CHAPTER 1

Context of, and motivation for, the study

The research reported in this dissertation investigated Grade 10 to 12 *Life Sciences* curriculum support materials as a possible source of misconceptions about evolution. Three types of support materials were investigated: the new *Life Sciences* Curriculum and Assessment Policy Statement (CAPS), all the new CAPS *Life Sciences* textbooks on the Department of Basic Education list of approved textbooks for Grade 10 to 12; and the teacher guide for each of the textbooks. Content analysis was used to identify manifest errors (actual misconceptions) and latent problems (wording which has the potential to lead to misconceptions).

Chapter 1 introduces the background to the study and the factors that motivated this research. Figure 1 shows an overview of this chapter.

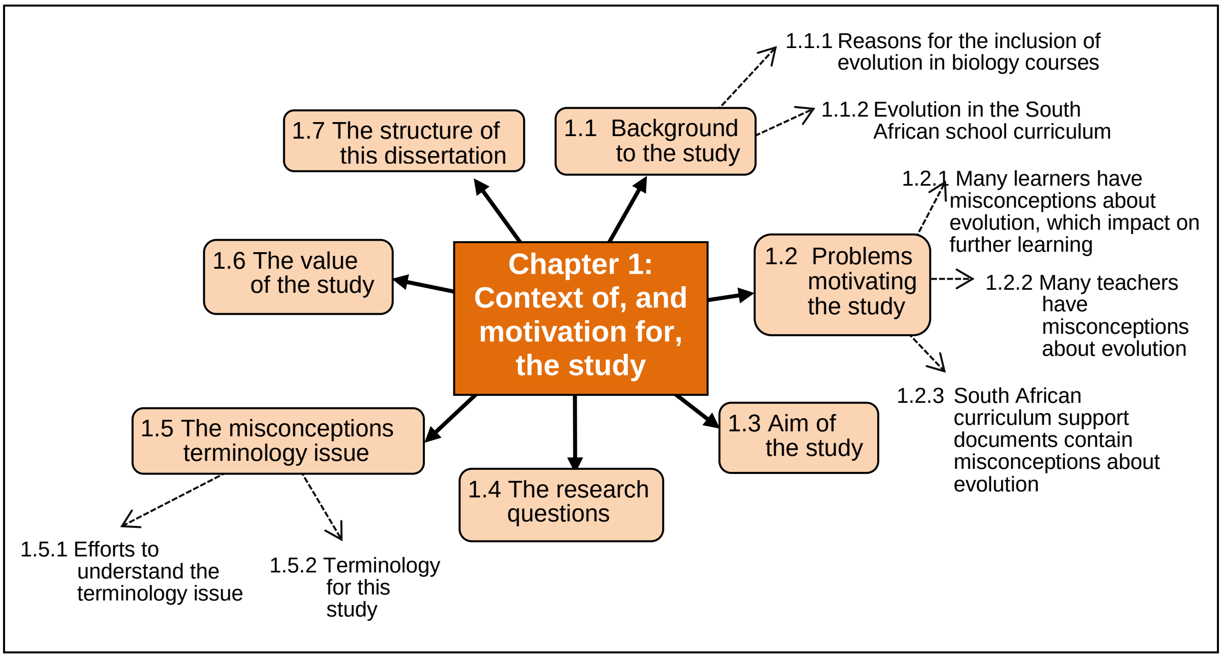

Figure 1: Overview of Chapter 1

1.1 BACKGROUND TO THE STUDY

An explanation of the background to research studies provides information against which the research can be understood and the research problem and questions formulated (White, 1985). This section provides background information about the importance of the topic of evolution in understanding biology and the introduction of this topic into the South African school curriculum.

1.1.1 Reasons for the inclusion of evolution in biology courses

Four main reasons emerge from the literature why it would be inconceivable not to include evolution in a biology curriculum.

Evolution provides an explanatory framework for understanding biology

Evolution offers a scientific explanation for many biological structures, phenomenon and processes. Dobzhansky (1973, p. 125) argues that "*nothing in biology makes sense except in the light of evolution.*" Therefore the inclusion of evolution in biology courses provides a framework for explaining biological ideas. For example, an understanding of **divergent evolution** (the development of different traits in related lineages of organisms) enables us to explain how related species evolve different traits (Freeman & Herron, 2007). Many vertebrate species (which are related due to common ancestry) have evolved different structures (such as their forelimbs) which look different and serve different functions but which are in fact homologous. Through divergent evolution by natural selection, the homologous structures (e.g. forelimbs) have evolved by adaptive radiation and are now specialized to perform a variety of functions for different modes of life (Scotland, 2011). Typical examples of homologous structures in evolutionary biology are the wings of bats and the pectoral fins of whales and fish (Futuyma, 2009). Evolution also enables us to understand similarities across vastly different organisms. For instance, lower life forms such as bacteria and higher ones such as human beings share striking molecular similarities. The similarities across different life forms can only be explained by their common evolutionary descent (Futuyma, 2009).

Understanding **convergent evolution** (the development of similar traits in organisms of different lineages) enables us to explain why some apparently unrelated organisms look similar. For example, whales (mammals) and sharks (fish) have a similar streamlined body shape, and dorsal and pectoral fins to provide stability (Futuyma, 2009). Whales and sharks have undergone convergent evolutionary adaptation to the same aquatic ecological environment through the process of natural selection (Freeman & Herron, 2007). Evolution enables us to understand many other examples where seemingly unrelated species independently developed similar traits by natural selection and become more and more similar as they adapted to the same kind of ecological niche (Futuyma, 2009). Unrelated fish in the Arctic and Antarctica have independently evolved 'antifreeze genes' for making a glycoprotein that stops them from freezing to death (Chen, DeVries, & Cheng, 1997). Insects, birds, some reptiles (pterosaurs), and some mammals (e.g. bats) have independently evolved wings which are functionally the same but structurally different (Freeman & Herron, 2007; Futuyma, 2009). The American cactus plant and the African euphorbia have both evolved spines which keep back potential predators from the fleshy stems which store water. Unrelated Australian, African, and America anteaters have all evolved the long, sticky tongue, few teeth, rugged stomach, and large salivary glands, for a diet of ants (Scotland, 2011). This understanding would not have been possible without the underlying explanatory framework of evolutionary theory.

