists, science teachers, and others purporting to give scientific ideas about evolution who are actually discussing ideas not technically part of biological education. It must be made clear that they are providing their thoughts and opinions.

In his conclusion, Colburn explains

... while the clergy interviewed here often spoke of God's hand in evolution, that view while reflecting some scientists' personal beliefs- is not open to scientific investigation and hence not part of the scientific world view. This does not mean that the scientific community is atheistic, only that science can take not position on the supernatural.

**Suggestions made by a science educationist**

**Science and Religion are different Worldviews**

(From Reiss (2008) p. 49 who in his summary raises the following points.)

The central argument is that creationism is best seen not as a misconception but as a worldview. The most that a science teacher can normally aspire to is to ensure that students with creationist beliefs understand the scientific position ...

**Effective teaching** in this area can not only help students learn about the theory of evolution, but also appreciate better the way science is done, the procedures by which scientific knowledge accumulates, the limitations of science and the ways in which scientific knowledge differs from other forms of knowledge.

**References**


5. **Issues - teaching evolution and the community**

Design you own concept cartoon.

Work in a group and elect a scribe.

Brain storm all possible suggestions and ideas. The scribe should keep a detailed record of all the information given.

Decide on a possible question or title.
Identify possible characters representing members of the community whose opinions will be reflected in the concept cartoon.

Construct statements, observations or comments made by these members of the community. Remember that the statements should encourage further discussion. The statements appear in the speech bubbles of the concept cartoon.

In your feedback to the other members of the workshop explain how you constructed the concept cartoon.
APPENDIX

Metaphor mischief about coelacanth article

Dr Ficker is being mischievous in his criticism (Letters, January 4) of James Clarke's journalistic article on the coelacanth (December 28). The coelacanths comprise a very long-lived group of bony fish, with numerous different species, all but one extinct.

The modern coelacanth is not exactly the same now as 380 million years ago, but it is remarkably similar to ancient species, particularly in having lobed fins.

It is in this sense that the one extant deep-water representative is called a 'living fossil'. The coelacanth is not unique in having such designation, as consulting any palaeontology text book will reveal.

Lobed fins are widely believed, by those professional palaeontologists whose life's work consists in studying these things, to be the evolutionary precursors to limbs like ours. In this sense, fossil coelacanths represent a 'missing link' or 'transitional form' between fish and tetrapods. Living coelacanths are not ancestral to tetrapods, of course, but are similar to (and descended from) the group offish that were ancestral.

The fossilised coelacanths lived in a variety of environments, both fresh and marine. Palaeontologists can determine past environments from the nature of the rocks containing the fossils, and can date rocks with a variety of methods, the most common being through radioactive decay of elements, such as uranium, trapped in the constituent minerals. (Of course, there are religious fundamentalists who don't believe that radiometric dating is valid, but it is based on the same physics as atomic bombs and nuclear power stations, so it manifestly works.)

Metaphor allows a journalist to "Tire that coelacanths 'belonged to a family of fishes that crawled out of the sea'. There is no direct evidence that any coelacanth species actually colonised land, but lobe-finned fish represent a well-documented step in the evolution of articulated bony limbs that made such colonisation possible (see the journal Nature December 4 2008 for a detailed description of just such a transitional form).

Selective quoting of Stephen (not Stephan) J Gould's The Panda's Thumb to misrepresent an important model for interpreting patterns of palaeontological diversity (Punctuated Equilibrium) is just naughty. Anyone seriously interested in understanding the complexities of evolutionary theory should read Gould's The Structure of Evolutionary Theory before venturing a personal opinion.

Dr Duncan Miller and Dr Rebecca Ackermann
Cape Town.

Workshop 2: Concept Cartoons
Doctoral Research by Maria van der Mark University of Johannesburg
Note: The four concept cartoons appear in APPENDIX D
APPENDIX F: RAW DATA QUESTIONS 1-5 OF QUESTIONNAIRE

Narratives: Question 1 pre-test

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Concept cartoons: totals of five questions

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APPENDIX G: INFERENTIAL STATISTICAL RESULTS

NPar Tests: TOTAL SCORES OVER 5 QUESTIONS
Wilcoxon Signed Ranks Test

Ranks

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a totposttest Post Questions total < totpretest Pre Questions total
b totposttest Post Questions total > totpretest Pre Questions total
c totposttest Post Questions total = totpretest Pre Questions total

Test Statistics(b)

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a Based on negative ranks.
b Wilcoxon Signed Ranks Test

Note: The pre-test and post-test scores of participant 26/2 were 0, leading to the inadvertent exclusion from the statistical procedures, hence N=14 for the concepts cartoons, not n=15.
### NPar Tests: TOTAL SCORES OVER 5 QUESTIONS
#### Mann-Whitney Test

#### Ranks

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#### Ranks

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a  Not corrected for ties.

b  Grouping Variable: group Group

#### Test Statistics (b)

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a  Not corrected for ties.

b  Grouping Variable: group Group
Wilcoxon Signed Ranks Test: QUESTION 1

### Ranks

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<td>Positive Ranks</td>
<td>8.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ties</td>
<td>4(c)</td>
</tr>
<tr>
<td></td>
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<td>Total</td>
<td>19</td>
</tr>
<tr>
<td>Concept cartoons</td>
<td></td>
<td>Negative Ranks</td>
<td>5(a)</td>
</tr>
<tr>
<td>Post_tot_1a - Pre_tot_1a</td>
<td></td>
<td>Positive Ranks</td>
<td>7.75</td>
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<tr>
<td></td>
<td></td>
<td>Ties</td>
<td>2(c)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>15</td>
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</table>

a Post_tot_1a < Pre_tot_1a
b Post_tot_1a > Pre_tot_1a
c Post_tot_1a = Pre_tot_1a

### Test Statistics(b)

<table>
<thead>
<tr>
<th>group Group</th>
<th>Post_tot_1a - Pre_tot_1a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrative</td>
<td>Z</td>
</tr>
<tr>
<td></td>
<td>Asymp. Sig. (2-tailed)</td>
</tr>
<tr>
<td>Concept cartoons</td>
<td>Z</td>
</tr>
<tr>
<td></td>
<td>Asymp. Sig. (2-tailed)</td>
</tr>
</tbody>
</table>

a Based on negative ranks.
b Wilcoxon Signed Ranks Test

### Mann-Whitney Test

### Ranks

<table>
<thead>
<tr>
<th>group Group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre_tot_1a</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Narrative</td>
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<td>20.45</td>
<td>388.50</td>
</tr>
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<td>Concept cartoons</td>
<td>15</td>
<td>13.77</td>
<td>206.50</td>
</tr>
<tr>
<td>Total</td>
<td>34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post_tot_1a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narrative</td>
<td>19</td>
<td>20.32</td>
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<tr>
<td>Concept cartoons</td>
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<td>209.00</td>
</tr>
<tr>
<td>Total</td>
<td>34</td>
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</tr>
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### Test Statistics(b)

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<tr>
<th></th>
<th>Pre tot 1a</th>
<th>Post tot 1a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>86.500</td>
<td>89.000</td>
</tr>
<tr>
<td>Wilcoxon W</td>
<td>206.500</td>
<td>209.000</td>
</tr>
<tr>
<td>Z</td>
<td>-2.029</td>
<td>-1.873</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.042</td>
<td>.061</td>
</tr>
<tr>
<td>Exact Sig. [2*(1-tailed Sig.)]</td>
<td>.051</td>
<td>.066</td>
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</table>

a. Not corrected for ties. b. Grouping Variable: group Group
## Wilcoxon Signed Ranks Test: QUESTION 2

