CHAPTER 2

The conceptual framework for the study

This chapter spells out the details of the conceptual framework which guided this research (see Figure 3 for an outline of this chapter). It provides details about what conceptual frameworks are and reasons why conceptual frameworks are important in improving the quality of research. It then describes the constructs which make up the conceptual framework for this study and the relationships between them, before concluding the chapter.

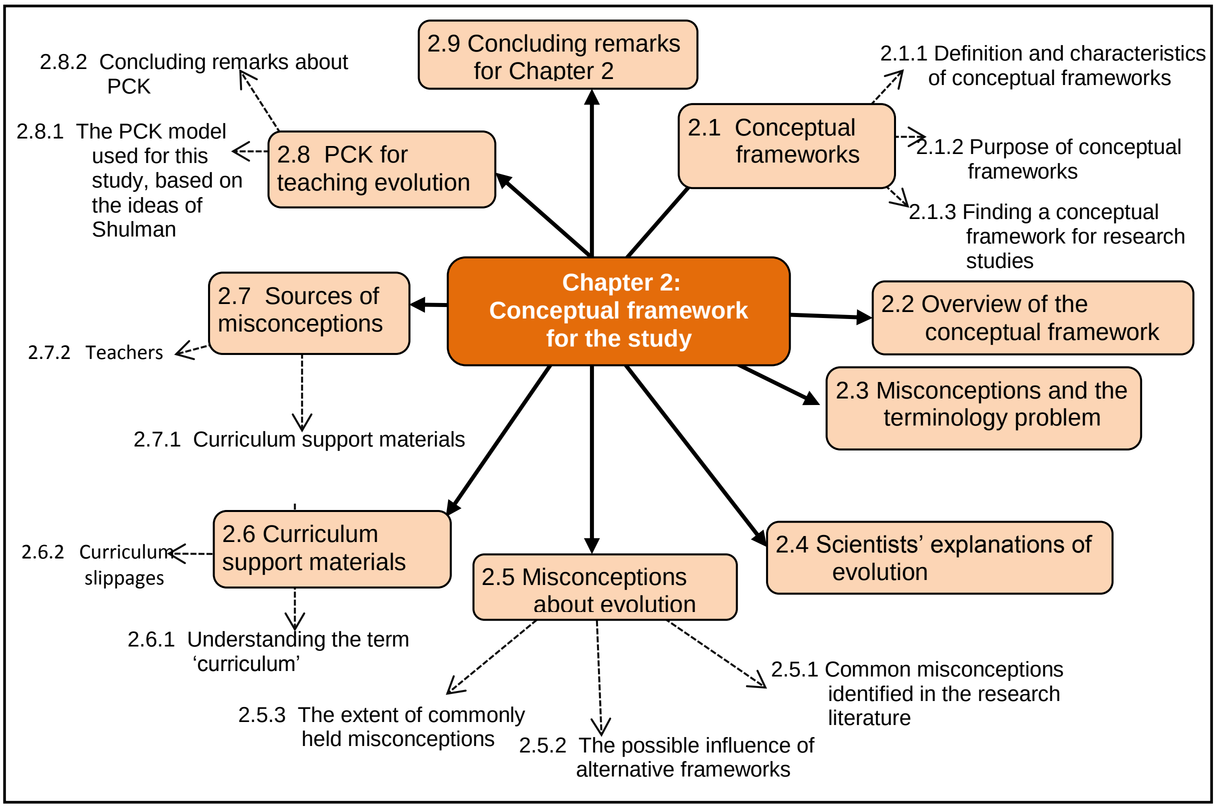

Figure 3: Overview of Chapter 2

2.1 CONCEPTUAL FRAMEWORKS

"The conceptual framework is alluded to in most serious texts on research, described in some and fully explained in few" (Leshem & Trafford, 2007, p. 93). However, because conceptual frameworks scaffold the research process, they are critical for the success of research efforts.

2.1.1 Definition and characteristics of conceptual frameworks

Because different authors define conceptual frameworks differently, it is not easy to come up with a single definition of a conceptual framework. However, Maxwell (2005) defines a conceptual framework as *"... primarily a conception or a model of what is out there that you plan to study, and what is going on with these things and why—a tentative theory of the phenomenon that you are investigating"* (Maxwell, 2005, p. 33). The conceptual framework may turn out to be written or unwritten beliefs, theories, or actual ideas a researcher holds about phenomena (Maxwell, 2005).

According to Miles and Huberman (1984, p.33), a conceptual framework is '*.... the current version of the researcher's map of territory being investigated,'* including "*... the main things to be studied - the key factors, concepts, or variables - and the presumed relationship among them" (*Miles & Huberman, 1994, p. 18). It is important to realise that researchers' conceptual frameworks can be changed as the research processes unfold. Miles and Huberman (1994) point out those researchers may start with tentative conceptual frameworks which can be revised and refined in the light of emerging insights from data collection. A conceptual framework should therefore be viewed as a flexible tool for researchers' use which "... *may evolve as the research evolves'* (Leshem & Trafford, 2007, p. 95), rather than as a "*.... a straitjacket into which the data is stuffed and bound"* (Bettis & Mills, 2006, p. 68).

Researchers formulate conceptual frameworks in order to scaffold particular studies. Ideas that inform the structure and coherence of conceptual frameworks are formulated by the researcher using insights from elsewhere to meet the demands of their particular research problems. It is therefore inappropriate to view conceptual frameworks for previous research studies as authorities which are already found and pre-defined by other authors (Maxwell, 2005).

According to Leshem and Trafford (2007), textbooks on research methodology do not use a common language when it comes to the issue of conceptual frameworks. In the education methodology literature, a conceptual framework is also sometimes referred to as a '*theoretical framework'* or '*idea context'* (Maxwell 2005, p. 33). Some of the constructs making up a conceptual framework may be well established theories and others may not necessarily have a theoretical basis. Following this line of thinking, and as used by prominent authors such as Miles and Huberman (1994) and Maxwell (2005), I used the term 'conceptual framework' instead of 'theoretical framework.' This is because, as referred to by Anfara and Mertz (2006), I consider the relationships between different constructs (both theories and non-theories) in this study as a framework, grid or scaffold to assist my understanding of the phenomena under investigation.

Referring to a conceptual framework using the term '*literature review'* is not appropriate. Maxwell (2005) points out three reasons for this. Firstly, it may lead to a narrow view on literature that excludes knowledge from the researcher's own experiences, the researcher's intuitive speculations, unpublished papers from other researchers in the same field, and theses. Secondly, it may lead to mere routine descriptive literature surveys which may omit some of the key constructs relevant to the study or may lack critical analysis. Thirdly, it may result in the production of reports on past research and theories with little articulation and relevance to the problem under investigation. Bak *(*2004) points out conceptual frameworks are not about just summarising research publications, they should also involve the voice of the researcher when the relatedness between all the constructs relevant to the study is highlighted. They should go beyond reading and reproducing what other researchers have worked on because the purpose of the framework is to provide researchers with a critical view of what is happening in the field of study (Bak, 2004).

Conceptual frameworks should be viewed as a way of listening to the conversation of practitioners in the discipline on what is already known as one can only '*... contribute fruitfully to the conversation once one has understood what it is all about (*Bak, 2004, p. 20). Reviewing the literature for the conceptual framework as a means of listening to existing dialogue in the field of study has some benefits. The first benefit is that it gives the researcher a broader understanding of what is documented in the literature, which allows a critical analysis of the phenomenon under study (Bak, 2004; Maxwell, 2005). The second benefit is that it gives the researcher room for locating constructs for the study and explaining the relationships between them in the context of other studies (Maxwell, 2005). It is for this reason that this chapter is entitled “Conceptual framework” and not “Literature review’’.

2.1.2 Purpose of conceptual frameworks

“*No study, naturalistic or otherwise, can be conducted without an underlying … model*” (Bailey 1997, p. 135). Conceptual frameworks act as a model. They are important as they allow researchers:

- to locate their study in the context of work done by other researchers (Leedy, 1985; Badenhorst, 2005; Leshem &Trafford 2007; Miller, 2007; Bodner & Orgill, 2007)
- to get ideas of how to set suitable research questions for their studies (Miles & Huberman, 1994; Maxwell, 2005; Bodner & Orgill, 2007)
- to choose a suitable research design and methods (Leshem & Trafford 2007)
- to interpret their results against the background of what other researchers have found (Leedy, 1985; Miles & Huberman, 1994; Maxwell, 2005; Anfara & Mertz, 2006; Badenhorst, 2005).

Conceptual frameworks act like a thread that runs through the entire research study from the start to the finish so as to give it structure and coherent meaning (Badenhorst, 2005). They allow researchers to see the link between the research problem, the literature, the methods, and the research results (Borgatti, 1996; Caliendo & Kyle, 1996; Leshem & Trafford 2007).

2.1.3 Finding a conceptual framework for research studies

Coming up with a single existing conceptual framework for use in research is difficult due to the complexity of science education research (Abd-El-Khalick & Akerson, 2007). Given this complexity, most researchers formulate their own conceptual frameworks for their research (Miles & Huberman, 1994), using four possible sources: the work of other researchers and existing theory (Maxwell, 2005; Leshem & Trafford, 2007); from personal experiences and observations (Leshem & Trafford, 2007); from insights arising from undertaking a pilot study (Maxwell, 2005); and from thought experiments, which are mental processes that draw from experience and theory and attempt to come up with plausible explanations of one’s own and other’s explanations of observed phenomenon by providing answers to ‘what if’ questions (Maxwell, 2005).

Different authors provide different guidelines on how to come up with a conceptual framework for a study. Miles and Huberman (1994) propose starting with tentative constructs which are relevant to the research and then refining the relationships between them to form a framework which will help with the research design and interpretation. As more insights arise from the researcher’s engagement with the research, they can then refine their framework, often producing a theoretical model.

Bak (2004) uses the terms ‘**inside out’** and ‘**outside in’** to describe different approaches when working with conceptual frameworks, reflecting the two stages mentioned by Miles and Huberman (1994). The ‘outside in’ approach assumes that reality and knowledge are well organised, predictable and pre-defined. With these philosophical assumptions in mind, the researcher identifies a well-established conceptual framework and then uses it to guide, interpret and make sense of the phenomenon under investigation (Bak, 2004). The ‘inside out’ approach assumes that “... *there are no neat conceptual parcels that correspond accurately with the real, messy, complex world”* (Bak, 2004, p. 19). Because of these philosophical assumptions, this approach allows the researcher to come up with a suitable conceptual framework (involving all the constructs identified from the literature review) that will be relevant to a particular study. For the ‘inside out’ approach (which was followed for this study), the researcher's construction of the conceptual framework is informed by practices in the discipline, as pointed out by various authors (Miles & Huberman, 1994; Bak, 2004).

2.2 OVERVIEW OF THE CONCEPTUAL FRAMEWORK FOR THIS STUDY

Miles and Huberman (1994) recommend that a conceptual framework should be visually represented in order to show all the constructs and the relationships between them. The constructs that make up the conceptual framework for this study, and the relationships between them, are shown diagrammatically in Figure 4, and the details are outlined in the following sections.