Evolution is a unifying theme across many sciences subjects

According to Dobzhansky (1973, p. 129), "… *in the light of evolution, biology is, perhaps, intellectually the most satisfying and inspiring science. Without that light it becomes a pile of sundry facts—some of them interesting or curious but making no meaningful picture as a whole"*. The idea that populations undergo changes over time acts as a thread that connects biology topics such as diversity, extinction of organisms (Flammer, 2006), genetics, biogeography, comparative embryology, and molecular biology (Cavallo & McCall, 2008). Without the theory of evolution, biology topics such as these appear to be isolated ideas (Dobzhansky, 1973).

Evolution (changes over time) also acts as a unifying theme across different science disciplines such as earth science, chemistry, and physics (National Research Council, 2012). In the earth sciences there have been evolutionary processes involving planet formation, rock, water cycles, river bed and river bank changes due to erosion, continental plate movements, and rises in sea levels (National Research Council, 2012; American Association of Advancement of Science, 1990). In chemistry the formation of new elements over time through nuclear fission (radioactive decay and nuclear reactions) and the reaction of carbon, hydrogen, oxygen, nitrogen and sulphur to form simple amino acids, which then formed proteins, which in turn formed RNA, DNA, and finally simple life forms, makes sense in the context of change over time (National Research Council, 2012; American Association of Advancement of Science, 1990). In physics the formation of solar systems, galaxies and stars over time is an evolutionary concept (The University of Liege, 2009; National Research Council, 2012). In palaeontology fossils from different time periods are not the same and such observations illustrate the theme of change (Alroy, 1999).

Applications of evolution theory underpin many technological advances

The importance of evolution is not only limited to its explanatory and unifying powers: an understanding of evolution is also useful for technological advances that have improved the quality of human lives. Ideas about evolution are playing, and will continue to play, an integral role in improving our practices in agriculture, biodiversity conservation, and medicine (Losos, Arnold, Bejerano, Brodie, & Hibbett, 2013).

In **agriculture**, an understanding of evolution by natural selection is used to bring about higher crop yields and to improve the quality of domestic livestock. Artificial selection and genetic modification of crops have been used to develop desirable traits in crops and livestock (Losos et al., 2013). Crops which are drought resistant and livestock which produce more beef and milk have been promoted through the process of evolution by artificial selection. Artificial selection has therefore resulted in the advancement of agricultural produce over decades (Johnson, 2005; Jeffrey, 2003).

Innovative genetic engineering (by introducing relevant genes from animals) has resulted in crops that are pest-, herbicide-, disease-, cold-, salinity-, and drought-resistant, which has improved agricultural output. Production of pest-resistant crops has led to reduced use of chemical insecticides, and reduced environmental pollution (Dahleen, Okubara, & Blechl, 2001; Ohkawa, Tsujii, & Ohkawa, 1999). Furthermore, genes from animals have been inserted into plant crops so as to enable them to produce certain nutrients (e.g. rice with proteins), pharmaceutical substances (e.g. bananas which produces medication for immunisation against targeted diseases), and also to rid the environment of poisonous heavy metals (Rockefeller Foundation, 1999; Hodgson, 2000; Scott, Clayton, & Richard, 2000; Moellenbeck, Peters, Bing, Higgins, & Sims, 2001).

In **medicine**, natural selection is being used to understand the development of drug resistance in pathogens, predict diseases that may emerge from shifts of pathogens (e.g. bird flu) to human hosts, trace the source of pathogens, and also to identify new drugs for detecting and treating diseases such as cancer, diabetes and asthma (Losos et al., 2013). The recent medical problem is that by natural selection, use of antibiotics eliminates those pathogens that are not drug resistant leaving those that have a resistant mutant gene spreading in the population. The non-resistant pathogens are eventually replaced by the resistant strains. An evolutionary process of genetically weakening a live disease-causing virus (attenuation), and letting it evolve to conditions outside the human body so that it becomes less virulent for later use, has also been used in the medical field for the development of many immunisation vaccines (Ewald, 1994; Losos et al., 2013). Evolutionary biology involving the use of phylogenetic trees of pathogens and DNA sequences of bacteria and viruses can be used to trace the parental population from which a given infection occurred so as to come up with appropriate treatment options (Ewald, 1994).

Knowledge of evolutionary processes has also been used to underpin **biodiversity conservation** strategies. For instance, evolutionary phylogenetic trees are used to tell the extent of biodiversity (or the loss of through extinction) for given groups of organisms (Faith, 1992). Measures to conserve biodiversity are therefore done in the light of information that comes from changes over time of groups of organisms (evolution) on the tree of life.

Knowledge of evolution is important for scientific literacy

The fourth reason why evolution should be included in biology curricula is that knowledge of evolution is important for scientific literacy, which is essential for sustainable environmental use, well-being of the populace, and general economic growth (Longbottom & Butler, 1999). Modern biology curricula often advocate using science, technology and society (STS) approach. This approach looks at ways in which science can be used to make our everyday lives easier (Jasanoff, Markle, Petersen, & Pinch, 1995). A scientifically and technologically skilled populace helps in the application of science to solve everyday problems. Scientific literacy levels are determined by the public's understanding of science and its applications (Holbrook & Rannikmae, 2009).

Knowledge of evolution in two categories of literacy identified by Shen (1975) is important for school curricula where the purpose is to educate the public by promoting scientific literacy: these are *practical scientific literacy* and *civic scientific literacy*. Scientific knowledge about evolution can be practically applied in fundamental areas such as health and food so as to solve problems facing society in order to make everyday human survival easier and to improve the quality of life.

In order to understand and participate meaningfully in debates about the controversial application of evolution knowledge in everyday lives there is a need for civic scientific literacy [knowledge needed in order to understand how science knowledge is being applied in society] (Shen, 1975). For instance, one can only partake meaningfully in societal debates on the application of evolution in processes such as biotechnology, and the production of genetically modified food and its possible long term effects, if one has adequate knowledge about biological evolution (Van Dijk & Reydon, 2010). Meaningful participation in public debates is the basis for enhancing democratic societies (Longbottom & Butler, 1998).

1.1.2 Evolution in the South African school curriculum

Despite the importance of the topic of evolution in understanding biology, as explained in Section 1.1.1, evolution was not part of the South African school curriculum for decades. Science educationists have cited different reasons as to why evolution was not included prior to 1994. Dempster and Hugo (2006, p. 106) point out that "[t]*he South African school curriculum before 1994 ignored evolution because it conflicted with the religious beliefs of the government*". According to Lever (2002), the National Party government (1948-1994) had in place the Christian National Education policy which considered Darwin's theory of evolution by natural selection to be anti-Christian.