### Ranks

<table>
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<tr>
<th>group</th>
<th>Group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrative</td>
<td>Post_tot_2a - Pre_tot_2a</td>
<td>4(a)</td>
<td>7.63</td>
<td>30.50</td>
</tr>
<tr>
<td></td>
<td>Negative Ranks</td>
<td>7.63</td>
<td>30.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Positive Ranks</td>
<td>12(b)</td>
<td>8.79</td>
<td>105.50</td>
</tr>
<tr>
<td></td>
<td>Ties</td>
<td>3(c)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concept cartoons</td>
<td>Post_tot_2a - Pre_tot_2a</td>
<td>2(a)</td>
<td>2.50</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>Negative Ranks</td>
<td>2(a)</td>
<td>5.00</td>
<td></td>
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<td></td>
<td>Positive Ranks</td>
<td>9(b)</td>
<td>6.78</td>
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<tr>
<td></td>
<td>Ties</td>
<td>3(c)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Total</td>
<td>14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a  Post_tot_2a < Pre_tot_2a  
b  Post_tot_2a > Pre_tot_2a  
c  Post_tot_2a = Pre_tot_2a

### Test Statistics(b)

<table>
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<th>Group</th>
<th>Post_tot_2a - Pre_tot_2a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrative</td>
<td>Z</td>
<td>-1.945(a)</td>
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<tr>
<td></td>
<td>Asymp. Sig. (2-tailed)</td>
<td>.052</td>
</tr>
<tr>
<td>Concept cartoons</td>
<td>Z</td>
<td>-2.527(a)</td>
</tr>
<tr>
<td></td>
<td>Asymp. Sig. (2-tailed)</td>
<td>.011</td>
</tr>
</tbody>
</table>

a  Based on negative ranks.  
b  Wilcoxon Signed Ranks Test

## NPar Tests

### Mann-Whitney Test

### Ranks

<table>
<thead>
<tr>
<th>group</th>
<th>Group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre_tot_2a</td>
<td>Narrative</td>
<td>19</td>
<td>21.00</td>
<td>399.00</td>
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<tr>
<td></td>
<td>Concept cartoons</td>
<td>15</td>
<td>13.07</td>
<td>196.00</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post_tot_2a</td>
<td>Narrative</td>
<td>19</td>
<td>18.84</td>
<td>358.00</td>
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<tr>
<td></td>
<td>Concept cartoons</td>
<td>14</td>
<td>14.50</td>
<td>203.00</td>
</tr>
<tr>
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<td>Total</td>
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<td></td>
</tr>
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### Test Statistics(b)

<table>
<thead>
<tr>
<th></th>
<th>Pre_tot_2a</th>
<th>Post_tot_2a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>76.000</td>
<td>98.000</td>
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<tr>
<td>Wilcoxon W</td>
<td>196.000</td>
<td>203.000</td>
</tr>
<tr>
<td>Z</td>
<td>-2.373</td>
<td>-1.297</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.018</td>
<td>.195</td>
</tr>
<tr>
<td>Exact Sig. [2*(1-tailed Sig.)]</td>
<td>.021(a)</td>
<td>.212(a)</td>
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</table>

a  Not corrected for ties.  
b  Grouping Variable: group Group
**Wilcoxon Signed Ranks Test: QUESTION 3**

### Ranks

<table>
<thead>
<tr>
<th>group</th>
<th>Group</th>
<th>Post_tot_3a - Pre_tot_3a</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrative</td>
<td>Negative ranks</td>
<td>2(a)</td>
<td>2</td>
<td>2.50</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>Positive ranks</td>
<td>5(b)</td>
<td>5</td>
<td>4.60</td>
<td>23.00</td>
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<tr>
<td></td>
<td>Ties</td>
<td>12(c)</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concept cartoons</td>
<td>Negative ranks</td>
<td>2(a)</td>
<td>2</td>
<td>2.75</td>
<td>5.50</td>
</tr>
<tr>
<td></td>
<td>Positive ranks</td>
<td>6(b)</td>
<td>6</td>
<td>5.08</td>
<td>30.50</td>
</tr>
<tr>
<td></td>
<td>Ties</td>
<td>7(c)</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- a  Post_tot_3a < Pre_tot_3a
- b  Post_tot_3a > Pre_tot_3a
- c  Post_tot_3a = Pre_tot_3a

### Test Statistics(b)

<table>
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<tr>
<th>group</th>
<th>Post_tot_3a - Pre_tot_3a</th>
<th>Z</th>
<th>Asymp. Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrative</td>
<td>Z</td>
<td>-1.527(a)</td>
<td>.127</td>
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<tr>
<td>Concept cartoons</td>
<td>Z</td>
<td>-1.831(a)</td>
<td>.067</td>
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</table>

- a  Based on negative ranks.
- b  Wilcoxon Signed Ranks Test

### NPar Tests

#### Mann-Whitney Test

<table>
<thead>
<tr>
<th>group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre_tot_3a Narrative</td>
<td>19</td>
<td>18.29</td>
<td>347.50</td>
</tr>
<tr>
<td>Pre_tot_3a Concept cartoons</td>
<td>15</td>
<td>16.50</td>
<td>247.50</td>
</tr>
<tr>
<td>Pre_tot_3a Total</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Post_tot_3a Narrative</td>
<td>19</td>
<td>17.08</td>
<td>324.50</td>
</tr>
<tr>
<td>Post_tot_3a Concept cartoons</td>
<td>15</td>
<td>18.03</td>
<td>270.50</td>
</tr>
<tr>
<td>Post_tot_3a Total</td>
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<td></td>
</tr>
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</table>

### Test Statistics(b)

- a  Not corrected for ties. b  Grouping Variable: group Group

---

APPENDIX F: RAW DATA QUESTIONS 1-5 OF QUESTIONNAIRE

APPENDIX G: INFERENTIAL STATISTICAL RESULTS
### Wilcoxon Signed Ranks Test: QUESTION 4

#### Ranks

<table>
<thead>
<tr>
<th>Group</th>
<th>Post_tot_4a - Pre_tot_4a</th>
<th>Negative Ranks</th>
<th>Positive Ranks</th>
<th>Ties</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean Rank</td>
<td>Sum of Ranks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>7(b)</td>
<td>8.29</td>
<td>58.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ties</td>
<td>6(c)</td>
<td>5.50</td>
<td>33.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concept cartoons</td>
<td>Post_tot_4a - Pre_tot_4a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td>3(a)</td>
<td>4.83</td>
<td>14.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>11(b)</td>
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<td>90.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ties</td>
<td>0(c)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* a Post_tot_4a < Pre_tot_4a
* b Post_tot_4a > Pre_tot_4a
* c Post_tot_4a = Pre_tot_4a

#### Test Statistics(b)

<table>
<thead>
<tr>
<th>Group</th>
<th>Post_tot_4a - Pre_tot_4a</th>
<th>Z</th>
<th>Asymp. Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrative</td>
<td></td>
<td>-.885(a)</td>
<td>.376</td>
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<tr>
<td>Concept cartoons</td>
<td>Z</td>
<td>-2.395(a)</td>
<td>.017</td>
</tr>
</tbody>
</table>

* a Based on negative ranks.
* b Wilcoxon Signed Ranks Test

### NPar Tests

#### Mann-Whitney Test

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre_tot_4a</td>
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<td>18.87</td>
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</tr>
<tr>
<td>Narrative</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Concept cartoons</td>
<td>15</td>
<td>15.77</td>
<td>236.50</td>
</tr>
<tr>
<td>Total</td>
<td>34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post_tot_4a</td>
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<td>15.05</td>
<td>286.00</td>
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<tr>
<td>Narrative</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Concept cartoons</td>
<td>14</td>
<td>19.64</td>
<td>275.00</td>
</tr>
<tr>
<td>Total</td>
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#### Test Statistics(b)