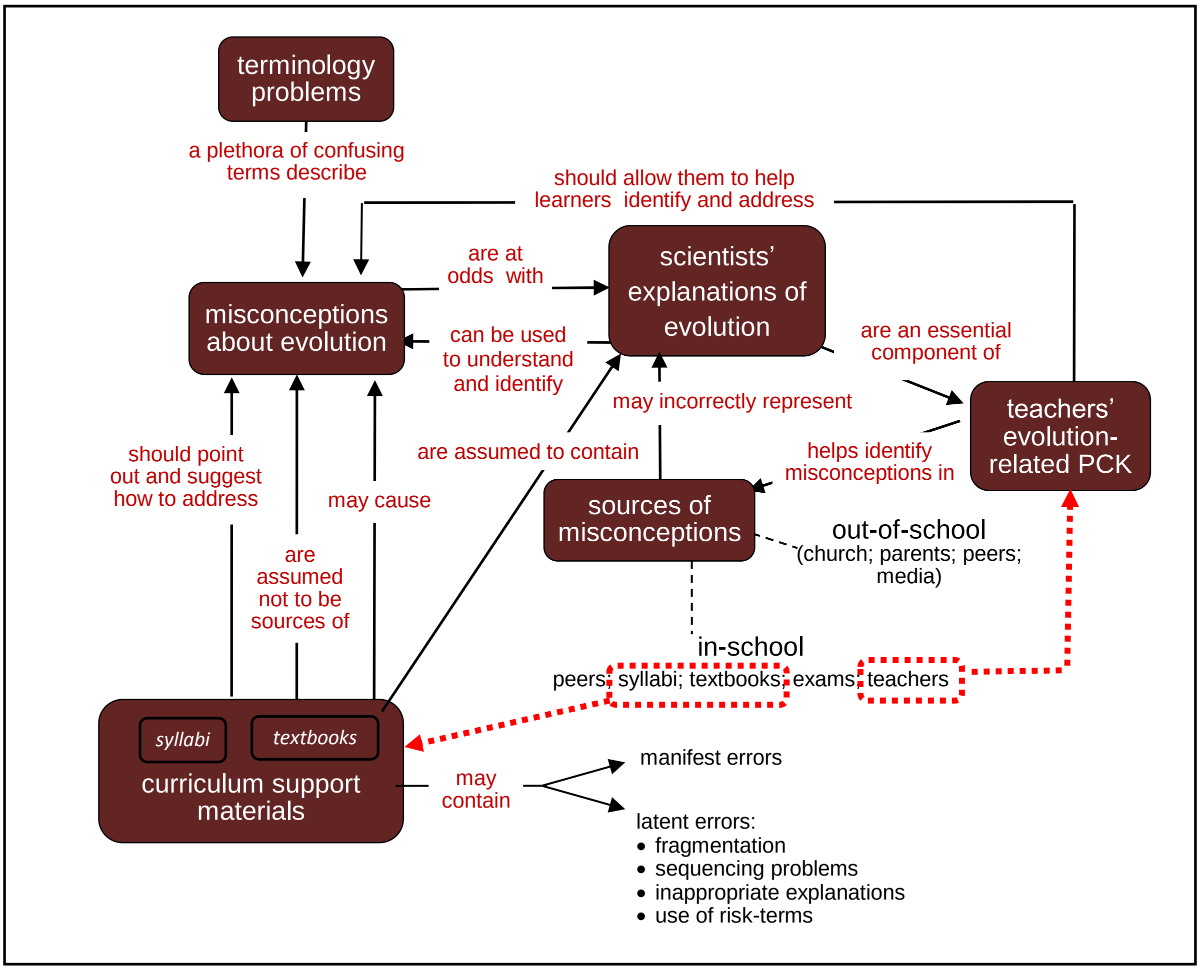

Figure 4. Conceptual framework for the study

2.3 MISCONCEPTIONS AND THE TERMINOLOGY PROBLEM

The first construct in my conceptual framework is the 'terminology problem'. Because the terminology issue has already been discussed under Section 1.5 of Chapter 1, I have not included it again in the conceptual framework chapter. However, the terminology problem is part of the conceptual framework diagram (Figure 4) because in order to understand the misconceptions about evolution in the literature, one needs to be aware of the different terms that are used to refer to unscientific ideas. Wandersee et al. (1994), point out that the use of different terms to describe students' misconception is problematic in the literature and is a source of confusion. In Section 1.5.2 of Chapter 1 I have explained why I will use the general commonly used term *misconception.* In this dissertation this is used in the everyday sense not the technical sense. I will use the term *acquired error* when referring to scientific errors which may be acquired verbatim by document readers, and *misconceptions* only when referring to unscientific ideas which according to Wandersee et al. (1994) are a result of mental construction.

2.4 SCIENTISTS' EXPLANATIONS OF EVOLUTION

The second construct in my conceptual framework is 'scientists' explanations of evolution'. As shown in Figure 4, this construct is important for this study for two reasons. Firstly, it can be used to understand and identify misconceptions. Secondly, as illustrated in Figure 4, it is an essential component of the teacher's knowledge needed to assist students deal with the problem of evolution misconceptions. In this study, an understanding of the science of evolution helped me, as a researcher, because in order for me to identify evolution misconceptions in curriculum support materials, I needed to be aware of the correct scientific explanations of evolution. Further details on scientific content about evolution are presented in Section 2.2.3, where correct scientific details are provided in the explanations to counter misconceptions about evolution

What we know about the world can be understood in many ways. When dealing with evolution and for purposes of this study, I am interested in 'scientific knowledge' for explaining evolution. However, many people explain aspects of evolution based on 'religious knowledge,' as shown in Figure 5. Religious explanations about the world are not considered to be valid explanations by the scientific community. For example, the idea that all living organisms in the world today were created by a Supreme Being over six 24-hour days and have not changed since is rejected by scientists because it cannot be empirically checked. Abimbola and Yarroch (1993), classify scientific knowledge about the world into three categories which show its dynamic in nature (see Figure 5): firstly, ideas **no longer accepted** (e.g. the ideas of Lamarck, which are based on the inheritance of acquired traits), secondly, the **currently accepted scientific ideas**, e.g. details based on Darwin's ideas dealing with evolution by the process of natural selection, as updated in the evolutionary synthesis (discussed below), and thirdly, new **ideas not yet completely established** (e. g. epigenetics, discussed later).

***Currently accepted scientific ideas*:** Three central ideas about evolution, emphasised by authors such as Futuyma (2009) and Mayr (1991), are that organisms share a common ancestry, that they undergo change over time (descent with modification), and that natural selection is the main mechanism through which the change happens and new species are formed.

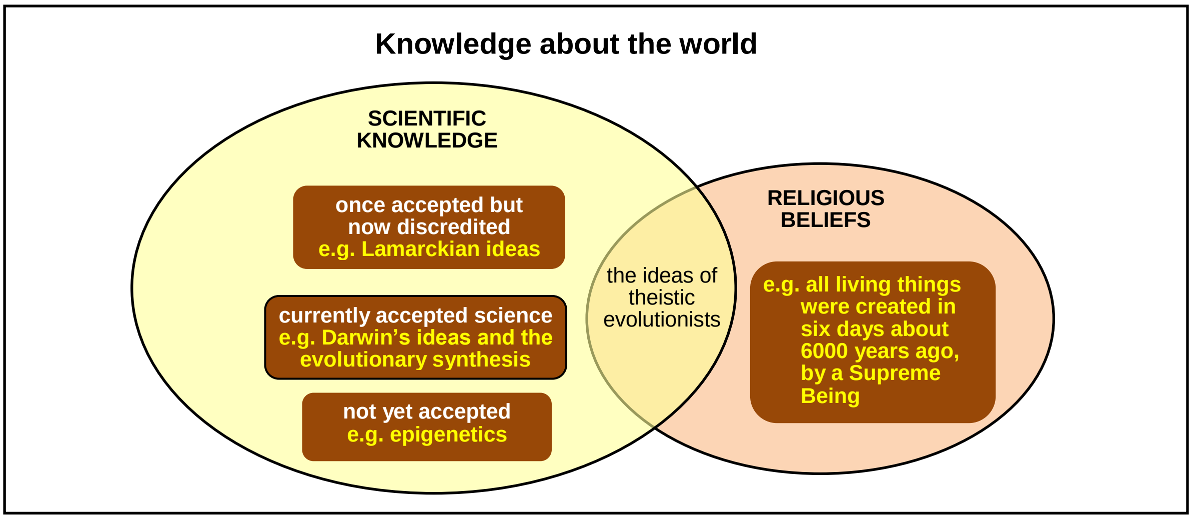

Figure 5. Categorising knowledge about the world (based on Abimbola & Yarroch, 1993)

There is an overwhelming body of evidence showing that organisms have **changed over time** and **evolved from a common ancestor.** Evidence of organisms having descended from a common ancestor includes comparative homology (the similarities in the structure of forelimbs of some vertebrates); comparative embryology (similar patterns shown by developmental stages of vertebrate embryos); molecular homology (similarities at molecular level shown by all living organisms); biogeography (the distribution of life on different continents); and changes in fossil appearances (palaeontology) For example, the presence of vestigial structures in organisms is an anatomical indication of common ancestry. A vestigial structure is a "*functionless or rudimentary version of a body part that has an important function in other closely allied species"* (Freeman & Herron, 2004, p. 39). The legless reptile (*Charina bottae*), for example, just has internal hips with little spurs in place of legs, which is evidence of descent with modification from their ancestors which had functional hind legs (Freeman & Herron, 2004).

Biological evolution has to do with changes in the characteristics of populations of organisms over many generations (Futuyma, 2009). Of the four currently accepted mechanisms by which evolution occurs, natural selection (outlined below) is the only one that does not happen by chance, is directed and sustained, and leads to evolutionary adaptations (Freeman & Herron, 2007; Starr, Evers & Starr, 2013). The other three, mutation, migration and genetic drift, are only sustained if natural selection occurs (Futuyma, 2009). Darwin's most significant contribution to our understanding of evolution was that "... *natural selection was the principal mechanism by which biological evolution occurs" (*Futuyma, 2009).

The current scientific model of **evolution by natural selection,** known as the evolutionary synthesis, is the result of scientists' consensus on the original ideas proposed by Darwin as well as contributions by other scientists from different fields for the past 150 years after the publication of the *Origin of species*. Futuyma (2009) lists 16 points which summarise the current views of scientists about evolution by natural selection. Key issues central to Futuyma's 16 points are based on the fact that there is variation amongst members of the same population. The underlying genotypic differences (caused by random spontaneous mutation) cause individuals of a population (members of the same species living in a given geographical area) to vary. Variations in members of a population are expressed phenotypically (behaviourally, or physiologically). Individuals with certain favourable characteristics may have survival advantages over those without those traits, in their particular environment. Members of the population with favourable traits are more likely to survive, and also have a better chance to produce more offspring (referred to as fitness) than those without the favourable traits. Fitness refers to reproductive success and not whether individuals of a population have favourable traits. Members of the population with favourable alleles are likely to pass them to more offspring in the next generation compared to those with the unfavourable alleles, due to the differences in their survival and reproductive success. The favourable traits (determined by the favourable alleles) therefore become more frequent in the population (gene pool) over many generations; as a result, an evolutionary change (or adaptive evolution) by natural selection is said to have occurred because the allele frequency of the population would have changed over many generations.

Scientists emphasise that evolution occurs at population level and not at the level of individual organisms. This is because the genetic make-up of an individual is fixed from birth (The University of California Museum of Palaeontology, Berkeley, 2006). According to Campbell, Reece, Urry, Cain, Wasserman, and Jackson (2008), two types of evolution can occur: microevolution ("[e]*volutionary changes below species level* ..." p. G-23) and macroevolution ("[e]*volutionary change above the species level, including the origin of new groups of organisms ...*" p. G-21).

Two alternative 'theories' about the way in which natural selection happens have been proposed. Darwin suggested the idea of 'gradualism' (which Mayr, 1991 refers to as the fourth of five theories within Darwin's theory of evolution). This mechanism postulates that changes in populations occur gradually and are cumulative (Johnson, 1982). However, in 1972, Eldredge and Gould proposed an alternative idea, the 'theory of punctuated equilibrium'. This 'theory' proposed that evolution takes place in *"bursts of activity separating relatively long periods of quiescece, rather than in a gradual manner"* (Bak & Sneppen, 1993, p. 4080). Evidence exists to support that both gradualism and punctuated equilibrium may occur, and that it is not a case of one or the other.