A new curriculum was introduced into the South African school curriculum in 1998 when the African National Congress government started revising what was to be learnt in South African schools.

Different scholars point out different reasons why the topic of evolution was included. It may have been introduced after independence to improve the scientific literacy of the populace (Dempster & Hugo, 2006) which has the potential to address socio-scientific issues such as the HIV/AIDS pandemic affecting South African communities (Lever, 2002). Longbottom and Butler (1999) point out that scientific literacy is associated with values such as critical thinking, which is important for one to be able to participate meaningfully in democratic debates, which in turn help uphold principles of a democratic nation. Furthermore, the introduction of evolution may have been because evolution provides a unifying theme across science disciplines (Lever, 2002).

Terminology used in the South African school curriculum

A number of terms used in the following sections are first explained. Excluding Grade R (pre-school), the South African school system spreads over 12 years (from Grade 1 to 12). The school grades are divided into two bands, the General Education and Training band (GET) and the Further Education and Training band (FET). The General Education and Training band includes Grade R to Grade 9 and is divided into three phases. The *Foundation Phase* (Grades 1 to 3); the *Intermediate Phase* (Grades 4 to 6); and the *Senior Phase* (Grades 7 to 9). The eight content disciplines at the GET level are no longer called ‘subjects’ but ‘learning areas’.

The new curriculum was first introduced in 1998 under the name *Curriculum 2005* although the syllabus document was called the Policy Document (Department of Basic Education, 1997). *Curriculum 2005* was introduced for the first time in Grade 1 in 1998. The curriculum was progressively implemented in the other GET grades in the subsequent years (Mahomed, 2004) as shown in Appendix A. For instance, in 1999 and 2000 it was implemented in Grade 2 and Grade 3 respectively, and moved up with the particular cohort of students until it finally reached Grade 9 in the year 2008.

The Further Education and Training band caters for the upper grades (Grades 10 to 12). At FET level the grades are not clustered into phases. The content disciplines in this band are not called ‘learning areas’ but ‘subjects’.

Since the new South African curriculum was first implemented in 1998 there have been a number of curriculum revisions which can be tracked via historical accounts by various authors (e.g. Lever, 2002; Dempster & Hugo, 2006; Johnson, Dempster, & Hugo, 2011; Johnson, Dempster, & Hugo, 2015). At the GET band the first curriculum revision led to the replacement of *Curriculum 2005* by the *Revised National Curriculum Statement* (*RNCS*). Although the *RNCS* was published in 2002, it was only introduced in the General and Education Training band for the first time in the Foundation Phase (Grades 1 to 3) in 2004 (see outline of the dates for implementation in Appendix A). In 2005 the new curriculum was introduced in the Intermediate Phase (Grades 4 to 6). At the Senior Phase, the new curriculum was introduced for the first time in in Grade 7 in the year 2006, in Grade 8 (in 2007) and finally in Grade 9 (in 2008) (Mahomed, 2004).

The current curriculum revision (the *Curriculum and Assessment Policy Statement*, commonly referred to as *CAPS)*, marks the second curriculum revision at the GET band. As shown in Appendix A, the GET *CAPS* was introduced in Grades 1 to 3 (Foundation Phase) in 2012; Grades 4 to 6 (Intermediate Phase) in 2013, and Grades 7 to 9 (Senior Phase) in 2014.

At the FET band, the *Curriculum and Assessment Policy Statement* replaced the *National Curriculum Statement (NCS*). The *NCS* was the name given to the original revised curriculum (introduced in in Grade 10 in 2006 as shown in Appendix A). The *CAPS* curriculum was progressively implemented at FET level in Grades 10 to 12 from 2012 to 2014. The introduction of the *CAPS* curriculum marks the first general curriculum revision at the FET band. In 2014 some examination guidelines were provided for *Life Sciences* teachers (Department of Education, 2014) to assist them with the details of what would be assessed in the examinations. These guidelines were not investigated in this study as they were issued after the documents had been selected for this research).

Evolution in the General Education and Training (GET) band

Curriculum 2005 was characterised by the fact that it did not spell out content which teachers could follow during teaching. Skoog and Bilica (2002) point out that the content of a curriculum is influenced by the philosophical standpoint of the designers. The philosophy behind the *Natural Sciences* statement for *Curriculum 2005* was that the development of skills was the top priority and content was just the means for developing the skills. Excluding content from the curriculum statement was based on the premise that teachers were subject content specialists with the prowess to design and make decisions in terms of the depth and type of content to be taught (Department of Education, 1997). In the *Natural Sciences,* examples of the content which teachers could follow if they so wished were provided as ‘exemplars’ under what were then called ‘range statements’. However, the range statements “… *were neither rigid nor prescriptive* …” in terms of content to be taught (Department of Education, 1997, p. NS-3).

Although the term ‘evolution’ was not used in the policy document for *Curriculum 2005,* some of the exemplars in two of the eight learning areas (*Natural Sciences* and *Human and Social Sciences*) contained evolution-related topics, as summarised in Table 1a. In the *Natural Sciences,* topics included as suggested examples are the *‘geological time scale’* in the Foundation Phase *(*Department of Education, 1997, p. NS-10), and “*theories about the origin of species, heredity”* in the Senior Phase (Department of Education, 1997, p. NS-21). In the *Human and Social Sciences,* the evolution-related content included *“Pre-colonial (from earliest hominids)” (*Department of Education, 1997, p. HSS-5) for Grades *4-6; “Archaeological sources (e.g. fossils, skeletal remains, rock paintings and engravings*)” (p. HSS-5); *and “Species extinction”* (p. HSS-27) *for Grades 7-9.* However, it is interesting to note that these evolution-related topics were mentioned not in terms of how evolution happened but in relation to human impact on the environment. Because the exemplars were not prescriptive some teachers may not have included the evolution-related topics in their teaching (Lever, 2002).