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<tr>
<td>Mann-Whitney U</td>
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<tr>
<td>Wilcoxon W</td>
<td>236.500</td>
<td>286.000</td>
</tr>
<tr>
<td>Z</td>
<td>-.965</td>
<td>-1.395</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.335</td>
<td>.163</td>
</tr>
<tr>
<td>Exact Sig. [2*(1-tailed Sig.)]</td>
<td>.372(a)</td>
<td>.186(a)</td>
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</table>

* a Not corrected for ties.
* b Grouping Variable: group Group
Wilcoxon Signed Ranks Test: QUESTION 5

<table>
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<th>group</th>
<th>Group</th>
<th>Post_tot_5a - Pre_tot_5a</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrative</td>
<td>Negative Ranks</td>
<td>4(a)</td>
<td>6.63</td>
<td>26.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Positive Ranks</td>
<td>11(b)</td>
<td>8.50</td>
<td>93.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ties</td>
<td>4(c)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concept cartoons</td>
<td>Negative Ranks</td>
<td>4(a)</td>
<td>3.50</td>
<td>14.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Positive Ranks</td>
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<tr>
<td></td>
<td>Ties</td>
<td>5(c)</td>
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<td></td>
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a Post_tot_5a < Pre_tot_5a
b Post_tot_5a > Pre_tot_5a
c Post_tot_5a = Pre_tot_5a

Test Statistics(b)

<table>
<thead>
<tr>
<th>group</th>
<th>Group</th>
<th>Post_tot_5a - Pre_tot_5a</th>
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<th>Asymp. Sig. (2-tailed)</th>
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<tr>
<td>Narrative</td>
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<td>.056</td>
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<td>Concept cartoons</td>
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<td>-.567(a)</td>
<td>.571</td>
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</table>

a Based on negative ranks.
b Wilcoxon Signed Ranks Test

NPar Tests
Mann-Whitney Test

<table>
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<th>group</th>
<th>Group</th>
<th>Pre_tot_5a</th>
<th>Post_tot_5a</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrative</td>
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<td>331.50</td>
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<td>Concept cartoons</td>
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<td>Total</td>
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<tr>
<td>Post_tot_5a</td>
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</tbody>
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Test Statistics(b)

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<th></th>
<th>Pre_tot_5a</th>
<th>Post_tot_5a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>105.500</td>
<td>86.000</td>
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<tr>
<td>Wilcoxon W</td>
<td>196.500</td>
<td>206.000</td>
</tr>
<tr>
<td>Z</td>
<td>-.732</td>
<td>-2.019</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.464</td>
<td>.044</td>
</tr>
<tr>
<td>Exact Sig. [2*(1-tailed Sig.)]</td>
<td>.495(a)</td>
<td>.051(a)</td>
</tr>
</tbody>
</table>

a Not corrected for ties.
b Grouping Variable: group Group
APPENDIX H: RESPONSES TO QUESTION 6

Responses to question 6:

(a) Why do you think that the teaching of evolution of life is controversial?
(b) What can you as a teacher do to address the issue?

Note: /1 denotes that the participant attended the workshop on ‘narratives’
/2 denotes that the participant attended the workshop on ‘concept cartoons’

<table>
<thead>
<tr>
<th>Pre- test response</th>
<th>Post-test response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1(a) Learners believe that God created man and earth (b) Take the learners to places that can make them see that evolution is a fact and that organisms still evolve</td>
<td>(a) Learners can not or do not believe in evolution, they believe in their religion (b) Take the learners to Cradle of Humankind where they can see for themselves evidence of fossils</td>
</tr>
<tr>
<td>2/1(a) No one was alive in millions of years ago (b) Get more facts to be able to explain to learners</td>
<td>(a) It places what happened for species to be what they are – it ignores creation of species by God</td>
</tr>
<tr>
<td>3/1(a) – (b) For now, to show the good of it, but I think I can have more ideas after I got more knowledge about evolution</td>
<td>(a) Because of Religious aspects that world was created like this, but as scientist, we believe that world is not static, keeps on changing now and then (b) Make learners aware that we can compare God &amp; Scientist, we talk of what we can measure &amp; see, but God is beyond of what we can measure</td>
</tr>
<tr>
<td>4/1(a) It is controversial due to the contradicting facts available in different subjects eg bible studies, History and Life Sciences (b) It is important to state the aims of the topic and stick to the LOs of the topic as well</td>
<td>(a) It isn't controversial because evolution is a change occurring as climate, continental drifts occur (b) Give background information on the evolution topic</td>
</tr>
<tr>
<td>5/1(a) Because learners come from different backgrounds eg. other's backgrounds eg Christians; or even cultural beliefs becomes barriers for them to make sense of what is being taught (b) He must detach himself from the topic which will make it easier for learners to detach their cultural &amp; religious beliefs from the topic. He must also try not to impose his views on the topic. He must derive his topic basing his facts on the facts based by the different scientists</td>
<td>(a) We have to address personal issues &amp; cultural &amp; religious issues first (b) Involve learners as much as possible. If they do their own research and findings it becomes interesting &amp; they have to also work as groups and then let the groups debate their findings</td>
</tr>
<tr>
<td>6/1(a) It does not talk about the spiritual life (b) Give pupils enough information about evolution</td>
<td>(a) Creation and evolution (b) Give information</td>
</tr>
<tr>
<td>7/1(a) It is necessary to know how the human developed from thousands of years ago until today (b) We can do research on the issue and teach our learners the importance of knowing about (r)evolution</td>
<td>(a) – (b) We can explain that God is above science and that he can not be measured</td>
</tr>
<tr>
<td>8/1(a) Some believe in a Creator and other in evolution. Religious reasons (b) Explain the different theories in detail and also give back ground on the different people responsible for the theory</td>
<td>(a) Religious issues (b) Be informed as best I could. Have all the background on people and the theories. A lot of study material, models ..</td>
</tr>
<tr>
<td>9/1(a) It is against our belief because we are from the picture of God who have created us. We are not from the bacterias as scientist are saying that (b) It is difficult</td>
<td>(a) We educators are not informative and we mispredict it comparing science and religion (b) Know the difference between science and religion</td>
</tr>
<tr>
<td>Pre-test response</td>
<td>Post-test response</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td><strong>10/1(a)</strong> It is a belief of many people that everything is created by God (b) will let the learners read and study more about evolution</td>
<td>(a) Because some do agree with the findings of the Scientists and some other people do not agree with the Scientists but believe that everything was created by God. (b) I can encourage the learners to read or study more about evolution. They must collect more information from different sources about evolution.</td>
</tr>
<tr>
<td><strong>11/1(a)</strong> Many people have different beliefs – believe in supernatural power (God) but not evolution. Theory of evolution has many gaps; the earth is not 6000 years old. People refer to it as a racist theory (b) As a teacher I can concentrate on content but, not aiming at changing learners beliefs. *Give a chance to my learners to participate in class. *Parents need to be informed of the topic evolution.</td>
<td>(a) Because it is contrary to people’s religions. People believe in the Creator-God. (b) Teach the concept of evolution but not changing people’s or learners’ beliefs.</td>
</tr>
<tr>
<td><strong>12/1</strong>(a) Evolution might not be seen as a “Godly” concept *It does not agree with the Bible or some religious and cultural beliefs. (b) State that the aim of evolution teaching is not to convince but to learn. In other words learners should be informed not to attempt to “erase” their cultural or religious beliefs to accommodate evolution theory hence the word “theory”.</td>
<td>(a) It might be against some Christian beliefs. *Some cultural beliefs are not covered. *It is believed that believing evolution is being “anti-God”. (b) *Indicate that evolution is not studied to change learner’s beliefs. *Indicate that we learn evolution to be aware of the existence of information as Scientists to be of for phenomenal(ogical) investigation.</td>
</tr>
<tr>
<td><strong>13/1</strong>(a) It is controversial with the creation, based on the origin of organism(s) (b) Shall encourage the debate on these issues, e.g. learners. The teacher must give each group a chance to explain their views.</td>
<td>(a) It is controversial because some people (Creationism) believe that every (thing) is created by God. (b) I can encourage learners debate so that at the end, Creationism understanding the evolution of organism(s).</td>
</tr>
<tr>
<td><strong>14/1</strong>(a) It is controversial with the Creation (b) Encourage debate about evolution</td>
<td>(a) It is controversial to other people who believe that God created every living thing. (b) To have a debate about Evolution.</td>
</tr>
<tr>
<td><strong>30/1</strong>(a) Because it only explains some aspects of the origin of species; some of it sounds far fetched! Learners are not quite ready (to) accept different views/Parents counter at home as soon as they talk about it (b) Teach it (at) varsity level when learners are out of the nest (home). They are ready to accept that life might be different from what their parents taught them. They (are) more open to it &amp; more accepting</td>
<td>(a) -Because various religions teach otherwise (Creation) -because it cannot be observed from beginning to end, in one lifetime. It therefore lends its self to a lot of speculation (b) Present the data the best way you know. Communicate to learners that all science started as a theory &amp; as proof and evidence &amp; technology improved as we scientists able to collect more evidence.</td>
</tr>
<tr>
<td><strong>31/1</strong>(a) Can go against religion/ one’s own beliefs and values (b) Remain impartial. Respect all views</td>
<td>(a) Could be very controversial due to religious beliefs. Many do not believe in evolution but the theory of evolution (b) Remain impartial, do not give your views. Take a very neutral stance. They are all beliefs.</td>
</tr>
<tr>
<td><strong>32/1</strong>(a) Because it becomes Science (vs) religion (b) Be in central position between Science and religion</td>
<td>(a) Because there are may theories which explain the beginning of life (b) Treat all issues in a most common standpoint.</td>
</tr>
<tr>
<td><strong>33/1</strong>(a) It is a scientific view of creation and not religious (b) Explain to learners that as we have different religious belief about creation and the creator this is a scientific belief and as we are studying life science we look at what scientists believe. You do not have to believe the same but when answering questions on evolution you are giving scientist’s view</td>
<td>(a) It does not allow for Religious beliefs (b) Teach learners that this is a scientific belief not religious.</td>
</tr>
</tbody>
</table>
34/1 (a) The Bible states that or most religions believe in man as a creation that was not derived from the ape or chimp, or from some organism from the sea.