The last of the five theories identified by Mayr (1991) within Darwin's theory of evolution by natural selection is the theory of the **multiplication of species.** The diversity of life on Earth is a result of evolution through adaptive radiation (divergent evolution) which occurs when one ancestral species differentiates into a vast array of different species (Freeman & Herron, 2004; Starr et al., 2013). For instance, mammals show adaptive radiation from a shrew-like insectivorous ancestor. The appendages of various mammals have evolved and are now suited to perform particular functions, such as flattened front limbs for digging in moles, flipper-like limbs for swimming in seals, wings for flying in bats, and hindlimbs suited for jumping in kangaroos. The original shrew-like species has become many different species. A species is a group of organisms that has the potential to interbreed amongst themselves to give fertile offspring (Futuyma, 2009). Small changes occur in members of the same population, and accumulate over time. When members of a population are so different that they can no longer breed and produce fertile offspring, speciation would have occurred. Speciation occurs in two main ways. If individuals of a population become geographically separated and they each adapt to the different environments, a stage may eventually be reached where, even if they were to come into contact with each other, they could no longer breed and produce fertile offspring. The two populations would have become two species. This is called allopatric speciation. The second mechanism of speciation, known as sympatric speciation, occurs when members of a population in one geographical area evolve differently and become reproductively isolated. Either they cannot mate or they can do so but the offspring are infertile. Each type has become a different species (Freeman & Herron, 2004).

Knowledge not yet accepted: The third category of scientific knowledge shown in Figure 5 is the cutting-edge scientific ideas which are not yet widely accepted but which are candidates for future acceptance. Epigenetics stands out as a new area of research that may eventually bring new insights for extending the evolutionary synthesis under what has been termed the 'extended synthesis' (Schrey, Richards, Meller, Sollars, & Ruden, 2011). The most notable thing about epigenetic modifications of the phenotypes of some organisms is that traits acquired during the lifetime of an organism, although they do not have a genetic basis, can sometimes be passed from parent to offspring (Schrey et al., 2011; Crews & Gore, 2012). Because of these new ideas on how traits can be inherited, epigenetics has the potential to change our understanding of how evolution occurs and, according to Crews and Gore (2012, p.1), it "… *is the next epoch in evolutionary theory, as these mechanisms alter heritability and force us to confront classical genetic ways of viewing the environment"*. In this study, the issue of epigenetics was excluded because, as outlined in Figure 5, it still needs further research and verification before it becomes widely recognised and accepted by the entire scientific community (Schrey et al., 2011).

2.5 'MISCONCEPTIONS' ABOUT EVOLUTION

The third construct in my conceptual framework, 'misconceptions about evolution,' or what Wandersee *et al*. (1994) term 'unscientific knowledge' about the world, is central to my research.

2.5.1 Common misconceptions identified in the research literature

In order to get a deeper understanding of the construct ‘misconceptions about evolution,’ I carried out a literature review on two important aspects, Firstly, the most common evolution misconceptions and why they qualify to be termed ‘erroneous’, and secondly, the nature and extent of commonly held misconceptions as established by research around the world. As illustrated in Figure 4, it was important for me to know common evolution misconceptions and why they are erroneous so that I would be able to identify them in the curriculum support documents I analysed.

Misconceptions about evolution may be associated with failure to understanding certain important aspects in biology, such as failure to understand key processes that lead to the appearance of new traits in a population (Kampourakis & Zogza, 2007); lack of knowledge about how or why new traits persist in the population over time (Bishop & Anderson, 1986); failure to comprehend that the process of natural selection acts on variations amongst individuals (phenotypes which are genetically determined) in a given population (Bizzo, 1994); misunderstanding of the nature of evolutionary change in a population (Bishop & Anderson, 1986); and incorrectly thinking that during evolutionary change all members of a population undergo slow change over time (Halldén, 1988). The idea of evolution by natural selection is a complex concept which many biology students struggle to understand (Bishop & Anderson, 1986, Halldén, 1988; Kampourakis & Zogza, 2007). Bishop and Anderson (1986) claim that students who do not understand that evolution occurs through mechanisms such as mutation, migration, genetic drift, and natural selection are more likely to develop misconceptions about evolution.

In this study, evolution misconceptions were grouped under four categories used by the Biology Education Research Group of the University of the Witwatersrand, of which I am a member. Classifying misconceptions into groups made locating individual misconceptions for use during coding of text documents easier, since misconceptions in the same group were assigned similar letters and numbers which were numerically close to each other. The letters and numbers for each cluster of misconceptions were used as codes for coding all the identified errors in texts (see Table 5a in Section 3.4.4 of Chapter 3 for the coding system used).

Misconceptions associated with misunderstanding the mechanisms of evolution

My literature review revealed that most misconceptions found in the literature are associated with misunderstanding of how evolution occurs. A total of 46 misconceptions under this category were investigated in this study (see Table 5a in Section 3.4.4 of Chapter 3 for misconceptions in this category). Those identified most frequently in the literature include the following.

- **Organisms pass evolutionary advantages to [all] their offspring:** This misconception implies that favourable characteristics of parents are guaranteed to be inherited by the offspring (Kapourakis & Zogza, 2007; Reiss, 1999). Inheritance of favourable traits by offspring is not necessarily a given as it depends whether the allele is dominant or recessive, and on the zygosity after the fusion of gametes from both parents (Prinou et al., 2008). For example, if the gene combination after fertilisation results in a homozygous recessive, then the offspring will not all get the favourable traits from the parents if the unfavourable traits are determined by a recessive allele (Futuyma, 2009; Science Daily, 2008).
- **Organisms change because they need to (in order to survive):** It is incorrect to think that an organism can intentionally change and acquire traits for use for its survival (Pedersen & Halldén, 1992). The traits formed by random mutation and genetic recombination during meiosis (which

cause inheritable variations) cannot be intentionally decided upon by organisms in order to adapt to changing environments so as to survive. The idea that evolution results in a goal-directed change which arises from the intentional thinking of an organism in order to survive is therefore a misconception (Olander, 2006; Gregory, 2009).

- **Environmental changes cause / result in evolution:** Evolution is not caused by environmental changes (Olander, 2006). Evolutionary processes do not need the environment to change first before they happen (Futuyma, 2009). Natural selection is not a conscious agent and cannot see that the environment has changed so that it can ensure the appropriate evolution of populations. Gregory (2009, p. 168) terms such erroneous thinking as "*external"* anthropomorphic thinking in the sense that 'nature' is assumed to be able to make conscious decisions in favour of the organisms.
- **Natural selection is passing useful traits to offspring:** Passing on useful traits to offspring occurs through reproduction and not natural selection (Herron & Freeman, 2007; Campbell et al., 2008)
- **Individuals with a favourable adaptation will mate only with each other:** Organisms with favourable characteristics do not make conscious decisions to mate with each other (anthropomorphic thinking). Organisms with unfavourable characteristics (in terms of evolutionary adaptation) can also mate with those having favourable traits (Futuyma, 2009), although in some cases of intersexual selection (selection between male and female), females are likely to choose males with showy displays rather than for other favourable adaptations they might have (Campbell et al., 2008).
- **Individuals with favourable characteristics will survive and reproduce, and those with less favourable characteristics will die or become extinct**:: To have favourable traits does not guarantee survival and reproduction. Organisms with favourable traits could die from disease or predation, in spite of having favourable traits. Furthermore, individuals with less than optimal traits may reproduce and do not necessarily die or become extinct. Organisms with unfavourable traits may not be as successful as those with favourable characteristics, but this does not guarantee their death or extinction (Science Daily, 2008).
- **'Survival of the fittest' means that only organisms that are physically strong survive:** The term 'fittest' has different meanings in science and everyday language (Nehm et al., 2009). Survival of the fittest is often misinterpreted in literal terms to mean that only the physically tough can survive and those which are not die out (Gregory, 2009). 'Survival of the fittest' in science means that those organisms which have traits that are favourable to a given environment have a relatively higher probability (chance) of surviving and reproducing than those with other traits (Herron & Freeman, 2007).
- **The theory of evolution explains that people evolved from apes:** Humans did not evolve from modern day apes. The genetic and anatomical similarities between human and apes are not because apes are our ancestors, but because *Homo sapiens* and modern apes shared a common ancestor five to six million years ago (Futuyma, 2009).
- **Only organisms with dominant alleles are selected for, and result in evolution:** Natural selection does not favour dominant alleles only. During evolution, populations may have a combination of homozygous dominant, heterozygous, and probably a relatively smaller proportion of homozygous recessive individuals (Campbell et al., 2008). Therefore to think that natural selection can select dominant alleles only, leading to evolution, is erroneous (Settlage, 1994; Gregory, 2009).

- **Mutations affecting phenotypes cause genetic diseases:** Gene mutation is a spontaneous and random process which can lead to three possible outcomes: harmful, neutral or beneficial mutation. These three possible outcomes may affect the phenotypes of organisms but do not necessarily result in genetic diseases (Gregory, 2009).
- **Fossils take millions of years to form:** The formation process can be quicker and it is how long it takes to find fossils that may be slow (Campbell et al., 2008), thus giving rise to this misleading concept. Some fossils only formed far less than a million years ago, for example, mummified remains of humans (about 200, 000 years old) have been found in arid places (Fossils-facts-and-finds.com, 2013).
- **Fossils are preserved in stone / only in sedimentary rock:** Some fossils have been discovered in ice, tree amber or lying loose in caves. Therefore it is not always the case that fossils only occur in stone or sedimentary rocks (Freeman & Herron 2007).

Scientifically incorrect ideas possibly associated with religious beliefs

The second category of misconceptions has to do with scientifically incorrect ideas which often seem to be associated with religious beliefs. Religious beliefs which are counter to scientific ideas are a cause for concern for science educationists because they are difficult to overcome (Lawson & Weser, 1990); make the learning of evolution ideas by students "… *simply overwhelming, academically, emotionally, and spiritually"* (Sinclair et al., 1997. p. 124) and they become major barriers to the learning of evolution (Findley, Lindsey, & Watts, 2001). According to Köse (2010) misconceptions associated with religious beliefs arise because of a) a lack of understanding of the difference between the nature of science and the nature of religion, and b) failure by teachers to deal with the perceived conflict between evolution and religion.

Misconceptions associated with religious beliefs are mainly of two types: actual misconceptions (for instance, the erroneous thinking that one cannot believe in God and evolution at the same time), and religious beliefs that are not acceptable to scientists (e.g. the belief that the Earth and all living things were created in six 24-hour days – Reiss, 2008). Such beliefs are problematic because they cannot be verified empirically. Misconceptions associated with religious beliefs, and reviewed in this study include:

- **Evolution and religion are incompatible (people who believe in evolution cannot believe in God, and vice versa):** Science and religion are different ways of viewing the world and this is a source of confusion for some people (The University of California Museum of Palaeontology, Berkeley, 2006; Martin, 2010). Some scholars suggest keeping science and religion separate to minimise confusion because

  > *"It is a dangerous thing to engage the authority of the scriptures in disputes about the natural world, in opposition to reason, lest time, which brings all things to light, should discover that to be evidently false which we had made scripture to assert …."* (Burnet, 1684, cited by Moore, Decker, & Cotner, 2010, p. 19).

  Whilst religion is based on belief systems involving the existence of a Supreme Being, science is based on empirical evidence and does not address issues of faith, and these two may co-exist without causing conflict (Martin, 2010). Scott (2009) points out that the relationship between evolution and creationism is not a dichotomy between two choices, but a continuum. The continuum, consists of literalist creationism at one extreme (where religious texts such as the Bible, Qur'an, or Torah are interpreted as literally true) and scientific evolutionists at the other (who accept only scientific reasons and not religious ideas). It is a misconception to think that one must accept either evolution or religion (The University of California Museum of Palaeontology, Berkeley, 2006; Martin, 2010) and the *"… thought that in some ways these ideas are mutually exclusive should be dispelled strongly"* (Reiss, 1999, p. 206).