Because the then minister of education had called for a new curriculum that focused on “*previously excluded areas of study and exciting new stories*” such as the topic of evolution (Human Sciences Research Council, 2002, p. 4), the number of evolution-related topics increased for some of the learning areas in the *Revised National Curriculum Statement*. Unlike *Curriculum 2005*, the RNCS had core knowledge details in a separate chapter that spelled out content for teachers to follow (Department of Basic Education, 2002). As shown in the Table 1a, in the *Natural Sciences* the evolution-related content included “*South Africa has a rich fossil record” in the* Intermediate Phase [Grades 4 to 6] and “*natural selection”, “mass extinction*” [Grade 8 and 9]. The *Human and Social Sciences* contained *“human evolution”* under the history component for Grade 7. The curriculum changes from *Curriculum 2005*, the *Revised National Curriculum Statement* and now to *Curriculum Assessment and Policy Statement* came with a decrease in terms of teacher autonomy to decide what to teach to the learners. As already explained, for *Curriculum 2005,* content was hardly prescribed; for the *RNCS* core content was provided which could be expanded upon by the teacher. In the new *CAPS* curriculum, all the content, learning activities and even lesson plans to be followed are provided. Therefore in terms of classroom curriculum design and implementation, the new *CAPS* curriculum has reduced teachers from being professionals to mere classroom technicians.

Table 1a: Changes in the evolution-related content in the GET band in the South African curriculum

	Date started	Grade	Subject	Strand	Evolution-related topics
Policy document (for *Curriculum 2005*)[1]	1998-2000	1-3	*Natural Sciences*	Earth and beyond	*Geological time scale (*p. NS-10)
	2001-2003	4-6	*Human and Social Sciences*	History	*Pre-colonial (from earliest hominids) (*p. HSS-5).
	2000-2002	7-9	*Natural Sciences*	Earth and beyond	*Theories about the origin of species, heredity (*p. NS-21)
	2000-2002	7-9	*Human and Social Sciences*	History	Archaeological sources (e.g. fossils, skeletal remains, rock paintings and engravings) (p. HSS-5) Species extinction (p. HSS-27)
Revised National Curriculum Statement[2]	2004	1-3	*Natural Sciences*	Biodiversity, change and continuity	*Variety in animals and plants* (p .62) *Plants and animals change (*p. 62)
	2005	4-6	*Natural Sciences*	Biodiversity, change and continuity	*South Africa has a rich fossil record* (p. 63)
	2006 - 2008	7	*Human and Social Sciences*	History	*Human evolution* (p. 89)
		7-9	*Natural Sciences*	Life and living	*Natural selection, mass extinction* (p. 62-64) *Diversity, variation in living things, natural selection, mass extinction* (p. 62-64)
				Planet Earth and beyond	*Fossils: remains of life preserved in rocks* (p. 70)
				Interactions in environment	*All organisms have adaptations for survival in their habitats (such as adaptations for maintaining their water balance, obtaining and eating the kind of food they need, reproduction, protection or escape from predators.)* (p. 64).
Curriculum and Assessment Policy Statement[3]	2013	4 -6	*Natural Sciences*	Life and living	*Adaptation, fossils: importance of fossils, importance of fossils found in South Africa* (p. 54)
		8	*Natural Sciences*	Life and living	*Adaptations* (p. 14)
		9	*Natural Sciences*	Life and living	*Adaptations: living things suited to their environment* (p. 17), *adaptations of flowers (p. 19), and adaptation allows organisms to* survive (p. 38).
		9	*Human and Social Sciences*	History	*Human evolution and our common ancestry* (p. 43)

[1] Department of Basic Education (1997); [2] Department of Basic Education (2007); [3] Department of Education (2011)

The implementation of the new *CAPS* curriculum came with further changes in the evolution and evolution-related content at the GET band. As shown in Table 1a, a notable change was the dropping of natural selection, although adaptation (which happens by natural selection, and is evolution), remains. This implies that the topic of evolution, which is a unifying theme for all biology topics, has been removed at earlier grades and this may compromise the building of a solid foundation needed for understanding evolution concepts at higher levels.

Evolution in the Further Education and Training (FET) band

The topic of evolution was added to the South African Further Education and Training band (Grades 10 to 12) *Life Sciences* school curriculum in 2008 in Grade 12, making up 25% of the matriculation examination (Department of Basic Education, 2008). As shown in Table 1b, the content to be covered under evolution remains largely unchanged from one curriculum revision to the next. Evolution content such as "*definition of evolution, evidence of biological evolution, origin of species by natural selection"* and *"Lamarck's and Darwin's ideas* has been maintained during the three curricular updates (from National Curriculum Statement, to the New Content Framework for *Life Sciences* and now the Curriculum and Assessment Policy Statement). The percentage weighting of evolution content has fluctuated with curriculum changes: (NCS 20%; New Content Framework for *Life Sciences* 9.6%; and CAPS 13.6% [Johnson et al., 2015]). Evolution was one of the content areas named by Johnson et al. (2011; and 2015) as involved in the shift in emphasis on canonical aspects (content-based 'pure science') and humanistic aspects ('applied science' relevant to learners' everyday lives), but levels have fluctuated so no general trend can be detected.

Table 1b: Changes in the evolution-related content in the FET band in the South African curriculum

	Date started	Grade	Knowledge area	Evolution-related topics
National Curriculum Statement [4]	2006	10	Diversity, change and continuity	*Adaptations for survival* (p. 30) *Definition of term adaptation; why it is necessary for organisms to adapt in the environment (p. 30)*
	2007	11	Diversity, change and continuity	*Biodiversity of plants and animals* (p. 37)
	2008	12	Diversity, change and continuity	*Definition of biological evolution; evidence for biological evolution of populations; definition of fossilisation; interpretation of the fossil record by means of morphological divergence; origin of species - evolution theories, mutation, natural selection, macro evolution and speciation; origin of species by means of natural selection and Lamarck's theory; mutations* (p. 42). *Popular theories of mass extinction; continental drift; Cradle of Mankind - South Africa; anthropology; palaeontology and archaeology* (p. 42)
New Content Framework for *Life Sciences*" (Not a curriculum revision for all subjects, but for *Life Sciences* only)	2009	10	Diversity, change and continuity	*Fossil formation and methods of dating* (p. 3); *life history: Cambrian explosion; mass extinction; evidence of early life in different parts of South Africa; life forms becoming similar to present life forms* (p. 3)
	2010	11	Diversity, change and continuity	*Modification of basic body plans: mammal forelimbs* (p. 6) *Modification of flowers for pollination* (p. 7) *Biogeography: diversity from one continent to another; different organisms on different land masses [continents]* (p. 7)
	2011	12	Life processes in animals and plants	*Adaptation of flowers to different forms of pollination such as wind and insects* (p. 5)
			Diversity, change and continuity	*Origin of an idea about origins* (p. 8) ***Evidence for the theory of evolution:** fossil record; modification with descent; Biogeography **evolution by natural selection:** Darwin's theory of evolution by natural selection**:** present life forms come from the previous life forms**;** natural selection acts on variation of selected traits; **a**rtificial selection mimics natural selection* (p. 8). ***Formation of new species:** concept of species; speciation as a*