(b) Introduce the topic of evolution with a little more sensitivity. Allow all opinions to be heard.

<table>
<thead>
<tr>
<th>Pre-test response</th>
<th>Post-test response</th>
</tr>
</thead>
<tbody>
<tr>
<td>15/2 (a) Yes, because it conflict with God believers. And the Scientist theory is based on assumptions (b) I can address the fact that God is the Creator of everything in life. But the Scientist prove beyond doubt how life began.</td>
<td>(a) Because it contradict with the Christians (b) God is the Creator but is because of his Power that will make the Scientist to think, investigate</td>
</tr>
<tr>
<td>16/2 (a) I think it is because it touches some of the religious theories about how life and the earth began (b) Teach evolution from a neutral perspective and always say according to the evidence found by evolutionists</td>
<td>(a) Religion beliefs Cultural beliefs Parental beliefs (b) Show learners that evolution does not replace any belief system</td>
</tr>
<tr>
<td>17/2 (a) I, for one don’t believe in evolution because I am a Christian (b) Evolution should not be done at High School level. It should be done at Tertiary(level) by those who are interested in that study</td>
<td>(a) Little knowledge about evolution or no knowledge at all (b) I will encourage my learners to believe what they believe, but as learners who do Life Sciences, Physical Science &amp; Mathematics they must also know or acknowledge what the Scientists do</td>
</tr>
<tr>
<td>18/2 (a) It is controversial because of people’s beliefs and religion (b) As a teacher I can teach it as it is and allow people or learners’ view points by at the end explain to them that it is important to know and understand this is part of their learning</td>
<td>(a) It is controversial because people have different beliefs. There are those student(s) who(se) beliefs in creation by God. (b) You should make those student who believe in creationism that evolution is the scientist theory or views and they have to learn and understand that</td>
</tr>
<tr>
<td>19/2 (a) Other religious beliefs, believe that life is subjected by the will of God (Super Being) (b) To be as open-minded and sensitive as possible</td>
<td>(a) Some Christians have strong views about God being the Supernatural Being – the creator of everything (b) That science does not have all the answers to all the problems. God is beyond science</td>
</tr>
<tr>
<td>20/2 (a) Religious beliefs (b) Address misconception between religion and evolution</td>
<td>(a) Because the Creationist who believe that God created the earth in 6 days and there is no change (b) Use cartoon activities</td>
</tr>
<tr>
<td>21/2 (a) There are still many gaps in the explanations *The earth is still 6000 years old (b) *Lots of research still has to be done *Evolution Centres be visited</td>
<td>(a) Some questions are left (un)answered *The earth is just 6000 years old *A serious gap in Periods and Age of organisms (b) Research more *Analyse concepts clearly *Make use of DVDs if available</td>
</tr>
<tr>
<td>22/2 (a) There is a lot of information that does not click (b) -</td>
<td>(a) Some/ most of the evidence is not convincing (b) Explain the misconceptions on evolution</td>
</tr>
<tr>
<td>23/2 (a) Because is still difficult to separate this from our own belief of origin of life (b) To deal with it in class as a theory like any other theories of science and not linked to any religion. Also to indicate to learner ....</td>
<td>(a) Evolution is new content in our curriculum so the(re) is a difficult distinction between it and religion (b) To treat it as a theory of science like other theories and avoid putting your opinion. And explain that evolution says nothing about God</td>
</tr>
<tr>
<td>24/2 (a) Very controversial to our religious beliefs (b) Difficult to teach the learners cannot be separated to our religious belief and has too much arguments</td>
<td>(a) It is controversial to our religious beliefs (b) Evolution does not replace God as (we) know that according to the Bible God is the Creator of all creatures. But is just a collection of information brought (about) by different scientists</td>
</tr>
</tbody>
</table>
25/2(a) It is very controversial because you have to accommodate all the learners of all religions. Evolution fight with the religions
(b) I will first ask any learners about their religion and what they know concerning their religion when (it) comes to the birth of the earth

(a) Is because when (it) comes to the changes that happen then (it) is that person is made by God's image but evolution ways that a person is made from the chimpanzee that involves apes and the apes made Human beings
(b) I will tell my learners that I'm not going to crash their belief but I want to tell them evolution (changes) of life

26/2(a) Because it evoke multi-cultural activities of people
(b) I can firstly ask learners to give their misconception about the topic

(a) It clashes with what we believe in. Our country is multi-racial
(b) Allow learners views with respect towards each other

27/2(a) The fact that humans share the same ancestors with monkeys/ chimpanzees creates confusions especially to Christians who believe that man is a creation of God
(b) Explain to learners that science and Christianity are two different theories and that the two cannot be combined. Explain that evolution is based on evidence that is available today
Assure learners that they are not forced to believe what evolution says

(a) Students got confused by the fact that humans come form a common ancestor with chimpanzees
(b) - First deal with misconceptions
   - Explain that scientists’ focus is on theories, investigations, evidence, facts
   - Teaching of evolution does not force them to abandon their Christian belief. Learners only need to learn what scientists have discovered
   - Christianity and Science are two different theories

28/2(a) It is controversial since most of the facts cannot be proved. Who is our common ancestor?
(b) We need to deal (with) it in class as theory

(a) Because we have creationists and evolutionists who have different opinions about evolution. Creationists believed in Superbeing – creating the Earth and everything on it. Evolutionists believed that everything evolved from common ancestor
(b) Should treat it as a theory do not discuss any issues that can destruct learners from their beliefs

29/2(a) Various religions. It is a challenge
(b) Focus on evolution as a concept not involve religion to it

(a) One has to consider various beliefs that learners have
(b) Explain what evolution is and what religion is and focus more on evolution as a concept to be studied for their own benefit (careers)
APPENDIX I: CONCEPT CARTOON DESIGNS FROM WORKSHOPS

[Image of a cartoon illustration with text and doodles related to evolution and religion debate.]