- **Evolutionary theory denies the existence of God:** The existence or non-existence of God cannot be verified empirically. The science of evolution explains the history of life and does not address whether God is there or not, because science is not based on faith (Gregory, 2009; The University of California Museum of Palaeontology, Berkeley, 2006).
- **Churches say evolution is ungodly:** According to Martin (2010), most major churches have church leaders who receive formal training in theology and do not teach biblical creation as literally explained in the book of Genesis. Such churches do not say evolution is ungodly. Most such major churches in the United States of America consider evolution as being compatible with their religious teaching (Martin, 2010).
- **Evolution explains how the Earth was created**: This misconception is probably due to lack of knowledge that biological evolution is about the origin of species and not how the Earth was formed (Rice, 2010). The formation of the Earth is not part of biological evolution but is dealt with in the field of physical sciences (The University of Liege, 2009; National Research Council, 2012). It is therefore a misconception to associate biological evolution and the creation of the Earth.
- **The first living organisms appeared on Earth at about the same time that the Earth was created:** Scientific evidence and calculations estimate the age of the Earth to be about 4.6 billion years old (Futuyma, 2009). After the formation of the Earth, temperatures were too high to support life. Life forms only evolved later when conditions changed. Radiometric dating shows that the first life forms (unicellular cyanobacteria) developed about 3.5 billion years ago and higher organisms evolved only a billion years ago (Campbell et al., 2008). The first forms of life therefore evolved about one billion years after the formation of the Earth (Dalrymple, 1991).
- **Creation beliefs can be taught as a valid alternative explanation to evolution in science:** Some fundamentalists believe that if religious beliefs are not taught in parallel to evolution, then some kind of spiritual imperialism (which disrupts the religious well-being of society) will be promoted (Berger, 2006). However, because creation beliefs are regarded as non-science by scientists, it is inappropriate to take them as an alternative explanation to evolution in science classes (Brem et al., 2003), as this may deny *"… learners, especially those from impoverished environments, meaningful access to higher-order concepts and ways of thinking …"* (Dempster & Hugo, 2006, p. 106).
- **Humans have not evolved since they first appeared on Earth:** The fossil record shows that hominins have evolved (changed) over time. For instance, when comparing the skulls of different hominins, the snout sizes become shorter as one moves up the evolutionary tree from *Homo habilis,* to *Homo erectus, Homo neanderthelensis,* and to *Homo sapiens,* which has the flattest face (Campbell et al., 2008).

Scientifically incorrect ideas which seem to be associated with a lack of understanding of the nature of science

The third category of misconceptions appears to be associated with a lack of understanding of the nature of science. Whilst there is '…*no consensus on what NOS means*" (DiGiuseppe, 2013, p. 1063) there are a number of tenets of the nature of science which characterise science knowledge and distinguish it from other ways of knowing such as religion (Lederman, 1992). Science knowledge is tentative and changing, empirically based, and comes as a result of collective efforts of scientists after careful observations, inferences and open scrutiny in scientific forums (Abd-El-Khalick & Akerson, 2003).

Abd-El-Khalick and Akerson (2003), claim that misconceptions about the nature of science could be caused by lack of accurate ideas about how science knowledge is discovered. For example, misconceptions could arise from the inaccurate thinking that science knowledge is only discovered through the steps of the universal scientific method (DiGiuseppe, 2013). A typical misconception associated with this is: *evolution is not science as it cannot be tested or proven by experiments.* However, contrary to this mistaken thinking, Darwin mainly used careful observations and inferences as opposed to experimenting, to come up with the theory of evolution by natural selection.

Evolution misconceptions associated with a lack of understanding of the nature of science which were investigated in this study include:

- **Evolution is just a theory (implying it is a hypothesis not yet proven to be true):** This misconception arises due to a misunderstanding of the meaning of the word 'theory' as used in everyday language and in science (The University of California Museum of Palaeontology, Berkeley, 2006). In everyday language the term 'theory' means just a hunch or guess which is still to be verified. In science 'theory' refers to an idea that "… *can explain numerous observations, and has been rigorously and repeatedly tested, providing evidence so convincing that the idea is widely accepted by scientists"* (Sanders, 2014b, p. 9).
- **Gaps which exist in the known record of fossils disprove the theory of evolution:** This is scientifically inaccurate because science predicts gaps in the fossil record (Futuyma, 2009). Such gaps could be explained in two ways. Firstly, soft bodied organisms fail to fossilise because they do not have any hard skeletal remains that can stay intact over time (Campbell et al., 2008), so gaps in the record are expected. Secondly, the absence of favourable conditions for fossilisation to take place could also explain gaps, for example, when dead organisms are eaten by other organisms or decay before they fossilise. Furthermore, as new fossils are discovered they fill in the gaps in the fossil record. For example, the discovery of feathered dinosaurs provided a link between reptiles and birds (The University of California Museum of Palaeontology, Berkeley, 2006).
- **Scientists disagree that evolution happened:** The body of evidence supporting evolution has resulted in scientists agreeing that evolution occurred, is still occurring, and that it is the only theory which can explain scientifically the diversity of life (Futuyma, 2009). There is consensus that evolution occurred and there are no ongoing debates about that. The debates amongst scientists about evolution are based on **how** evolution happens [mechanisms leading to evolution] (Campbell et al., 2008). Critics of evolution erroneously take these debates to mean that scientists are in disagreement about whether evolution (descent with modification) happens (The University of California Museum of Palaeontology, Berkeley, 2006).
- **Evolution is a theory in crisis:** One of the tenets of the nature of science is that science knowledge is tentative and is always subjected to open scrutiny and discussions. People who lack knowledge about the nature of science may misconstrue such discussions on evolution and incorrectly conclude that scientists are not seeing eye-to-eye about it. Evolution is therefore not a theory in crisis but is a theory being enriched all the time by new discoveries and discussions (The University of California Museum of Palaeontology, Berkeley, 2006).

Incorrect ideas perhaps just a result of 'lack of knowledge'

Lack of knowledge about evolution may result in mistaken ideas about evolution. Some misconceptions are based on social practices that involve a lack of accurate information about evolution (Yates & Marek, 2013).

Examples of such misconceptions include:

- **Evolution (of new species) has never been observed:** This misconception is based on the inaccurate thinking that evolution takes a long time to occur so that within our 'short' life time evolution of new species cannot be observed (The University of California Museum of Palaeontology, Berkeley, 2006). Empirical evidence shows that new species of bacterial populations can evolve over a short period of time: a few hours or days depending on the length of the life cycle. (Ewald, 1994; The University of California Museum of Palaeontology, Berkeley, 2006; Losos *et al*., 2013). People with this misconception may simply just not know the facts.
- **A long time ago humans hunted dinosaurs:** Humans cannot have hunted dinosaurs because the dinosaurs became extinct 65 million years ago, and the first human-like ancestors evolved only about 7, 5 million years ago (Shreeve, 2009). Humans and dinosaurs never co-existed. This inaccurate thinking is perhaps a result of lack of knowledge (Campbell *et al.,* 2008).
- **Humans or their human ancestors first evolved in South Africa, in the Cradle of Humankind:** The name of the World Heritage site is misleading. Human ancestors did not first evolve in the Cradle of Humankind in South Africa, as the oldest hominin fossils were found in east central Africa (Fleminger, 2008). The oldest hominin fossil, *Sahelanthropus tchadensis (about 7.5 million years old)* was found in Chad, compared to the oldest fossil (of 3.5 million years old) found at the Cradle of Humankind (Shreeve, 2009).

2.5.2 The possible influence of alternative frameworks

According to Southerland et al. (2001), unscientific ideas may turn out not to be just isolated errors, but may be influenced by alternative frameworks. An alternative framework is a broad way of thinking through which individuals interpret and make sense of the world around them (Smith *at el*., 1993). Alternative frameworks "… *present a parallel distributed processing theory of the acquisition, representation, and use of human semantic knowledge"* (Rogers & McClelland, 2008, p. 689). Alternative frameworks are described as alternative because they are not acceptable as part of the body of knowledge recognised by scientists at a given point in time. A faulty way of thinking about the world may result in the development of individual misconceptions about evolution (Southerland et al., 2001).

Both alternative frameworks and misconceptions are often based on our experiences because we construct ideas about the world around us and sometimes inaccurate understanding of reality is involved (Southerland et al., 2001). Between alternative frameworks and misconceptions, questions may be asked as to which causes which. Two views are raised in the literature. Firstly, similar isolated scientifically incorrect ways of thinking (phenomenological primitives) can result in a broader alternative framework (diSessa, 1993). Details of how the phenomenological primitives can be activated resulting in the formation of specific ideas about the world around us in the mind of an individual have already been discussed in Chapter 1, under Section 1.2.1. Secondly, a broader unscientific 'way of thinking' (an alternative framework) for a particular topic may result in the development of specific misconceptions (Southerland et al., 2001). An attempt to point out which one results in which may degenerate into some kind of chicken-and-egg debate, and this is beyond the scope of this project and could be a subject of further research. However, this section places emphasis on the latter idea.

There are three common alternative frameworks which are relevant for this study.

The 'evolution on demand' alternative framework

This framework is based on the mistaken thinking that evolution happens due to the 'survival needs' of organisms. Misconceptions influenced by the 'evolution on demand' framework, as pointed out by Jensen and Finley (1995) and Van Dijk and Reydon (2010), are based on the mistaken premise that there is a need to evolve or the organisms may face death. Sanders (2014b), and Tshuma and Sanders (2015) identify misconceptions influenced by this framework and these were also investigated in this study: *individual organisms evolve; environmental changes cause evolution; evolution involves organisms trying to adapt to these changing environments or food sources; organisms change because they need to (in order to survive);* and *individuals evolve in their lifetimes.*

'Survival of the fittest' alternative framework

The second alternative framework has been termed 'survival of the fittest' by authors such as Nehm et al. (2010). According to Barrass (1984, p. 201), misconceptions influenced by this framework "*… are so widespread as to indicate that many teachers, even if they do not share them, either do not try or are unable to dispel them*". The 'survival of the fittest' framework entails the incorrect thinking that only the physically strong survive and those that are physically weak die out. This framework can be associated with a lack of understanding that words used in everyday language may have a different meaning in science (Nehm et al., 2010). In everyday language the word 'fit' refers to physical strength and stamina (van Dijik & Reyden, 2010). Misconceptions influenced by the 'survival of the fittest' framework, and investigated in this study, include: '*survival of the fittest' means that only organisms that are physically strong survive; the fittest survive and the less fit or physically weak die; only the fittest can survive and reproduce; individuals with a favourable adaptation will only mate with each other; the well-adapted become the next parental generation; individuals with favourable characteristics will survive; Individuals with less favourable characteristics will die / become extinct; individuals with favourable characteristics will reproduce;* and *if individuals have favourable characteristics they will be inherited by the offspring* (Sanders, 2014b; Tshuma & Sanders, 2015).

'Lamarckian thinking' framework

The third alternative framework relevant to this study is based on Lamarckian ideas. Van Dijk and Reydon (2010) point out that the Lamarckian way of explaining phenomenon has an influence on the development of several misconceptions about evolution. This alternative framework involves the assumption that characteristics acquired during the lifetime of an organism can be passed on from parents to offspring (Van Dijk & Reydon, 2010). This way of thinking is problematic because traits acquired during the lifetime of an organism are not genetically determined and so cannot be passed on during reproduction[7]. For instance, a weight lifter may develop strong muscles due to spending a lot of time lifting weights in the gym, but will not have a child who is born with strong muscles. Other misconceptions influenced by the Lamarckian way of explaining phenomenon include: people who develop a tanned skin due to exposure to the hot tropical sun will also have children with dark skin (Cody & Lee, 1990); body parts which are not used degenerate and those that are used become

[7] Cases of epigenetics, which have already been explained in section 2.4, were not considered here

more pronounced in order to serve the needs of an organism (Burkhardt, 1995); changing environments cause organisms to acquire new traits so that they survive (Bowler, 1992); and fossils of earlier organisms are different from extant ones because they get replaced by the more complex ones as the decedents evolve towards complexity (Bowler, 1992; Burkhardt, 1995).