				mechanism of producing new species; geographic speciation due to isolation (p. 8); *reproductive isolation mechanisms* (p. 9) ***Human evolution:*** *evidence of common ancestry**;** Out of Africa hypothesis (*p. 9) ***Evolution in present times:*** *resistance of insects to insecticides and bacteria to antibiotics* (p. 9) ***Alternative explanation:*** *alternative to Darwin's explanation; cultural and religious explanations* (p. 9)
Curriculum and Assessment Policy Statement [6]	2012	10	*Diversity, change and continuity*	*Modern life forms have a long history extending from the first bacteria, around 3.5 billion years ago. South Africa has a rich fossil record of some key events in the history of life. Changes in the life forms are related to climatic changes as well as movements of continents and oceans over long periods of time* (p. 35) ***Life's history: change throughout the history of life on Earth*** (p. 36) • *geological events and their effects on biogeography* • *evidence for changing sea level and rise and fall of the land* • *the three eras: Palaeozoic, Mesozoic and Cenozoic are each divided into periods* ***Geological timescale*** (p. 36) • *the meaning and use of timescales* ***Cambrian explosion*** (p. 36) • *gives us insights into the origins of the major forms of all animal groups.* • *in the last four million years, significant changes occurring in Africa (e.g., humans).* ***Mass extinctions*** (p. 36) • *five mass extinctions throughout history; the sixth mass extinction* ***Understanding fossils:*** *fossil formation and methods of dating them [radiometric dating and relative dating]; scientist's use deductive reasoning to understand fossils and the history of life on Earth* (p. 37). **Fossil tourism:** a source of income and employment in some localities (p. 37).
	2013	11	Diversity, change and continuity	*Life exists in a wide variety of forms which live in different niches. This section enables learners to be exposed to an array of life forms from microorganisms to microscopic plants and animals. This strand also includes some evolutionary development in plant and animal phyla* (p. 39).
	2014	12	Diversity, change and continuity	*It is necessary to have a firm grasp on work done earlier in the year on DNA, genetics and heredity in order to understand the concept of change, natural selection and evolution. This knowledge strand is expanded on by exploring the mechanisms of evolution and specifically human evolution in Africa* (p. 89). ***Evolution*** *by natural selection (*p.61-65)*; origin of ideas about origins, artificial and natural selection, speciation; mechanisms for reproductive isolation: evolution in present times, human evolution, out of Africa hypothesis; importance of the Cradle of Humankind, alternatives to evolution*

[4] Department of Basic Education (2008); [5] Department of Basic Education (2007); [6] Department of Basic Education (2011)

Although the Further Education and Training curriculum has only undergone one revision, the *Life Sciences* curriculum has undergone two, the first of which involved major changes in the teaching of evolution. The first revision (which started in 2009) involved introducing the *New Content Framework* for *Life Sciences* (Department of Basic Education, 2007). The *New Content Framework for Life Sciences* was not a curriculum change *per se* as it did not happen across all subjects in the curriculum, but was a revision for *Life Sciences* only. The rationale provided for introducing the *New Content Framework* for *Life Sciences* as explained by the Education Department was that "… *the content in the subject Life Sciences as listed in the National Curriculum Statement (NCS) Grades 10 – 12 (General) was underspecified, it was deemed necessary to revise the subject with a view to* *supporting the implementation of the NCS Grades 10 – 12 (General)"* (Department of Education, 2007, p. 3).

The revisions involved evolution-related content spreading down from Grade 12 into the Grade 10 and Grade 11 curricula. As shown in Table 1b, the topics moved to lower grades included *modification of basic body parts of plants and animals (*such as *flowers* and *mammalian forelimbs)*, *biogeography*, and *diversity of organisms* in *different land masses* (moved to Grade 11). Evolution topics moved to Grade 10 included *fossil formation, life history (Cambrian explosion, mass extinction)* and *similarities between present and past life forms.* Table 1b also shows that a notable change from the National Curriculum Statement for the *Life Sciences* was the shift of the topic *adaptation* from Grade 10 to Grade 12. However, *Darwin's theory of evolution by natural selection, human evolution, alternative explanations to Darwin' theory* and *fossils as evidence for the theory of evolution* remained in the Grade 12 *Life Sciences* curriculum.

The second schoolwide revision to the FET curriculum was the introduction of the Curriculum and Assessment Policy Statement, a single document replacing the "…*proliferation of curriculum policy and guideline documents"* under the NCS (Johnson et al., p.104). As shown in Table 1b, the evolution content has remained largely the same at FET level in all the grades during this current curriculum revision (CAPS). Major topics which were part of the content in the old curriculum (NCS), such as: *fossil formation and methods of dating* (Grade 10); *modification of basic body plans: mammal forelimbs* (Grade 11*)* and *evidence for the theory of evolution; formation of new species; human evolution; evolution in present times; and alternative explanation (*Grade 12) are also part of the new *Curriculum and Assessment Policy Statement* (see Table 1b).

1.2 PROBLEMS MOTIVATING THE STUDY

A number of problems linked to the threats posed by evolution misconceptions in science education motivated this study.

1.2.1 Many learners have misconceptions about evolution, which impact on further learning

The world over, many students have misconceptions about the topic of evolution (Deadman & Kelly, 1978; Brumby, 1984; Bishop & Anderson, 1990; Jiménez Aleixandre, 1994; Gregory, 2009; Nehm,, Rector, & Ha, 2010). South African studies show that many of our learners also have such misconceptions (Kagan, 2011; Lawrence & Sanders, 2011; Mpeta, de Villiers, & Fraser, 2014). A review of the relevant research on misconceptions is discussed in Section 2.5 of Chapter 2. As shown in Table 2 in Chapter 2, examples of misconceptions are identified in topics such as evolution by natural selection, adaptation, and the concept of fitness.