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APPENDIX I: CONCEPT CARTOON DESIGNS FROM WORKSHOPS 337
APPENDIX I: CONCEPT CARTOONS DESIGNS FROM WORKSHOPS

**APPENDIX I: CONCEPT CARTOONS DESIGNS FROM WORKSHOPS**

APPENDIX I: CONCEPT CARTOONS DESIGNS FROM WORKSHOPS

RELIGIOUS vs. EVOLUTIONARY

1. TRADITIONAL HEALER
   - Fossils and bones are used to predict the future and medication

2. MINISTER OF THE CHURCH
   - Everything existing is created by God for a specific purpose

3. PARENTS
   - Evolution of life is the view of learned people

4. LEARNERS
   - I am not sure as whether to believe in evolution or the creator
**APPENDIX I: CONCEPT CARTOONS DESIGNS FROM WORKSHOPS**

**PROBLEMS THAT COULD BE EXPERIENCED BY LEARNERS WHILE STUDYING EVOLUTION**

* Meaning of Evolution
  * Change of species over a long period of time.

* What are the benefits of studying Evolution?
  * Career-wise
  * Knowledge

* Is Evolution there to replace Religion?
  * No, cannot compare Ev. & God

* Do human beings also evolve?
  * Yes → E.g. chimpanzees evolved from apes → humans.

**What are Fossils?**

* Remains of organism existed in the past.
VISITING CAVERNS

1. Traditional healers visiting caves in connection with their ancestor and traditional medicine.

2. Ordinary people visiting caves for receiving their healing.

3. Students for educational purposes: Palaeontologist preserving our caves as it provides evidence of evolution in the form of fossils;

   Geologist: studying types of rocks

   Indigenous resources useful for the purpose of research.

   Tourist: creating jobs (as guides) and looking at fossils.

   In general, educating all people visiting the caves preserve it for future generations and also to bring to their attention knowledge of evolution especially fossils as they are found in caves in SA.
Is the earth the creation of God, or is it as a result of evolution?

- God created earth in the beginning.
- Multicellular organisms have complex structures that cannot originate from nowhere.
- Fossil evidence proves that organisms changed forms over a period of time.
- Continental drift...
THE CHIMPANZEE

1. What is a Chimpanzee?
   * Primates, but not monkeys

2. Origin of the Chimpanzee
   * Evolved from manual-like reptile
   * Niche originated in Pliocene period
   * The first primate

3. Species
   * Two species exist: Pan troglodytes
   * Humans are closed relatives

Habitat

* Are terrestrial mammals

Structure

* Most small, had large brain size
* Trailed them to survive, improve memory and identify smells and sounds

Fossil Record

* No fossil record
* Phylogeny can be used to trace information

Chimpanzee

* Earliest mammals, ancient apes, Central West Africa
* Nocturnal, active at night
1. 35 MY: Paleocene Epoch
2. 20 MY: Fossil shows diversity of modern types of apes
   * 10 MY: Gibbons, arm-swingers
   * Orangutans, tree dwellers
   * Chimpanzees, ground
3. Warm, moist, forest
   * Continental drift
4. 35 MY: Today, only evolved from one species to another
5. Humans & Chimpanzees most common ancestor
   * Than any other apes
FRAME WORK

1. What is a chimpanzee?
   - It is a mammal which had evolved from monkey-like creatures which lived in the forests about 35 million years ago. The ancient ancestor is a small nocturnal animal.

2. When did they originate?
   - Chimpanzees originated in the Permian period about 260 million years ago.

3. How did the Earth look like during the times?
   - The Earth was cool, with plenty of forests.

4. How long did they live?
   - Though chimpanzees are still living, the actual ancestor mammal-like reptile lived only until Triassic period. They lived only for about 200 million years.

5. What happened to them?
   - They evolved from nocturnal reptile to day-active mammal to the modern primate.

CHIMPANZEE

- They existed during the Cenozoic Era about 20 million years ago.
- Conditions were warm and moist and suited the warm-blooded mammals.
- Then it cooled down and the dinosaurs died, and the mammals remained.
- Mammals are from mammal-like reptiles from Permian.
- Ate at night when dinosaurs were inactive, and had larger brain size. They were memorizing the landscape. Monkeys and Apes evolved...
Over 90 million years ago the Protea family appeared. Due to the continental drift of the Gondwana landmass, the climate of the region underwent significant changes. The fluctuation in climate affected the distribution of the forests and the drier fynbos vegetation. The distribution of Protea expanded during the wetter climate and contracted during drier periods. The first evidence of burnt fossil leaves indicates fires which swept the fynbos vegetation. Mediterranean climates resulted in the establishment of Protea, and also the animals that adapted to this environment, such as Springboks and elands.
APPENDIX J: NARRATIVES DESIGNED DURING WORKSHOPS

346
PROTEA

• What? • Where?
  - Flower + (India, Asia) South America
  - Southern hemisphere

• Earliest record
  - 95 million years ago

• Earth look like?
  - Cretaceous period - climate < moist subtropical
  - Dominated by flowering plants

• Happened
  - Continents already splitting
  - No ice sheets present S-pole
  - 35 million years - climate < cooler - proteas
  - Warmer - dryer climates = expands distribution
  - 5 million - proteas established

GLOSSOPTERIS

1. What is glossopteris?
   - Refers to different varieties of tongue-shaped leaves

2. Which period did it appear?
   - Early Permian period about 280 Mya

3. How was the climate during the Permian period?
   - Climate was cooler and dryer and glaciation occurred in the Antarctic
   - The glossopteris diversified

4. Which period did they extinct?
   - Early Triassic period because global warming was triggered by volcanic activity which lead to mass extinction

5. Where does it found?
   - Swampy areas in the wetlands of South America
Triassic Period

- Time line. (250-210 million)
- Continent (Pangea) (End of 2 continents)
- Climate
- End of period 2 continents
- Marine life
- On land - Glossopteris
  - Mammal - Reptiles
  - Early dinosaurs
    - Small (Coelophysis)
  - Vegetation spars
  - Large variety of carnivors compared to herbivores
DINOSAURS

- **What are Dinosaurs**
- Small reptiles with two legs, upright posture
- Bird-like in appearance
- Jaw with large gap, sharp teeth
- Their habitats - plains, savannas, jungles
- They were found in the vegetative areas, ferns, primitive conifers
- Climate was warm and moist tropical and subtropical climate

- Why were the dinosaurs successful
- Climate was warm and moist tropical and subtropical climate
- Increased volcanic activity caused large amounts of carbon dioxide to form - no high mountains, pressure air could circulate freely between equatorial and polar regions.