2.5.3 The extent of commonly held misconceptions

This section deals with research-based evidence on the nature and extent of commonly held misconceptions about evolution. The review of misconceptions held by school-level students worldwide is summarized in Table 2. Reading about commonly held misconceptions about evolution (as revealed by worldwide research over about four decades) gave me insights on two aspects: firstly, the type of misconceptions commonly encountered within the evolution education literature and, secondly, the extent of commonly held evolution misconceptions so that I was on the lookout for them as I conducted my study.

There are four trends emerging from the studies reviewed in Table 2. The first is that there are gaps for some studies where there are no frequency counts. Gaps in Table 2 do not mean that the investigated students did not have those misconceptions but rather that those particular misconceptions were not targeted.

The second trend is that prior to 2006, no student misconceptions associated with religious beliefs and misunderstanding of the nature of science are reported. This does not necessarily mean that the investigated students do not have these misconceptions, but is probably because the instruments used in these particular studies did not check for these misconceptions.

The third trend is that the two South African studies reviewed are characterised by the presence of many misconceptions compared to studies conducted elsewhere. This can be explained by the fact that these two South African studies used instruments that checked each of these misconceptions. The other studies did not use such instruments, and tended to see what misconceptions emerged during interviews.

The fourth trend is that students from different countries hold similar evolution misconceptions. For instance the misconceptions '*organisms evolve by trying to adapt to changing environments or food,' 'organisms evolve in responses to environmental changes,'* and '*individual organisms* evolve' were found across different countries and had frequencies ranging from 10% of the sample investigated to 100%, as outlined in Table 2.

Table 2: The extent of misconceptions about evolution in 22 studies reviewed at primary and high school level

Author and country	**Sample**	**Possibly associated with religious beliefs**	*You cannot believe in evolution and God*	*Humans have not changed since they first appeared on Earth*	*The first living organisms appeared on Earth 4000-6000 years ago*	*The theory of evolution explains how living organisms first appeared*	*Evolution explains how the Earth was created*	*Evolution Is no longer happening today*	**Associated with misunderstanding the nature of science**	*Gaps in the fossil record disprove evolution*	*Evolution is just a theory not yet proven*	*Evidence for evolution is weak*	*Scientists disagree about evolution happening*	**Associated with misunderstanding the mechanisms of evolution**	*Organisms evolve in responses to environmental changes*	*Similar individuals are the only ones that evolve*	*Individual organisms evolve*	*'Survival of the fittest' means only physically strong organisms survive*	*Organisms evolve by trying to adapt to changing environments / food*	**Probably due to a lack of information about evolution**	*A long time ago humans hunted dinosaurs*	*Lower organisms evolve but higher organisms do not*
Jungwith (1975) Israel	10 Grade 9 classes																		88%			
	10 Grade 11 classes																		75%			
Deadman & Kelly (1978) The United Kingdom	high school students (n=52)																		100%			
Engel Clough & Wood-Robinson (1985) USA	12-16 year-olds (n=82)														90%							
Jimenez Alexandrė (1987) Spain	high school students (n=69)																	97%				
Halldén (1988) Sweden	Grade 11 (n=23)																79%					
Tamir & Zohar (1991) Israel	Grade 10 (n=12)														88%	56%	25%		81%			
	Grade 12 (n=16)														42%	67%			75%			
Pedersen & Halldén (1992)	13 year-olds (n=32)																		81%			

		Possibly associated with religious beliefs							Associated with misunderstanding the nature of science					Associated with misunderstanding the mechanisms of evolution						Probably due to a lack of information about evolution		
Sweden	16 year-olds (n=16)																		88%			
Settlage (1994) USA	high school students (n=200)														10%	90%			20%			
Bizzo (1994) Brazil	high school students (n=192)																63%					
Dermastes et al. (1995) USA	high school students n = 180)															96%	89%					
Beardsley (2004) USA	Grade 8 (n = 82)																		100%			
Shulman (2006) USA	high school students(n = 29)																	78%	51%			
Olander (2006) Sweden	11-16 year-olds (n =180)																		76%			
Prinou et al. (2008) Greece	Grade 10s from 12 schools (n=411)										42%				28%		50%		48%			
Kampourakis & Zogza (2008) USA	high school students (n=100)																	98%	84%			
Spindler & Doherty (2009)USA	Grade 10s (n=90)																84%					
Kose (2010) Turkey	high school students(n=250)		69,7%			74.1%					80%	53%										
Kagan (2011) South Africa	Grade 12 (n=32)		7%		65%	59%	23%			26%	42%	36%	26%		90%		58%		87%			16%
Lawrence & Sanders (2011) South Africa	Grade 10 (n=68)		50%	35%	54%	85%	62%	33%		53%	46%	49%	19%		52%	40%	53%	63%	73%		35%	46%
	Grade 11 (n=77)		44%	32%	45%	96%	69%	26%		30%	33%	23%	16%		59%	46%	55%	47%	73%		26%	38%
	Grade 12 (n=22)		36%	36%	48%	91%	86%	18%		50%	41%	79%	18%		59%	36%	82%	68%	76%		23%	23%
Rofo *et al*. (2013) Italy	high school students(n=1108)			3%	14%	9.8%	92%											25%				
Yates & Marek (2014) USA	high school students (n=536)				17%		72%			26%		72.%			33%		4%	72 %	57%			

Figures rounded off to the nearest percent

2.6 CURRICULUM SUPPORT MATERIALS

The first aspect to be discussed under ‘sources of misconceptions’ is ‘misconceptions in curriculum support materials.’ Curriculum support materials are resources that are used during teaching and learning (The Cambridge University Press, 2012) and their key role is to “*help the teacher address the learning goals”* (Schwarz, Gunckel, Covitt, & Bae, 2008, p. 346). Examples include syllabi, textbooks, teacher guides, and past examination papers and memoranda. The first three are relevant to this study.

2.6.1 Understanding the term ‘curriculum’

Because my study look at misconceptions in curriculum support materials, I started off by finding out what the word ‘curriculum’ mean. Complexity surrounds the definition and enactment of a school ‘curriculum’ for three reasons. Firstly, curricula being implemented in schools pass through different stages of transformations (see Figure 6) from the time of conceptualisation (by curriculum planners) to the time they are implemented in the classroom. Secondly, contrary to common understanding, a curriculum goes beyond a simple list of subjects and their content to be taught (Tanner & Tanner, 1995). ‘Curriculum’ is about a contract between three stakeholders: the state, society, and educational professionals in terms of the selected educational experiences of the students in a school setup (Apple, 1979; Rajput, 2002). Curriculum specifies what, when, where, how, why, and to whom information should be taught (Cooper, 1997). Goodlad, Klein and Tye (1979) further point out that ‘curriculum’ also entails part of the school life (ways of doing daily things which are peculiar to a given school) not documented, and often referred to as the ‘hidden curriculum’.

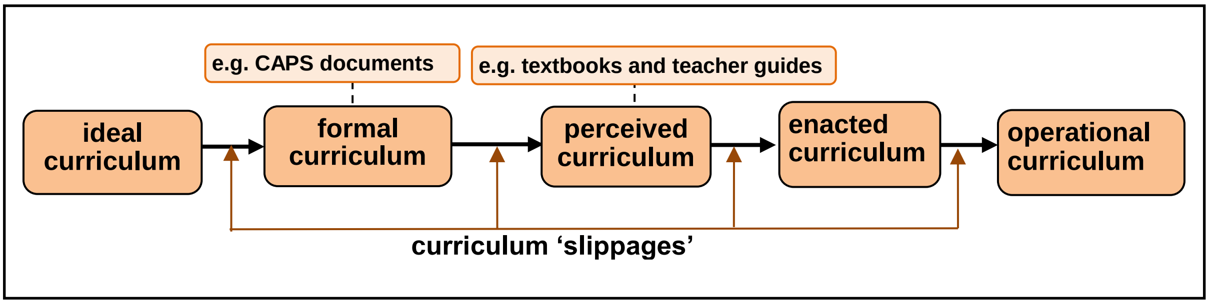

Figure 6. Curriculum types and slippages (source Goodlad et al., 1979)

In an attempt to clarify our understanding of ‘curriculum’, Pinar (1978) and Goodlad et al. (1979) identified five types of curricula, as shown in Figure 6. The first is the *ideal curriculum,* conceptualised by the curriculum designers and planners, and often upholding some ideological undertones of the state. The *ideal curriculum* is not necessarily written down, but is passed on to the education authorities who modify and draw up a written version of it.

The written version, commonly called a syllabus (or curriculum document in the South African context) is termed the *formal curriculum* by these authors. The *formal curriculum* is handed down to key stakeholders (e.g. textbook writers), who in turn modify it due to their unique interpretations, resulting in the *perceived curriculum*. Textbook writers use the *formal curriculum* to write textbooks and teachers use the formal curriculum to draft their lesson plans. The *enacted curriculum* comes into effect when the textbooks and lesson plans are used in the classroom. The students’ day-to-day experiences and perceptions of what happens during teaching and learning is termed the *experienced curriculum* (Pinar, 1978; Goodlad et al., 1979).

2.6.2 Curriculum slippages

As the curriculum is being implemented by different stakeholders, it may undergo modifications, or what Goodlad et al. (1979) called ‘slippages.’ Other authors (e.g. Johnson et al., 2011; Bertram, 2009) use Bernstein’s notion of recontextualisation of knowledge to explain similar modifications. One aspect of Bernstein’s recontextualisation deals with changes in content knowledge captured in curriculum statements and textbooks, two concepts I deal with in my study. However, in this study the concept of curriculum ‘slippages’ (Goodlad et al., 1979) was used as a framework for my research. ‘Curriculum slippages’ arise due to differences in interpretation by different stakeholders along the chain, as shown in Figure 6. For instance, education authorities tend to use their own interpretations in order to determine what the *ideal curriculum* is about, when they come up with the *formal curriculum* (syllabus). Teachers often find the *formal curriculum* to be devoid of essential details (Chisholm, 2002), so use textbooks to get the missing details. The details teachers use to come up with the *enacted curriculum* are influenced by the curriculum support materials at their disposal. Therefore if there are misconceptions in textbooks and syllabus documents, these are likely to be found in their lesson plans and may subsequently filter down to their students. The ‘slippages’ which occur when the *ideal curriculum* is passed down the chain shown in Figure 6 result in transformations and modifications that render the *operational curriculum* different from what the curriculum designers had initially come up with when they conceptualised the ideal curriculum. This probably explains why, as noted by Johnson et al. (2015, p. 102), “… *a school subject is different from its parent discipline”*.

In this study, looking at this curriculum model was important for helping interpret my results. For instance, if misconceptions are found in textbooks, this could be interpreted as ‘slippages’ resulting from the interpretation of the curriculum document (*formal curriculum*) by the textbook authors when they transform it into the *perceived curriculum* when writing textbooks. As pointed out by Sanders and Makotsa (2016), errors found in the syllabus (curriculum document) tend to get multiplied in the textbooks.

Ottevanger (2001) uses the analogy of an enzyme-catalysed chemical reaction to explain that teaching becomes less energy-demanding if good curriculum support materials (e.g. textbooks) are used, compared to when they are not used (see Figure 7).