If students have prior misconceptions, these can have a serious negative effect on the learning of new science concepts because learning involves reorganising existing cognitive structures (Ausubel, 1968) or what Piaget (1952) calls 'schemata'. According to Freyberg and Osborne (1985) students' prior ideas, which could be scientifically inaccurate, play an important part in allowing them to make sense of the world around them. diSessa (1993) points out that correct learning of science concepts is only possible if existing knowledge is restructured or reorganised.

Learning occurs when knowledge about the world is perceived and then mentally processed (see Figure 2). After our senses perceive the world around us (sensory input), the sensory data in turn activates particular prior ideas, or 'knowledge pieces' or what diSessa (1993, p. 111) calls "*phenomenological primitives (p-prims)"*, and this can be problematic if these ideas are unscientific (Ausubel, 1968). diSessa explains phenomenological primitives as science-linked ideas that explain reality for an individual, whether these ideas are accurate or inaccurate. It is through p-prims that individuals see, interpret their experiences, and make sense of the world (diSessa, 1993) and therefore a faulty interpretation of the world could be realised by individuals whose prior ideas are unscientific. As shown in Figure 2, during learning, specific p-prims are activated and restructured to assimilate or accommodate new ideas about science. Learning (involving appropriate sensory data input) is intended to confront and restructure inaccurate knowledge pieces (p-prims), or what some would call individual science misconceptions, thereby leading to the formation of conscious new and scientifically accurate ideas about the world (diSessa, 1993).

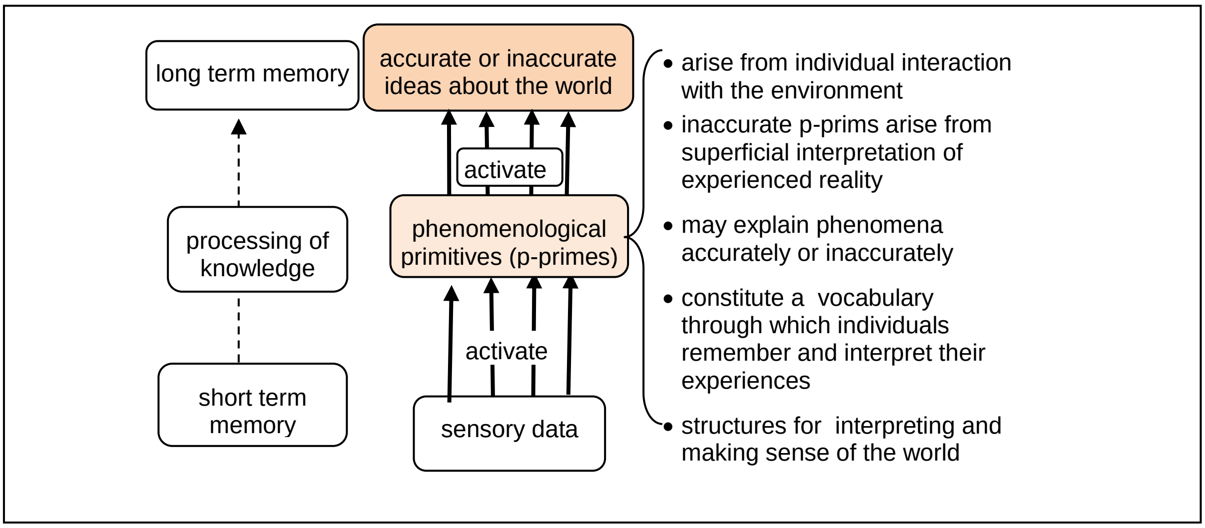

Figure 2. Acquisition of knowledge (based on diSessa, 1993)

The information contained in the long term memory affects the perception and interpretation of new knowledge (Freyberg & Osborne, 1985). The memory store (which could have scientifically accurate or inaccurate information) contains the knowledge base for interpreting and giving meaning to all sensory input (Ausubel, 1968; Freyberg & Osborne, 1985). Ausubel (1968, vi) emphasises the importance of prior ideas for new learning: *"The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly".*

The problem is that when learning new science concepts, existing *"misconceptions affect the way children understand a variety of scientific ideas"* (Eaton, Anderson, & Smith, 1984, p. 366). Freyberg and Osborne (1985) suggest that when students have misconceptions there are four possible negative learning outcomes:

- The ***undisturbed children's science outcome*****:** Learners are not convinced by the new scientific concepts and so hold on to their erroneous ideas. Teaching and learning do not have any effect on changing the learners' erroneous ideas.
- The ***reinforced outcome*****:** The teaching and learning efforts are misconstrued to such an extent that the learner's misconceptions get support and are reinforced.
- The ***two-perspective outcome*****:** Learners are not convinced by the new ideas and keep two perspectives, their own erroneous ideas which they use to make sense of the world around them, and the scientific knowledge for class use and examination purposes.

- The ***confused learning outcome*****:** This occurs when teaching and learning leaves learners in a mental dilemma: the scientific knowledge is not comprehensible enough to fully embrace, and their misconceptions are not useful enough to explain all situations around them.

Because prior ideas influence new learning (Ausubel, 1968), and because evolution is pivotal in the understanding of most biology topics (Dobzhansky, 1973), students' erroneous ideas about evolution may negatively affect their understanding of further biological concepts they are taught.

1.2.2 Many teachers have misconceptions about evolution

Teachers are expected to "… *act as filters for misconceptions and alternative conceptions, thereby preventing them from getting to their students as knowledge"* (Olakanmi & Baba, 1996, p. 19). However, research has revealed that many teachers worldwide have erroneous ideas about the topic of evolution (e.g. Rutledge & Mitchell, 2002; Nehm & Schonfeld, 2007; Jungwirth 1975, 1977; Tidon & Lewontin, 2004; Berkman, Pacheco, & Plutzer, 2008; Vlaardingerbroek & Roederer, 1997; Nehm et al., 2009; Nehm et al., 2010; Yates & Marek, 2014). A review of the research on this matter is dealt with in more detail in Chapter 2. Studies in South Africa show that some student teachers and teachers here also have erroneous ideas about evolution (Stears, 2006; Abrie, 2010; Ngxola, 2012; Molefe, 2013). Furthermore, in the district where I work, interactions during the teaching of evolution cluster meetings, which involve sharing pedagogical practices, show that many teachers have weak evolution content knowledge, often claiming that their professional training never included the topic. They also exhibit misconceptions. Yip (1998) points out that a teacher whose content knowledge is poor poses the risk of passing on unscientific concepts to the students. When teachers are poorly equipped to teach a topic, curriculum support materials have a very important role to play.