- End of Dinosaurs
- Change of environment 80m lyr
- Sea levels dropped
- Seas flowing the land drained back into the deeper oceans

EXPOSURE OF MORE LAND

CAUSE CLIMATE TO BECOME COOLER AND LESS TROPICAL

HABITAT CHANGES

MANY BECAME SPECIALITIES TO ADAPT TO THE ONGOING CHANGES OF THE EARTHS SURFACE AND CLIMATE
5.5.1.2 Discussion of the ‘nature of science’ - fact, law and theory

Included in the source material was information about the ‘nature of science’ and the methods used by scientists to find out more about the Earth’s past. Too much information was deliberately given in the workshop material. This was done to encourage discussion about the selection of suitable information and thus to acquaint the teachers with important knowledge which they could use in the follow up activities, which is shown in Figure 5.7. The workshop material was also designed to serve as a source of information, which teachers could refer to at a later stage, when preparing their own lessons.

Figure 5.6 Source material outlining information about the nature of science involving ‘fact’, ‘law’ and theory (p. 252)

Figure 5.7 Structuring information about the methods that scientist use to find out more about the Earth’s past

5.5.1.3 The construction of narratives

A video showing the introduction to ‘Walking with Dinosaurs’, a TV series telling the story of the evolution of dinosaurs, was used to illustrate how ‘narratives’ could be presented in an interesting scientific context. Because it was a new experience for teachers to design such a narrative, an example of how to structure a narrative, based on the information in the source material (see
Comparing the pre-test responses for question 2 between E1 and E2, the Mann-Whitney U Test showed a statistically significant difference between E1 (Md = 2) and E2 (Md = 1), U = 76,000, z = -2.373, p = 0.018, r = 0.407 and a medium effect size.

The null hypothesis, H07, was rejected and it was concluded that there was a statistically significant difference between the responses of E1 and E2 to question 2. Based on these responses to question 2 it was highly probable that these two groups, E1 and E2, were derived from two different populations of teachers.

Both question 1 and question 2 dealt with a similar topic exploring the relationship between evolution and environmental change or the changes that the Earth has undergone. These topics were presented in the workshop on ‘narratives’ (Figure 6.5) and the workshop on ‘concept cartoons’ (Figure 6.6). The examples given below illustrate how the concepts are dealt with in different ways in these two workshops.

Figure 6.5 The construction of ‘narratives’ involved the idea of ‘change’ in both the Earth/environment and that of life (p. 250)

Figure 6.6 Shows a concept cartoon exploring the relationship between the emergence of new islands and new forms of life (p. 294)
The story of the trilobites’ and ammonites’ adaptations to new environments and their ability to fill new niches created by the impact of mass extinctions on life, formed an important part of the knowledge necessary to answer the question well (Figure 6.7). The null hypothesis $H_05_{\text{question3}}$ was not rejected and the effect size of the intervention was ‘small’, which indicated that the intervention had had little impact on the teachers’ ability to deal with the idea of mass extinctions.

The last two questions of the questionnaire were designed to separate the effect of the intervention dealing with narratives and the effect of the intervention dealing with concept cartoons.
Given below are examples from both the interventions to illustrate the opportunities created in the interventions for encouraging group discussion amongst the teachers about ‘Darwin as a scientist’. Figure 6.9 and Figure 6.10 show the information given about the topic in the workshop on concept cartoons.

**Figure 6.9** The concept cartoon which was used to encourage discussion about Darwin as a scientist (p. 295)

**Figure 6.10** Part of the background information on Darwin as a scientist (p. 306)
**WORKSHOP ACTIVITY**

With the bicentenary of Darwin’s birth to commemorate, here are two investigations relating to his voyage around the world and his subsequent development of the theory of evolution by natural selection.

Darwin’s Finches - ‘Design a Beak’

You’ll find out more about ‘Darwin’s Finches’ in workshop 2. (Finches are sparrows of miniature).

The Galapagos Islands which Darwin visited in 1835, are situated near the equator and close to South America. There are many islands, and the flora and fauna are similar, but slightly different on each island. On some islands only one finch species occurs, on other islands more than one species live together. (The species are evolving further even today. Several researchers have studied these birds in the past sixty years.)

Darwin announced in his book, ‘The Voyage of the Beagle’ published in 1843, ‘the resulting land-birds form a small regular group of finches, related to each other in the structure of their beaks, short tails, form of body and plumage; there are thirteen species... The most curious fact is the perfect gradation in the size of the beaks of the different species of Geospiza... Seeing this gradation and diversity of structure in one small intimately related group of birds, one might really fancy that... one species had been taken and modified for different ends’ (p.361).

The introduction to the narratives workshop with some incidental discussion about Darwin as a scientist (p. 287)

**Question 5:** Explain how ‘Darwin’s Finches’ found on the Galapagos Islands, illustrates that evolution is a fact; evolution is a theory; evolution can be a law.

**Table 6.6 A statistical analysis of the data from question 5**

<table>
<thead>
<tr>
<th>Group</th>
<th>Median</th>
<th>n</th>
<th>z</th>
<th>p</th>
<th>Significant</th>
<th>r</th>
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<td>E1 (Narratives) Hypothesis</td>
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<tr>
<td>E2 (Concept cartoons)</td>
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Comparing the post-test responses to question5 between E1 and E2, the Mann-Whitney U test showed a statistically significant difference between E1 (Md = 3) and E2 (Md = 0), U = 86,000, z = -2.019, p = 0.044, r = 0.401 and a medium size effect.
6.2.5 Findings and answers to research questions 1, 2 and 3

The statistical analyses established that both interventions, the use of narratives and of concept cartoons, significantly improved the teachers’ ability to answer the questions of the questionnaire using higher-order level thinking skills. However, it is worthwhile to re-examine the wording of the first two research questions:

**Research Question 1**

How will the design of a narrative, about how scientists construct the story of the evolution of organisms on Earth, encourage teachers to display higher-order thinking skills?

**Research Question 2**

How will the use of concept cartoons generate discussion about issues relating to evolution of life, and, of science and religion, encourage teachers to display higher-order thinking skills?
The second set of responses is from teacher/participant 26/2

Pre-test scores: 0+0+0+0+0=0
Post-test scores: 0+0+0+0+0=0

Aim for attending the workshops:
The main aim of attending this workshop is to share ideas with colleagues and present my judgment about the misconceptions I have concerning evolution. Secondly, I wanted to gather information so that I can easily handle and solve learners' problems with confidence. How to present this evolution effectively.

Question 1: What can we learn from evolution of life and the changes that the Earth has undergone in the past?

Question 1 Pre-test:
We can learn that some animals or plants have vanished without trace.
It challenges our beliefs and culture about certain things.
It tells us about the importance of researchers or scientists about changes that they have brought (about). It never leaves God behind he is our creator.

Question 1 Post-test:
I have learnt that because of the different beliefs and multi-racial, this topic must be treated with care and should not aim to changing learners' mind. After explaining the sub-topic, not the content, you may ask learners to give their view, according to how they were raised and what they think in relation to other cultures with (due) respect.

The second set of responses is from teacher/participant 26/2 continued

Question 3: What evidence do we have that mass extinctions happened in the past?

Question 3 Pre-test:
There are animals that we only see in pictures (black and white). Geographically changes that take place in stones, erosion..

Question 3 Post-test:
- Pictures of dinosaurs
6.3.7.1 The importance of a connecting factor in ‘world view’ theory

George (1999) also stated that the seven separate ‘universals’ needed to be connected in order to create a holistic picture of the worldviews. A rather ‘tongue in the cheek’ interpretation gave a clue to a possible connecting factor, shown in Figure 6.23.