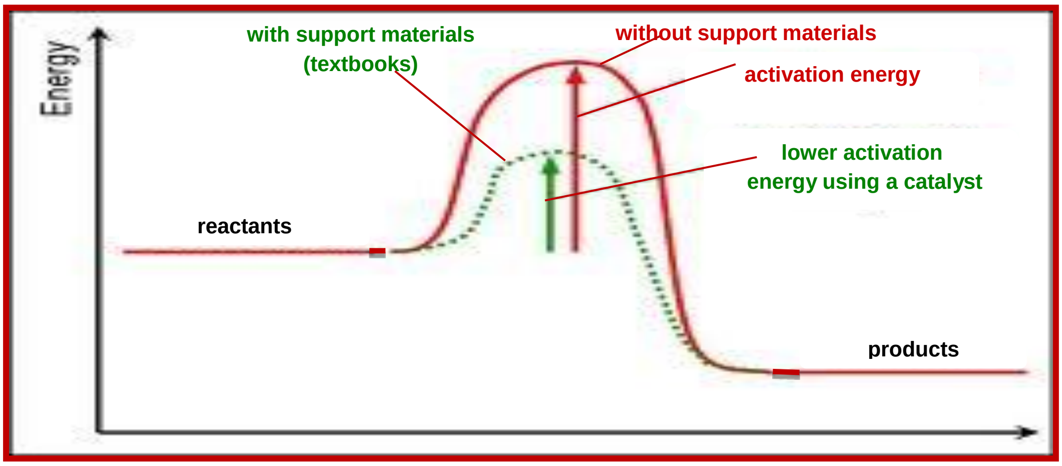

Figure 7. The ‘curriculum support materials as a catalyst for teaching’ analogy

The analogy is based on what happens in chemical reactions. An enzyme or catalyst added to chemical reactions can reduce the total amount of activation energy needed for the reaction to start. Catalysed chemical reactions may require less activation energy to kick-start than reactions without catalysts. If the teachers do not use curriculum support materials, they have to '*overcome an enormous activation barrier before things really start to work for them in the classroom'* (Ottevanger, 2001, p. lll-315). For instance, the role of textbooks includes assisting classroom instruction by providing direction for discussions and other class activities, and providing a source of readily prepared homework, saving teacher's time (Hutchinson &Torres, 1994). Hammer (1991) cited by Richards and Mahoney (1996) explains why:

> *Where a textbook is involved there are obvious advantages for both teacher and students. Good textbooks often contain lively and interesting material; they provide a sensible progression of (language) items, clearly showing what has to be learnt and in some cases summarising what has been studied so that students can revise grammatical and functional points that they have been concentrating on. … Good textbooks also relieve the teacher from the pressure of having to think of original material for every class* (Hammer, cited by Richards and Mahoney, 1996, p. 41)

Textbooks therefore make student instruction easier (Ball & Cohen, 1996). Research by Hutchinson and Torres (1994) led to the conclusion that textbooks make the teachers' work less time consuming and better organised.

Whilst it can be acknowledged that curriculum support materials have an important role to play in making teaching less energy-consuming (Ball & Cohen, 1996), teachers ought to analyse them for any weaknesses so that they can make appropriate modifications before using the books in class. Analysis of textbooks for aspects such as misconceptions gives teachers an opportunity to filter the misconceptions for the students (Abimbola & Baba, 1996) thereby making productive use of curriculum support materials during teaching and learning (Schwarz *et al*., 2008). This is because "… *misconceptions affect the way children understand a variety of scientific ideas"* (Eaton et al., 1984, p. 366). However, analysing curriculum support materials is time consuming and requires great skill (Eaton et al., 1984). A problem arises because many teachers do not have the skills or the will to do so (Schwarz *et al*., 2008). Conducting research on evolution misconceptions in curriculum support materials, and making the findings available to teachers through science journals, science conferences and workshops, may help teachers make productive use of textbooks.

2.7 SOURCES OF MISCONCEPTIONS

The fourth construct in my conceptual framework is 'sources of misconceptions' because, as pointed out by Sanders (1993, p. 931), *"[b]efore pupils' errors can successfully be remediated, we need to understand more about factors that contribute to their formation."* As shown in Figure 4, misconceptions can be categorised as *out-of-school* or *in-school*. Out-of-school erroneous ideas may originate from parents, churches, media, or students' everyday experiences if socially based (Yates & Marek, 2013). Because these are not relevant to my study, they will not be dealt with in detail. In-school sources are those that arise from the teaching and learning environment, and include syllabi, textbooks, teachers, peers, and examinations and memoranda if they are used for teaching and learning. Two of these (syllabi and textbooks) are curriculum support materials which were investigated in my study, and are hence looked at in more detail below

2.7.1 Curriculum support materials as a possible source of erroneous ideas about evolution

In this study curriculum support materials investigated include the *Life Sciences CAPS* document, *Life Sciences* textbooks and teacher guides. As illustrated by the relationships between constructs shown in my conceptual framework (Figure 4), a number of assumptions are made about curriculum support materials. Curriculum support materials such as textbooks are assumed to a) contain correct scientific explanations of evolution, and not to be sources of misconceptions; b) be helpful to readers by pointing out common misconceptions; and c) provide the correct science to counter the identified evolution misconceptions. However, a problem arises because whilst syllabi and textbooks are assumed to contain accurate information, this is not always the case (Nehm & Schonfield, 2008; Makotsa, 2012) despite their indispensable role in making teaching and learning easier (Ottevanger, 2001).

Syllabi as a potential source of unscientific ideas about evolution

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). As is the case in most countries, South African textbook writers use curriculum documents to guide them when writing their books. In South Africa, textbook writers who do not follow the curriculum document risk having the Department of Education omit their books from the list of books approved for use in South African schools.

However, despite the important use of the syllabus document, research on the previous South African curriculum documents (*The Revised National Curriculum Statement* for Grades 7 to 9 *Natural Sciences* and the *National Curriculum statement* for Grades 10 to 12 *Life Sciences*) revealed that these documents contain erroneous statements about evolution (Makotsa, 2012; Tshuma, 2012). Because many South African teachers are inadequately trained (Stears, 2006), lack adequate pedagogical content knowledge to teach evolution (Molefe, 2013), and the curriculum documents (syllabi) they are expected to use have erroneous ideas about evolution (Makotsa, 2012; Tshuma, 2012), South African teachers may turn to textbooks for content knowledge and ideas about how to teach evolution. It also becomes problematic if textbooks, the teachers' immediate source of information (Hutchinson & Torres, 1994), have errors, as outlined in Table 3b.

Textbooks as a potential source of unscientific ideas about evolution

The use of textbooks during teaching and learning is indispensable, as evidenced by the fact that most teachers worldwide rely on textbooks during teaching (Aguillard, 1999). In a survey of teachers in the United States of America, Aguillard (1999) found that "… *only 13 percent of biology teachers presented more information on evolution in instruction than was presented in textbooks*" (Aguillard, 1999, p. 186). Another empirical study conducted by Hutchinson and Torres (1994) in the United States of America on textbook use led to the conclusion that teachers recognise that the use of textbooks during teaching and learning is something they cannot do without. Because textbooks provide the best guidelines of what should be taught in schools (Barrass, 1984), and are followed by most teachers (Carvalho et al., 2009), relying on textbooks during teaching and learning creates a dilemma for teachers and students if their textbooks are a source of unscientific ideas about evolution (Aguillard, 1999).

Two different types of textbook errors can be identified: *manifest* errors and *latent* problems. *Manifest errors are* obvious and easily detectable scientifically incorrect statements and *latent problems* are statements that are not misconceptions *per se* but have the potential to be misinterpreted, leading to the development of misconceptions (Fraenkel et al., 2012). Problems in textbooks have been found worldwide (including South African textbooks) and these are discussed in the following sections.

A review of studies done on textbooks showed that science textbooks in different countries contain scientific errors in general, as summarised in Table 3a, and evolution-related problems in particular, as outlined in Table 3b.

Table 3a: General problems identified in science textbooks in different countries

Author & year	Country	Number of books	Problems identified in documents
Malatesta (1950)	USA	1 commonly used high school science textbook	• Use of content that is boring to the adolescent mind. • Use of complex terms and explanations beyond the comprehension of high school text book readers
Gibson (1996)	USA	15 college science textbooks	• Found erroneous ideas about 'succession' in population ecology in 8 of the 15 textbooks
Abimbola & Baba (1996)	Nigeria	22 chapters in one science textbook	40 unscientific ideas in 18 out of 22 chapters of the book
Decker *et al.* (2007)	USA	11 high school biology textbooks	The experimental method portrayed as if it is the only means of getting science knowledge
Alshamrani (2008)	USA	7 high school physics textbooks	None of the books had details on the nature of science that emphasis how science knowledge is acquired: that science knowledge is based on observations and inferences.
Chabalengula *et al.* (2008)	Zambia	3 high school science textbooks	Superficial science content coverage: • content not covered in depth, • details missing
Carvalho *et al.* (2009)	European and African countries	78 high school science textbooks	Superficial coverage of science ideas • lacking illustrative or annotated diagrams to explain science ideas • details missing
Delgato (2009)	USA	34 high school science textbooks	Superficial coverage of science ideas • an attempt to infuse science with indigenous knowledge systems resulted in some science details missing
Schussler *et al.* (2010)	USA	sample investigated not specified (high school science textbooks from two publishers)	Imbalance of plant and animal biology content coverage: • 54% of the science in the textbooks is based on animals compared to only 46% on plants).
Gould (2010)	USA	3 popular high school biology study textbooks	Books used language which is difficult for the average student to comprehend. Readability levels too high for the target age group (15-16 year olds).
King (2010)	The United Kingdom	29 high school science textbooks	The presence of science misconceptions • one science misconception per page investigated • 500 science misconceptions identified
Deadline over NCERT rectifies 8 errors in biology textbooks for classes XI, XII. (2014)	India	8 high school science textbooks	78 science misconceptions identified and 15 of them remained unrectified even after these were brought to the attention of publishers
The Indian Express (2014)	India	8 high school biology textbooks	6 content errors identified in biology textbooks

Studies in different countries have identified the following problems: science textbooks whose readability levels were too high for the target age group of readers (Malatesta, 1950; Gould, 2010); science content not covered in depth, or with some details missing (Delgato, 2009; Carvalho, 2009; Chabalengula *et al.,* 2008); the presence of science misconceptions: (Abimbola & Baba, 1996; Gibson, 1996; Deadline over National Council of Educational Research and Training rectifies 8 errors in biology textbooks for classes XI, XII., 2014; The Indian Express, 2014); imbalance of plant and animal biology content coverage (Schussler *et al.,* 2010); and the experimental method portrayed as if it is the only means of getting science knowledge (Decker *et al.*, 2007; Alshamrani, 2008). Table 3a outlines these findings.

Four types of problems (outlined in column 4 of Table 3b) have been identified in evolution textbooks: ‘evolution misconceptions,’ ‘superficial evolution content coverage’, ‘problematic language uses’ and ‘fragmented evolution ideas’. Some of the problems have already been outlined in previous sections but are repeated here to give the reader a single consolidated view of the types of problems in textbooks:

Evolution misconceptions were found in textbooks

Different studies have found the presence of evolution misconceptions in textbooks (see Table 3b), e.g. Rees (2007); Tshuma and Sanders (2015); and Sanders and Makotsa (2016).