1.2.3 South African curriculum support documents contain misconceptions about evolution

Previous studies reveal that many South African teachers are not adequately trained to teach the topic of evolution (Stears, 2006), and that some lack sufficient pedagogical content knowledge for teaching evolution (Molefe, 2013). Struggling teachers require help and this help may come from informative workshops and good quality curriculum support materials. Such materials include policy documents, textbooks, teacher guides, and past examinations papers, which could help struggling teachers during teaching.

Because syllabus documents (called curriculum statements in South Africa) act like maps that guide teachers in terms of which topics to teach, what order to teach in, and depth of content coverage (Hutchinson & Torres, 1994), they are important tools for making teaching easier (Parks & Harris, 2002). However, if such documents contain misconceptions, these are likely to be perpetuated by teachers. Research on the previous South African curriculum documents, the Revised National Curriculum Statement for Grade 7 to 9 Natural Sciences (Makotsa, 2012) and the National Curriculum Statement for Grade 10 to 12 *Life Sciences* (Tshuma, 2012), revealed that these documents contained erroneous statements about evolution. A dilemma arises because teachers have to follow curriculum statements, sometimes in order for their students to pass external examinations, which causes problems if such documents contain misconceptions. South African textbook writers also use curriculum statements to guide them when writing their books, so that their books can be considered for approval by the Department of Education.

Research elsewhere in the world shows that curriculum support materials such as textbooks are important resources upon which students and teachers rely during teaching and learning (Jiménez

Aleixandre, 1994; Hutchinson & Torres, 1994). During their classroom instruction, science teachers tend to follow the scientific knowledge provided in their textbooks (Carvalho, Lustigova, & Lustig, 2009; Olakanmi & Baba, 1996). However, such reliance is problematic if the textbooks used contain unscientific ideas. The presence of misconceptions in South African *Natural Sciences* and *Life Sciences* textbooks, as revealed by research (Makotsa, 2012; Tshuma, 2012) poses a dilemma for struggling teachers who rely on them for teaching.

1.3 AIM OF THE STUDY

The aim of this study was to investigate the new *Life Sciences* curriculum support materials (Curriculum and Assessment Policy Statement, associated textbooks and teacher guides) to identify the nature and extent of manifest errors (actual misconceptions) and latent problems (wording which has the potential to lead to misconceptions). Manifest errors are obvious and easily detectable scientifically incorrect statements, while latent errors are statements that are not misconceptions *per se* but have the potential to be misinterpreted, leading to the development of misconceptions (Fraenkel, Wallen, & Hyun, 2012). This study also aimed to find out whether, and to what extent, the teacher guides help teachers with pedagogical ideas for teaching and addressing misconceptions about evolution.

My Masters research built on work done for my Honours project, but significantly extends the work. My Honours research (Tshuma, 2012) investigated the now outdated *Life Sciences* National Curriculum Statement (NCS) document, a limited sample (six) of old *NCS* textbooks from only two publishers, and did not look at teacher guides. My Masters study expanded on the scope of the Honours project in a number of ways. Firstly, the new CAPS document was investigated as a potential source of misconceptions about evolution. Secondly, all available CAPS *Life Sciences* textbooks and teacher guides on the Department of Education approved list (a total of 32) were investigated (of these, 7 Grade 12 textbooks and their teacher guides were investigated extensively). These came from eight different publishers. Thirdly, the issue of anthropomorphic and teleological reasoning was not investigated during my Honours project, but since it has emerged as an important latent problem (Sanders, 2014a), documents were also analysed for these problems. The textbook instrument used for my Honours project therefore had to be adapted in order to investigate anthropomorphic and teleological reasoning (details discussed in Section 2.7 of Chapter 2). Fourthly, in order to investigate teacher guides, a new instrument for analysis was developed from scratch.

1.4 THE RESEARCH QUESTIONS

Research aims are usually too broadly worded to guide research unless broken into manageable sub-units, often in the form of research questions (Leedy, 1989). The advantage of considering the aim through the research questions is that the researcher gets a better logical understanding of the target areas for the research because the questions focus the attention of the researcher more effectively than a mere declarative statement (aim) would do (Leedy, 1989).

The following research questions guided this study:

Research question 1:

What is the nature and extent of **misconceptions about evolution** found in Grade 12 *Life Sciences* curriculum support materials (the Curriculum and Assessment Policy Statement, textbooks, and teacher guides)?

Research question 2:

What is the nature and extent of **latent problems** found in Grade 12 *Life Sciences* curriculum support materials?

Research question 3:

To what extent do the Grade 12 *Life Sciences* **textbooks** point out common misconceptions and provide the correct scientific explanations to counter the misconceptions?

Research question 4:

To what extent do the teacher guides address teachers' pedagogical content knowledge (PCK) by a) pointing out common misconceptions; b) providing the correct version of the specific misconceptions; c) pointing out pre-requisite knowledge which ought to be learnt first in order to understand the topic of evolution; d) pointing out typical difficulties students encounter when learning the topic of evolution?

1.5 THE MISCONCEPTIONS TERMINOLOGY ISSUE

A plethora of different terms is used in the literature to describe students' misconceptions. This is a source of confusion, particularly for novices (Wandersee, Mintzes, & Novak, 1994). The use of multiple terms by authors is an indication that science educationists do not seem to agree on a single term to be used to describe students' unscientific ideas (Wandersee et al., 1994). The first problem is that different authors may use the same term to mean different things, for example, *misconceptions* to refer to two types of errors: those mentally constructed and those simply rote-learned. The second problem in the literature is that sometimes authors use different words to refer to the same thing. When referring to mentally constructed misconceptions, different authors use a range of terms such as *misconceptions, alternative conceptions,* or *prior conceptions,* which confuses readers (Wandersee et al., 1994).