When considering all the ‘universals’ there seemed to be a conflict between, for example, ‘evolution’ and the ‘church’, and, ‘science’ and ‘religion’. A possible connecting factor was ‘conflict causes confusion’, which was the interpretation shown by the authors of the concept cartoons shown in Figure 6.24.

‘Conflict and confusion’ may also act as barriers to the understanding of evolution. Linking some of the barriers to the understanding of evolution, ‘conflict’ may then be caused by a lack of knowledge, in particular knowledge of the nature of science.

The ideas of ‘barriers’ and ‘worldviews’ can be linked to show how certain teachers experience difficulty in understanding and accepting the scientific explanations of the evolution of life and the geological history of the Earth. In answer to research question 4, concept cartoons can be a useful
THE NATURE OF SCIENCE – WHY IS IT IMPORTANT TO INCLUDE THIS IN THE NARRATIVE?

Scientists unlock clues held in fossils and rocks to construct a story of the Earth’s past and how Life evolved.

This is an interesting story, challenging and thought provoking. Knowledge of the nature of science can give us an insight into the processes used by scientists to find out more about what happened in the Earth’s past.

Understanding the nature of science involves, amongst other things, the importance of facts, scientific laws and theories. Therein lies the power of science, but also its limits.

In science we deal only with facts that result from observations about things in the material world that we can see, hear, touch, smell and taste. These facts can be in the form of numbers, words or drawings and diagrams. There are many things that cannot be observed in this way, for example, ‘beauty’ or ‘faith’ which fall outside the scope of science.

Scientific laws are useful in science because they describe a pattern of behaviour and the relationship between things that are being investigated. The pattern is consistent and helps scientists to calculate and derive further facts.

Theories are constructed to explain observations and why things happen the way they do.

What inspires scientists to want to know more?

Here is a suitable example for this workshop:
Walking up a hill you notice a different coloured layer of rock, which contains fossilized sea shells. The fossilized shells look similar but are not quite the same as shells which you found at the sea. Somehow something is strangely different. Furthermore, you now see other similar bands of fossilized shells present in rocks further away.
This is strange, you wonder: ‘How old are these fossils and what are they?’

5.5.1.2 Discussion of the ‘nature of science’ - fact, law and theory

Included in the source material was information about the ‘nature of science’ and the methods used by scientists to find out more about the Earth’s past. Too much information was deliberately given in the workshop material. This was done to encourage discussion about the selection of suitable information and thus to acquaint the teachers with important knowledge which they could use in the follow up activities, which is shown in Figure 5.7. The workshop material was also designed to serve as a source of information, which teachers could refer to at a later stage, when preparing their own lessons.

![Figure 5.6 Source material outlining information about the nature of science involving 'fact', 'law' and theory (p. 252)](image1)

![Figure 5.7 Structuring information about the methods that scientist use to find out more about the Earth’s past](image2)

5.5.1.3 The construction of narratives

A video showing the introduction to ‘Walking with Dinosaurs’, a TV series telling the story of the evolution of dinosaurs, was used to illustrate how ‘narratives’ could be presented in an interesting scientific context. Because it was a new experience for teachers to design such a narrative, an example of how to structure a narrative, based on the information in the source material (see
Comparing the pre-test responses for question 2 between E1 and E2, the Mann-Whitney U Test showed a statistically significant difference between E1 (Md = 2) and E2 (Md = 1), U = 76,000, z = -2.373, p = 0.018, r = 0.407 and a medium effect size.

The null hypothesis, $H_{07^{\text{question2}}}$, was rejected and it was concluded that there was a statistically significant difference between the responses of E1 and E2 to question 2. Based on these responses to question 2 it was highly probable that these two groups, E1 and E2, were derived from two different populations of teachers.

Both question 1 and question 2 dealt with a similar topic exploring the relationship between evolution and environmental change/or the changes that the Earth has undergone. These topics were presented in the workshop on ‘narratives’ (Figure 6.5) and the workshop on ‘concept cartoons’ (Figure 6.6). The examples given below illustrate how the concepts are dealt with in different ways in these two workshops.

![Figure 6.5 The construction of ‘narratives’ involved the idea of ‘change’ in both the Earth/environment and that of life (p. 250)](image)

![Figure 6.6 Shows a concept cartoon exploring the relationship between the emergence of new islands and new forms of life (p. 294)](image)
The story of the trilobites’ and ammonites’ adaptations to new environments and their ability to fill new niches created by the impact of mass extinctions on life, formed an important part of the knowledge necessary to answer the question well (Figure 6.7). The null hypothesis $H_{05 \text{question3}}$ was not rejected and the effect size of the intervention was ‘small’, which indicated that the intervention had had little impact on the teachers’ ability to deal with the idea of mass extinctions.

The last two questions of the questionnaire were designed to separate the effect of the intervention dealing with narratives and the effect of the intervention dealing with concept cartoons.
Given below are examples from both the interventions to illustrate the opportunities created in the interventions for encouraging group discussion amongst the teachers about ‘Darwin as a scientist’.

Figure 6.9 and Figure 6.10 show the information given about the topic in the workshop on concept cartoons.


There are many sides to ‘Darwin the Scientist’.

Skills of a scientist

Kendrick-Thompson (2007) comments:

‘Not only did Darwin master the skills of observation, description and classification common to all natural history, he applied his gift of critical intelligence to almost every animal and plant group. More than anyone else, he also exercised that work, was deep, and analytic, and theory. ’ (p. 257)

As Darwin approached his seventeenth birthday, he wrote some notes to his children to tell them what he had done in his life time and who he was (Ayton, 2008 p. 260).

‘On the fashionable state of the balance, I think that I am superior to the common run of men in noticing things which escape attention, and in observing them carefully – from my early youth I have had the strongest desire, whatever I observed, that is, to group all facts under some general law. These causes combined have given me the patience to reflect ... for any number of years over any unexplained problem.’

Darwin as an acknowledged scientist

Darwin spent eight years studying barnacles, a group of marine crustaceans. Examining them in specimen he was surprised to note such variation that the barnacles divided. This lead him to study and describe the 40,000 varieties of barnacles. He published his classification of barnacles in three volumes. His scientific peers gave him great acclaim and he was awarded the Royal Society’s Royal Medal for his work on barnacles. This gave him the credibility and authority as a recognized scientist.

In his correspondence with his friend, William Fox in 1839 Darwin commented:

‘I mean with my great pleasure to give all arguments & facts on both sides, but I have a number of people helping me in every way.’ (Ayton, p. 260).

Darwin as an acknowledged authority

In preparing the three volumes on the classification of barnacles, Darwin developed a writing style reflecting clear and accurate descriptions as well as the ability to craft his hypotheses in a way that was ‘incisive with noetic common sense’ (Huxley, p. 253).

His unique contribution to the theory of evolution was not the idea but the explanation of how evolution works.

Darwin’s writing skills were such that he could make his ideas accessible to all who read his books. His book ‘On the Origin of Species by Natural Selection’, is almost unique in that he presented a new and revolutionary idea in such a way that it could be understood.
CHAPTER 6: RESULTS AND ANALYSIS

WORKSHOP ACTIVITY

With the 200th anniversary of Darwin’s birth to commemorative, here are two investigations relating to his voyage around the world and his subsequent development of the theory of evolution by natural selection.

Darwin’s Finches – “Design a Beak”

You’ll find out more about “Darwin’s Finches” in workshop 2. (Finches are sparrows of massive).