Table 3b: Problems (evolution-related) identified in textbooks in different countries

Author & year	Country	Number of books	Problems identified in documents
Skoog (1979)	USA	93 high school biology textbooks	Evolution content in textbooks has been reduced over decades (since the 1960’s).
Skoog (1984)	USA	105 high school biology textbooks	superficial coverage of evolution content in textbooks published between 1900 and 1983 • evolution content covered not in depth • evolution details missing
Rosenthal (1985)	USA	22	Decrease in evolution content details per given length of biology text material published between 1963 and 1983.
Woodward & Elliott (1987)	USA	15 high school biology textbooks	Exclusion of: • evolution by natural selection, • human evolution Evolution only presented (when presented) as one of the many competing theories to explain diversity of life
Jiminez-Aleixandrè (1994)	Spain	17 high school biology textbooks	Superficial handling of natural selection: • more learning activities on deterministic reasoning than probabilistic reasoning (which is essential for understanding principles of heredity and evolution models) • lack of attention paid to students’ alternative ideas • little variety in learning activities
Linhart (1997)	USA	50 college biology textbooks	Superficial handling of natural selection in the 1990s: textbooks lacked essential details about how evolution by natural selection occurs
Skoog (2005)	USA	113 high school biology textbooks	Coverage of human evolution fluctuated during the 20th Century: • 1900 to 1968: 44 out of 83 books emphasised the human fossil record and only 29 of the 83 textbooks explicitly stated that humans were products of biological evolution. • 1900 to 1919: no textbook covered human evolution; • 1920 to 1950: some textbooks had brief details on human evolution and others had nothing.
Decker *et al.* (2007)	USA	11 high school biology textbooks	Timeline dealt with in ways that confuses readers: • no proper scales to show the eras and periods, • over-emphasis on dates without linking to key evolutionary features
Rees (2007)	United Kingdom	12 high school biology textbooks	• erroneous details about evolution by natural selection: adaptive evolutionary changes of populations over time • inaccurate description of Darwin's contribution to the theory of evolution by natural selection (over-emphasis on what

			Darwin did not do)
Matsumura (2007)	Japan	Not Specified	Each book investigated either coverage of 'classification of organisms and evolution' or 'population biology' and did not include both in the same book
Skoog & Bilica (2002)	USA	50 high school science standards documents (textbooks) from 50 different states	• human evolution was covered in only seven of the 50 documents. • superficial evolution content coverage in all the 50 documents (some state standards did not mention -the word 'evolution')
Selden (2007)	USA	73 high school biology textbooks	Evolution presented in a way that suggests science as a discipline is against moral aspects of people.
Catley & Novick (2008)	United Kingdom	31 high school biology textbooks	702 faulty cladograms: • their theoretical underpinning and structure not explained • open to multiple interpretations and possible development of misconceptions
Takayama & Wakabayashi (2008)	Japan	Not Specified	Books published from 1959 to 2007 had problems of: • gradual decrease in ideas about human evolution • decrease of details on evolution by natural selection
Nehm *et al.* (2009)	USA	3 high school biology textbooks	• There was no evidence of evolution being presented as a unifying theme across all biology courses
MacDowell & Nappo (2012)	USA	110 high school biology textbooks	Books which discussed human evolution dropped from 58 to 28 for the period 1956 to 1963
Tshuma & Sanders (2015)	South Africa	6 high school *Life Sciences* textbooks, Grades 10 to 12, from two different publishers	Presence of evolution misconceptions (n=27) Statements with problematic wording that may lead to the development of evolution misconceptions: • poor explanation (explanation unclear, either because the use of language is poor, or the explanation is poorly explained): (n=144) • incomplete explanation (explanation lacks essential concepts necessary for full understanding): (n=73) • misleading wording (wording implies something incorrect – e.g. that there are alternative <u>scientifically acceptable</u> theories to natural selection): (n=11) • use of risk terms (words or phrases which are not erroneous *per se*, but which may be misinterpreted, leading to the development of misconceptions) (n =148) • Poor sequencing of evolution content (n=11)
Sanders & Makotsa (2016)	South Africa	6 *Natural Sciences* textbooks Grades 7 to 9, from two different publishers	Presence of evolution misconceptions [n=19] Statements with problematic wording that may lead to the development of evolution misconceptions

Superficial evolution content coverage

Empirical evidence shows that some textbooks which have been investigated in different parts of the world are characterised by superficial evolution content coverage. Three categories of superficial content coverage emerged from the studies which were reviewed: evolution by natural selection content not covered in depth (Skoog, 1984; Skoog & Bilica, 2002; Delgato, 2009; Jiminez-Aleixandrè, 1994); gradual decrease in the number of books that covered human evolution (Woodward & Elliott, 1987; Skoog, 2005; Takayama & Wakabayashi, 2008; MacDowell & Nappo, 2012); and gradual decrease in evolution content over time (Skoog, 1979; Skoog, 1984; Woodward & Elliott, 1987; Rosenthal,1985; Linhart, 1997; Skoog, 2005; Takayama & Wakabayashi, 2008; MacDowell & Nappo, 2012).

Problematic language use in textbooks

Language-related problems may be misinterpreted by readers and this means that they have the potential to influence the development of evolution misconceptions. Because the central focus of my study is to investigate the potential influence of curriculum support materials on evolution misconceptions, I found an understanding of the nature and extent of typical language-related problems found in the literature important for two reasons as already hinted above. Firstly, so that I could identify them from the textbooks I investigated, and secondly, so that I was able to discuss their potential influence in my results chapter.

If language is not used with care in textbooks, this may cause confusion for readers such that they may find it difficult to understand ideas being put across. Language beyond the comprehension of students poses problems because learning can be hampered and misconceptions may arise (Jungwith, 1975; Meyer, Crummey, & Greer, 1988; DiGiuseppe, 2013). Merzyin (1997) points out that the use of complex language negatively affects especially those who use English as a second language. Whilst it is expected that textbooks for English second language students would make use of simple sentences (Letsoalo,1996) some textbooks for English second language speakers are not written in clear simple language but use complex grammatical structures and terms which create confusion and complexity for many students (Barrass, 1984).

Problems of language use found in textbooks include '**unsatisfactory explanations'.** Unsatisfactory explanations are language-related problems which are not really misconceptions *per se.* I reviewed them in the literature for two reasons. Firstly, to enable me to recognise typical examples of *unsatisfactory explanations* common in the literature, and secondly, so as understand each of them. These two aspects were important for me so that it became easy for me to identify them during content analysis of the textbooks. Five sub-categories of *unsatisfactory explanations* were reviewed:

- **Poor explanations**: A *poor explanation* is one where the explanation is unclear, either because the use of language is poor, or the explanation is poorly explained (Tshuma & Sanders, 2015). Reviews of Grades 7 to 9 *Natural Sciences* textbooks from two publishers (Sanders & Makotsa, 2016) and Grades 10 to 12 *Life Sciences* textbooks from two different publishers (Tshuma & Sanders, 2015) found 40 and 144 poorly explained statements respectively in textbooks written for the previous curriculum (see Table 3b for details).
- **Incomplete explanations:** These occur when explanations lack essential concepts necessary for full understanding (Tshuma & Sanders, 2015). As shown in Table 3b, Sanders and Makotsa (2016); and Tshuma and Sanders (2015) found totals of 16 and 73 incomplete explanations respectively in their investigations.
- **Misleading wording**: *Misleading wording* implies something incorrect. As outlined in Table 3b, Sanders and Makotsa (2016) and Tshuma and Sanders (2015) found 12 and 11 instances of misleading wording respectively, in the science textbooks they investigated.
- **Anthropomorphic statements:** Anthropomorphism is when "... *human-like conscious intent is ascribed either to the objects of natural selection or to the process itself"* (Gregory, 2009, p.168). Anthropomorphic thinking is evident when adaptive change is attributed to the intentional efforts, plans, desires or wishes of an organism (*internal anthropomorphism)* or when natural selection is assumed to be a conscious agent that chooses the types of organisms to die out and those that survive, what Gregory (2009) terms *external anthropomorphism*. Internal anthropomorphism is associated with the misconception that the environment poses threats and challenges which cause

the individual organisms to intentionally evolve in order to survive (Tamir & Zohar, 1991; Gregory, 2009).

- **Teleological statements:** Teleology is when phenomena are explained in "... *terms of purposes which fit the way we are accustomed to view our own purposeful behaviour"* (Tamir & Zohar, 1991, p. 58). Central to teleological reasoning is that structures evolve to serve a particular purpose (Gregory, 2009). Structures of organisms are erroneously assumed to be designed for a particular purpose or to perform certain functions which benefit their possessors (Kampourakis, 2007). Typical teleological reasoning includes, for instance, the childish thinking that rocks possess sharp edges so that animals do not sit on them, and also the incorrect thinking that desert plants have needle-shaped leaves so that they minimise water loss which prevents them from wilting, rather than thinking of natural selection having selected plants which had thin leaves because it gave them survival advantages in arid places (Moore et al., 2010). A study by Tamlr and Zohar (1991) found that common teleological reasoning is associated with major biological themes, such as the relationship between structure and function. Teleological statements on structure and function are problematic because they actually mirror *"different and faulty assumptions about the nature of the universe*" which may lead to Lamarckian interpretation of evolution (Jungwirth, 1975, p. 95).

- **The use of risk terms: "**Risk-terms' are words or phrases which are not erroneous *per se*, but which may be misinterpreted, leading to the development of misconceptions (Tshuma & Sanders, 2015). Barrass (1979, 1984) points out that terms which may be misconstrued leading to confusion and misunderstanding are often used in textbooks. A problem arises if teachers do not explain them to students, because they may be misinterpreted, thereby causing confusion during learning, and may lead to the development of evolution misconceptions (Merzyin, 1997). Risk terms have been found in South African textbooks (Sanders & Makotsa, 2016; Tshuma & Sanders, 2015), who found 124 and 148 risk terms respectively (see Table 3b for the details of these studies). Three types of 'risk' terms cause problems:

  – **Euphemisms**: A euphemism is a "*mild or indirect word or expression substituted for one considered to be too harsh or blunt"* (Oxford English Dictionaries, 2014). The words '*become*' and '*develo*p' are often used in place of the appropriate term 'evolve' (Thompson, 2008). According to Thompson (2008), using euphemisms for 'evolution' is problematic in that people may not be aware they are dealing with ideas about evolution. A content analysis of Grades 10 to 12 *Life Sciences* textbooks from two different publishers in South Africa found 56 instances where the terms 'adaptations' or 'adapt' were used in place of the term evolve (Tshuma & Sanders, 2015). Biology textbooks could be avoiding the term 'evolve' for two reasons. Firstly, textbook authors may not be aware that the use of euphemisms in place of the term '*evolve'* may stop readers from getting to know what evolution is all about. Secondly, empirical evidence shows that textbook writers could be deliberately avoiding the term 'evolve' as a deliberate marketing plan so that their books receive acceptance by anti-evolution textbook users:

    > *"…. patterns of response reveal that publishers decided to handle the highly controversial topic evolution quite differently and the path each publisher chose reveals much about how publishing companies attempt to shape their textbooks so that they can sell to the school market* (Woodward & Elliot, 1987, p. 167).

  Sanders (2014b, p. 171) warns that "…. *without explanation euphemisms are likely to lead to misconceptions*". Therefore teachers and textbook authors should explain euphemisms used in science textbooks so as to avoid misinterpretation and possible development of misconceptions by readers (especially students).

- **Metaphors:** According to Reimer and Camp (2006, p. 846) "… *a metaphor is a figure of speech in which one thing is represented (or spoken of) as something else"* in a "*profound and emphatic manner*". Metaphors are ambiguous because they are expressed using everyday language and this makes them open to multiple interpretations (Brooks, 2011). For instance, the metaphor 'survival of the fittest' could mistakenly be interpreted literally to mean only the fit organisms survive, and those that are 'weak' will die (Sanders, 2014b). Careless use of metaphors about evolution poses linguistic threats (Sanders, 2014b) because readers may misinterpret the content being presented and this may hamper effective learning (Cameron 2002).

  Despite the problems associated with the use of metaphors, different authors point out that metaphors have a number of useful functions. Brooks (2011) points out two functions of metaphors for scientists. Firstly, they enable scientists to express new abstract ideas in a way which can be easily understood by other scientists because of their direct link to what people already know from their everyday lives (Brooks 2011). Secondly, they add new terminology needed to accommodate new ideas and insights from research findings. Metaphors play an important educational role as they are used as analogies in explaining science ideas (Reimer & Camp, 2006) because, according to Pramling (2008), in cases where we need to explain new conceptually difficult ideas, we tend to fall back on familiar ideas and use them as a basis for making sense of the unknown.