1.5.1 Efforts to understand the terminology issue

Several authors have tried to develop typologies of errors in an effort to avoid the confusion in the science education literature. Abimbola (1988) suggested categories based on the philosophy of the writers, so students' misconceptions are considered either from an *empiricist* or from the '*new*' *philosophy of science* epistemological standpoint. Abimbola (1988) suggests that authors whose philosophical standpoint is empiricist tend to view erroneous ideas as scientifically 'wrong', using judgemental terms such as *misconceptions, erroneous ideas, mistakes,* or *misunderstandings.* Empiricists may also consider some ideas not to be part of the scientific world, and use terms such as *incidental knowledge, unfounded beliefs, superstitions,* or *world knowledge*. Abimbola (1988) claims that scholars with the 'new philosophy of science' perspective tend to view students' unscientific ideas as a stepping stone to new learning, subdividing them (authors) into those who use incorrect ideas as a starting point to evolve new ideas (the evolutionists) and those who try to replace these ideas with more scientific ones (the revolutionists). This taxonomic subdivision is problematic in that empiricists and revolutionists tend to use the same terms (*misconceptions, erroneous ideas, mistakes,* or *misunderstandings*) to describe students' unscientific ideas, so the logic behind the classification is questionable. However, whilst some new philosophers use judgemental terms similar to the empiricists, some use non-judgemental terms which may be neutral (*prior schemata, prior conceptions,* or *existing conceptions)* or terms which are more accepting of the unscientific ideas (*alternative ideas, alternative frameworks* or *alternative conceptions*).

Abimbola's typology does not distinguish between the two major types of unscientific ideas, those that are mentally constructed by the person holding the idea and those that are simply acquired. There is a difference between constructed ideas and acquired errors (Wandersee et al., 1994). The work of Ausubel on meaningful versus rote-learning is useful in explaining the difference. According to Ausubel (1968), meaningful learning involves mental processing, often requiring restructuring of the existing cognitive structure in order to incorporate the new knowledge. Posner, Strike, Hewson and Gertzog (1982) call this process 'conceptual change'; this can be equated to the construction of new ideas. Ausubel (1968) points out that not all new knowledge is learned meaningfully, and describes rote-learning as an alternative, explaining it as the non-cognitive memorisation of information. In science education, scientific errors which are mentally constructed should be distinguished from those that are just acquired from an external source with minimal cognitive processing.

The term 'misconception', commonly used in the literature, has two meanings, an everyday and a technical meaning, and few authors distinguish between the two. Many authors use the term *misconception* in the everyday sense, meaning a *mistake* or *error* (Oxford English Dictionary, 2014) without thinking about whether the idea has been mentally constructed. Members of the public, including many teachers, some of whom later become textbook writers (Jiménez Aleixandre, 1994), tend to understand the term *misconception* from this layperson's point of view. However, a number of science education researchers use the technical term 'misconceptions' to refer only to scientific errors which are mentally constructed by the learner (Wandersee et al., 1994). However, in this study, the term *misconception* is used in its everyday sense, and the following section provides justification for this.

1.5.2 Terminology for this study

Whilst the term *unscientific ideas* is suitable for referring to both *acquired errors* (ideas acquired from an external source without any cognitive processing) and *true misconceptions (*cognitively constructed but scientifically incorrect ideas), in this research, the term *misconceptions* will be used in its everyday sense as an umbrella term. This is because it is a single term, commonly used in the literature, and is more easily understood by different stakeholders in science education than the more correct term *unscientific ideas.*

1.6 THE VALUE OF THE STUDY

Leedy (1989, p. 61) points out two related questions that can be asked in order to justify the importance of undertaking a research study: "*Of what use is it? What practical value does the study have*?" The purpose of science education research should be to lead to insights that inform and improve classroom practice (Novak, 1977). Because researching misconceptions is a time-consuming and difficult process for teachers, "... r*esearchers can make valuable contributions to science education by identifying ... misconceptions and telling teachers about them"* (Eaton et al., 1984, p. 378).

My study makes several contributions: Firstly, no research has yet been conducted on the new *Life Sciences* CAPS policy documents, textbooks and teacher guides as a potential source of misconceptions about evolution, so this research helped to fill a research gap. Secondly, my research findings are of potential benefit to key stakeholders (publishers, authors, teachers, and South African Department of Education officials) if the findings are shared through workshops, conferences, and science education journals. Thirdly, using evolution as the topic of investigation, the study illuminated the shortfalls of using teacher support documents without critical reflection on their accuracy in terms of misconceptions. This could improve awareness by practising teachers of the need to check textbooks for misconceptions before classroom use. Fourthly, curriculum reforms have a number of effects on those implementing them. A new curriculum tends to deskill stakeholders, and comes with stressful demands which cause anxiety amongst teachers. Teachers need external support to cope with the demands of curriculum reforms, and to help them implement the new curriculum (Jensen, 1990; Rogan & Grayson, 2003). Civic groups and researchers have a significant supportive role to play in supporting stakeholders during curriculum reforms (Jensen, 1990; Lewin, 2000). This study provides information to stakeholders on the nature and extent of evolution misconceptions in the new CAPS curriculum support documents so that appropriate intervention strategies may be put in place to bring about smooth curriculum reforms.

The presence of misconceptions in the old *Life Sciences* curriculum documents has been pointed out to stakeholders so that something can be done to address the same problems during the implementation of the new curriculum. In addition to publishing the results in an international science education journal (Tshuma & Sanders, 2015), a number of workshops were conducted for South authors and publishers (Sanders, Tshuma, & Makotsa, 2012; Sanders in association with Tshuma & Makotsa, 2012; Sanders, Tshuma, & Makotsa, 2013) on the problem of misconceptions in the South African *Life Sciences* curriculum support materials. The rationale for this information campaign was that the problem of misconceptions in science education needs a multi-faceted approach from different stakeholders so that it can be resolved. All the stakeholders ought to be aware of the severity of the evolution misconceptions problem, initiated and perpetuated by errors in the curriculum statement document (as revealed by this and the previous research) so that the need to work together to resolve it becomes a priority.

1.7 THE STRUCTURE OF THIS DISSERTATION

This chapter has highlighted the context of, and motivation for, the study. Chapter 2 provides details of how the literature-based theory and research (practice) was used as a conceptual framework which informed this study. Chapter 3 takes the reader through the procedures which were followed (and their justification) in order to gather evidence to answer the research questions, as recommended by Hatch (2002). Chapter 4 outlines how data was organised and interrogated in ways that allowed the emergence of patterns, themes, explanations, and relationships that helped in the provision of answers to the research questions. Finally, Chapter 5 looks at how discussions which arose from the emerging patterns of Chapter 4 led to inferences and conclusions which responded to the aims of this study.