The Galapagos Islands, which Darwin visited in 1835, are situated near the equator and close to South America. There are many islands, and the flora and fauna are similar, but slightly different on each island. On some islands only one species occurs, on other islands more than one species live together. (The species are evolving further even today. Several researchers have studied these birds in the past sixty years.)

Darwin assembled in his book, “The Voyage of the Beagle” published in 1839, the reasoning that birds form a most regular group of finches, related to each other in the structure of their beaks, short tails, form of body and plumage: there are thirteen species... The most curious fact is the perfect gradation in the size of the beaks in the different species of Geospiza... Seeing this gradation and diversity of structure in one small intimately related group of birds, one might really fancy that... one species had been taken and modified for different ends” (p. 30).

Figure 6.11 The introduction to the narratives workshop with some incidental discussion about Darwin as a scientist (p. 287)

Figure 6.12 Testing their “design a beak” work with some incidental discussion about Darwin as a scientist (p. 287)

Question 5: Explain how ‘Darwin’s Finches’ found on the Galapagos Islands, illustrates that evolution is a fact; evolution is a theory; evolution can be a law.

Table 6.6 A statistical analysis of the data from question 5

<table>
<thead>
<tr>
<th>Group</th>
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<th>n</th>
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The second set of responses is from teacher/participant 26/2

**Pre-test scores:** $0+0+0+0+0=0$
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**Aim for attending the workshops:**
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CHAPTER 6: RESULTS AND ANALYSIS

WORKSHOP ACTIVITY

With the 200th anniversary of Darwin’s birth in 2009, two investigations relating to his voyage around the world and his subsequent development of the theory of evolution by natural selection are presented here.

**Darwin’s Finches — ‘Design a Beak’**

You’ll find out more about ‘Darwin’s Finches’ in workshop 3. (Finches are sparrows of the finch family.)

The Galapagos Islands, which Darwin visited in 1835, are situated near the equator and close to South America. There are many islands, and the flora and fauna are similar, but slightly different on each island. On some islands only one finch species occurs, on other islands more than one species live together. (The species are evolving further ever since.)

Several researchers have studied these birds in the past sixty years.

Darwin summarised in his book, *The Voyage of the Beagle* published in 1845, the interesting land-birds form a natural, similar group of finches, related to each other in the structure of their beaks, short tails, form of body and plumage. There are thirteen species. The most curious fact is the perfect gradation in the size of the beaks in the different species of Geospiza. Seeing this gradation and diversity of structure in one small, intimately related group of birds, one might easily fancy that... one species had were taken and modified for different ends.” (p.30)

*Figure 6.11: The introduction to the narratives workshop with some incidental discussion about Darwin as a scientist. (p. 287)*

*Figure 6.12: Testing their ‘design a beak’ workshop.*

**Question 5: Explain how ‘Darwin’s Finches’ found on the Galapagos Islands, illustrates that evolution is a fact; evolution is a theory; evolution can be a law.**

**Table 6.6 A statistical analysis of the data from question 5**

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<td>0.044</td>
<td>*</td>
<td>0.401</td>
<td>medium</td>
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<td>H08question5</td>
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Comparing the post-test responses to question 5 between E1 and E2, the Mann-Whitney U test showed a statistically significant difference between E1 (Md = 3) and E2 (Md = 0), U = 86,000, z = -2.019, p = 0.044, r = 0.401 and a medium size effect.
6.2.5 Findings and answers to research questions 1, 2 and 3

The statistical analyses established that both interventions, the use of narratives and of concept cartoons, significantly improved the teachers’ ability to answer the questions of the questionnaire using higher-order level thinking skills. However, it is worthwhile to re-examine the wording of the first two research questions:

Research Question 1
How will the design of a narrative, about how scientists construct the story of the evolution of organisms on Earth, encourage teachers to display higher-order thinking skills?

Research Question 2
How will the use of concept cartoons generate discussion about issues relating to evolution of life, and, of science and religion, encourage teachers to display higher-order thinking skills?
The second set of responses is from teacher/participant 26/2

Pre-test scores: 0+0+0+0+0=0
Post-test scores: 0+0+0+0+0=0

Aim for attending the workshops:
The main aim of attending this workshop is to share ideas with colleagues and present my judgment about the misconceptions I have concerning evolution. Secondly, I wanted to gather information so that I can easily handle and solve learners’ problems with confidence. How to present this evolution effectively.

Question 1: What can we learn from evolution of life and the changes that the Earth has undergone in the past?
Question 1 Pre-test:
We can learn that some animals or plants have vanished without trace.
It challenges our beliefs and culture about certain things.
It tells us about the importance of researchers or scientists about changes that they have brought (about). It never leaves God behind he is our creator.
Question 1 Post-test:
I have learnt that because of the different beliefs and multi-racial, this topic must be treated with care and should not aim to changing learners’ mind. After explaining the sub-topic, not the content, you may ask learners to give their view, according to how they were raised and what they think in relation to other cultures with (due) respect.

The second set of responses is from teacher/participant 26/2 continued

Question 3: What evidence do we have that mass extinctions happened in the past?
Question 3 Pre-test:
There are animals that we only see in pictures (black and white). Geographically changes that take place in stones, erosion..
Question 3 Post-test:
- Pictures of dinosaurs
6.3.7.1 The importance of a connecting factor in ‘world view’ theory

George (1999) also stated that the seven separate ‘universals’ needed to be connected in order to create a holistic picture of the worldviews. A rather ‘tongue in the cheek’ interpretation gave a clue to a possible connecting factor, shown in Figure 6.23.

![Figure 6.23](image)

When considering all the ‘universals’ there seemed to be a conflict between, for example, ‘evolution’ and the ‘church’, and, ‘science’ and ‘religion’. A possible connecting factor was ‘conflict causes confusion’, which was the interpretation shown by the authors of the concept cartoons shown in Figure 6.24.

![Figure 6.24](image)

‘Conflict and confusion’ may also act as barriers to the understanding of evolution. Linking some of the barriers to the understanding of evolution, ‘conflict’ may then be caused by a lack of knowledge, in particular knowledge of the nature of science.

The ideas of ‘barriers’ and ‘worldviews’ can be linked to show how certain teachers experience difficulty in understanding and accepting the scientific explanations of the evolution of life and the geological history of the Earth. In answer to research question 4, concept cartoons can be a useful
THE NATURE OF SCIENCE – WHY IS IT IMPORTANT TO INCLUDE THIS IN THE NARRATIVE?

Scientists unlock clues held in fossils and rocks to construct a story of the Earth’s past and how Life evolved.

This is an interesting story, challenging and thought provoking. **Knowledge of the nature of science** can give us an insight into the **processes** used by scientists to find out more about what happened in the Earth’s past.

Understanding the nature of science involves, amongst other things, the importance of **facts, scientific laws and theories**. Therein lies the power of science, but also its limits.

In science we deal only with **facts** that result from observations about things in the **material world** that we can see, hear, touch, smell and taste. These facts can be in the form of numbers, words or drawings and diagrams. There are many things that cannot be observed in this way, for example, ‘beauty’ or ‘faith’ which fall outside the scope of science.

**Scientific laws** are useful in science because they describe a **pattern** of behaviour and the **relationship between things** that are being investigated. The pattern is consistent and helps scientists to calculate and derive further facts.

**Theories** are constructed to explain observations and why things happen the way they do.

What inspires scientists to want to know more?

**Here is a suitable example for this workshop:**

Walking up a hill you notice a different coloured layer of rock, which contains fossilized sea shells. The fossilized shells look similar but are not quite the same as shells which you found at the sea. Somehow something is strangely different. Furthermore, you now see other similar bands of fossilized shells present in rocks further away.

This is strange, you wonder: ‘**How old are these fossils and what are they?**’