  According to Al-Zahrani (2008, p. 56), Darwin used the metaphor *evolution by natural selection* to explain the mechanism for evolution. Not using this term would have "… *deprived Darwin's theory of its untranslatable cognitive content and undermined the metaphorical system by virtue of which the theory has assumed a powerful explanatory potential"* (Al-Zahrani, 2008, p. 56). This metaphor allows the abstract idea of 'evolution by natural selection' to be presented in a manner that has coherence and simplicity that may otherwise be difficult to reduce to literal meanings (Black, 1979).

  Whilst the use of metaphors in science textbooks is unavoidable, if they are not used with care they may confuse readers (Brooks, 2011). For instance, the term 'evolution by natural selection' is a metaphor which learners find difficult to understand (Pramling, 2008). The use of metaphors in science textbooks without explaining them is therefore problematic and the extent to which students struggle to understand metaphoric statements remains an issue "… *of some educational interest"* (Pramling, 2008, p. 536). It is important for stakeholders to know the problems and weaknesses of using metaphors in science textbooks so that they are in a better position to deal with them (Cameron, 2002).

  According to Brooks (2011), some scientists do not trust the use of metaphors because their use may go along with ambiguous presentation of science ideas. Sanders (2014b) points out that even though Darwin purposely used metaphors in his writing so that his abstract concept of natural selection was easier to understand, he acknowledged that "…*no doubt, natural selection is a false term" …* (Darwin, cited by Al-Zahrani, 2008, p. 55). Unexplained use of metaphors to simplify abstract ideas poses the risk that science knowledge may be distorted (Leatherdale, 1974; Pramling, 2008).

- **Paradoxical jargon:** Paradoxical jargon refers to words that have different meanings, often one everyday English one and one science meaning (Leatherdale, 1974). According to Pramling, (2008, p. 536) terms that have an ordinary language meaning which is different to science meaning "…*create difficulties for learners trying to learn scientific knowledge"*. van Dijk and Reyden (2010) provide examples of paradoxical jargon used when talking about evolution: '*theory', 'pressure', 'fitness,'* and *'adapt,'* all of which have different meanings in science and everyday language. Paradoxical jargon is problematic in that people tend to use the everyday meaning instead of the scientific meaning of words and this may cause misconceptions (Nehm et al., 2010).

Because most 'risk terms' differentiate science from other disciplines, their use is unavoidable (Barrass, 1984). However it is important that these terms and the threats they pose are known by readers of textbooks so that experienced readers (e.g. teachers) may explain them to novice readers (e.g. students). For instance, the overemphasis of an individual's name by use of terms such as: **'***Darwinism,***'** *'Darwin's theory'* and *'Darwin's finches',* is problematic and may cause confusion and eventually misconceptions (Braterman & Holbrook, 2009)**.** Some anti-evolution creationist writings make an effort to discredit biological evolution by using Darwin's name (Braterman & Holbrook, 2009). Over-emphasising an individual's name (Darwin's theory) when referring to a worldwide accepted body of biological knowledge is problematic in that it reduces evolution to the level of being just an idea of a sole individual instead of it being viewed as a consensus by all scientists (Braterman & Holbrook, 2009). Many scientists have made contributions towards shedding insights on Darwin's original ideas. Many things had been a black box in Darwin's time:

> *He did not know about genes, mutations, molecular biology, information theory, DNA, population dynamics and ecology, or the age of the Earth. Not realizing the discrete nature of inherited information, he could know neither how variation arose, nor how variation could be copied without diluting it. His fossil record was full of major gaps, while the use of biochemistry to explore phylogeny lay almost a century in the future* (Braterman & Holbrook, 2009, p. 84).

Therefore to use the terms 'Darwinism' or 'Darwin's theory' when referring to the theory of evolution is misleading and, according to Braterman and Holbrook (2009, p. 84), it is *"... ill judged, inaccurate, and a public relations blunder.*" Padian (2013) claims that the inappropriate use of terms such as 'Darwinism' and 'Darwin's theory' in order to discredit the theory of evolution is common in American textbooks which are pushing for creationist teachings in public schools.

Furthermore, as already explained above, because the term 'theory' in everyday language means a guess (The University of California Museum of Palaeontology, Berkeley, 2006), its careless use when using the term 'Darwin's theory' could be an attempt to render the theory of evolution a mere tentative guess. Using the term ***'****Darwin's finches'* is also problematic as it might suggest that the finches on the Galapagos Islands belong to him.

Fragmentation and sequencing

Two other latent issues investigated in this study were fragmentation and sequencing. Johnson *et al.*, (2011) refer to Schmidt, Wang and McKnight's notion of 'curricular coherence', which covers these two aspects. Essentially coherence deals with the logical progression of topics (sequencing) and, if the topics are dealt with in different places (fragmentation), the links explaining how the topics are related ought to be used.

- **Fragmentation:** According to the Oxford English Dictionaries (2014), fragmentation is the "*… process or state of breaking or being broken into fragments."* In this study, fragmentation is referred to when related concepts are dealt with in different sections of the textbook. The content of evolution could be scattered throughout the same book or in different books by the same publisher covering different grades. A problem arises if evolution-related topics are presented as isolated individual units which are not linked because this may cause confusion for the readers.

Fragmenting a topic in textbooks may result in superficial understanding, which may, in turn, influence the development of misconceptions (Simanek, 2008).

Research studies show problems of fragmentation and sequencing of evolution content in biology textbooks. In two South African studies on textbooks for the previous curriculum, evolution content was found to be fragmented across grades, and across book sections or chapters within a given grade, with few or no links (Sanders & Makotsa, 2016; Tshuma & Sanders, 2015).

Fragmentation of content in textbooks is problematic for three reasons. Firstly, isolation of topics in textbooks into fragmented units may cause the reader to experience '*cognitive dissonance'* because if related concepts are presented in different sections without linking them, they may appear to be contradictory (Novak, 1977). Secondly, readers may fail to realise that evolution is a unifying theme in all biology topics (Nehm *et. al*., 2009). Thirdly, fragmentation may prevent the development of a single coherent framework necessary for understanding a complex topic such as evolution (Nehm et al., 2009).

- **Sequencing problems:** Sequencing has to do with a logical "*… order in which related things follow each other*" (Oxford English Dictionaries, 2014). When information is fragmented the additional problem of inappropriate topic sequencing may result. Poor sequencing occurs when pre-requisite background knowledge for understanding the topic of evolution is covered only later in the book, a problem pointed out by Nehm et al. (2009) and Cho et al. (1985), or if the pre-requisite topics are covered only in later grades. Johnson et al. (2011, p. 32) highlight that in "… *a coherent curriculum, new topics are not introduced before the prerequisite knowledge has been covered …"*.

  If textbooks lack a logical conceptual organisation of evolution-related topics due to poor sequencing, students may fail to see the big picture or the conceptual relationships between evolution and all other biology topics (Cho et. al, 1985). Pre-requisite knowledge, which Dreyer and Loubser (2005) explain as topics which should be learnt prior to a new topic so that they act as background information for learning a new topic, should therefore act as basis for understanding new content. For instance, an understanding of genetics is important before learning about variation in organisms, and both topics need to be understood first in order to understand evolution by natural selection. If evolution topics are logically sequenced, then students may find it easy to link related sections so that they use the knowledge they learnt earlier and contained in their memory store Wittrock,1977) to learn and make sense of new evolution ideas in other later book sections.

In this study, the curriculum support materials were investigated for coherence by checking if the content was fragmented, poorly sequenced, and if any cross-referencing was made to link related concepts.

Teacher guides as a potential source of unscientific ideas about evolution

An extensive search for literature on the influence of teacher guides on evolution misconceptions proved fruitless. This study would probably fill this research gap currently existing in the science education literature.

2.7.2 Teachers as a possible source of 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, who are expected to help students on the problem of misconceptions, themselves have erroneous ideas about the topic of evolution. Studies in dfferent countries show that teachers have erroneous ideas about evolution which falls under three categories.

Evolution misconceptions associated with the process of natural selection

Several studies in different countries show that science teachers have misconceptions associated with misunderstanding of the process of natural selections: 50% of the 44 United States of America science teachers investigated (Nehm & Schonfeld, 2007); 75% of the 167 United States of America pre-service science teachers (Nehm et al., 2009), 90% of the 132 Greek teachers studied (Deniz et al., 2008); many of 138 Canadian teachers investigated (Asghar et al., 2007); 59% of the 71 Brazilian teachers studied (Tidon & Lewontin, 2004), 70% of the 102 trainee New Guinea teachers investigated (Vlaardingerbroek & Roederer, 1997); and 85% of the 78 South African teachers surveyed (Molefe, 2013), had evolution misconceptions based on how natural selection works, that is, how the mechanisms of evolution bring about evolutionary changes in populations to give new species.

Evolution misconceptions associated with teleological reasoning

Studies show that some teachers have misconceptions associated with teleological reasoning. An Israeli researcher conducting research involving 24 Australian teachers discovered that the majority of them had evolution misconceptions associated with teleological and anthropomorphic thinking (Jungwith, 1977). Of the 33 teachers and 42 trainee teachers from Israel investigated by Jungwith (1977), most of them showed evolution misconceptions associated with teleological and anthropomorphic thinking.

Misconceptions associated with lack of accurate knowledge about evolution

There is empirical evidence to support that some teachers have misconceptions associated with lack of accurate knowledge about evolution. Yip (1998) investigated 26 Chinese teachers and found that most of them had misconceptions associated with a lack of knowledge about the process of evolution in 54% of the questions used during the investigation. In a study conducted with 76 United States of America teachers, Yates and Marek (2013) found 72.9% of them held 23 evolution misconceptions.
The previous discussions on the constructs for this study show a dilemma. When teachers who have evolution misconceptions (Ngxola & Sanders, 2009; Yates Marek, 2014) need help they turn to, and rely on, textbooks for updating their science ideas (Barrass, 1984; Aguillard, 1999). However, textbooks (the teacher's immediate source of help) may have erroneous ideas about evolution (Nehm & Schonfield, 2008; Sanders & Makotsa, 2016). The teachers, in turn, may pass the evolution misconceptions to their students during instruction as pointed out by Yates and Marek (2014, p. 1): *"… teachers may serve as sources of biological evolution-related misconceptions or, at the very least, propagators of existing misconceptions.*" Teachers have been shown to be propagators of misconceptions: 536 Oklahoma public high school students had 4812 pre-instruction evolution-related misconceptions which rose to 5072 after instructions in a study by Yates and Marek (2014). These misconceptions in turn *"… interfere with students' abilities to grasp accurate scientific explanations and serve as fundamental barriers to understanding evolution"* (Yates and Marek, 2014, p. 1). Therefore this dilemma of evolution misconceptions is a question of an escalating scenario of blind man leading another blind man without an immediate solution in sight.

2.8 PEDAGOGICAL CONTENT KNOWLEDGE FOR TEACHING EVOLUTION

The sixth construct for my conceptual framework is 'teachers' pedagogical content knowledge' (PCK). Because, in this study, I wanted to look at how teacher guides assist teachers teach the topic of evolution and address the problem of misconceptions about evolution, I needed a framework to help me investigate this aspect. I found reviewing pedagogical content knowledge models important because they provided me with insights on the types of knowledge which, according to Berry et al. (2008) and Tamir (1991), are needed by teachers in order to teach a particular topic (in this case the topic of evolution) effectively.

2.8.1 The PCK model used for this study, based on the ideas of Shulman

The phrase '*pedagogical content knowledge'* was introduced when Shulman made his address to the American Educational Research Association in 1985, which was published as Shulman (1986). This idea emerged during research he and his colleagues did, investigating practising novice and expert teachers to find out what made a good teacher. They looked at what novice teachers knew and how their knowledge developed over time. They observed lessons, interviewed teachers, and analysed their lesson plans (Shulman, 1986). Shulman was advocating teaching reforms that emphasised content knowledge (Shulman, 1987). It was something of interest to Shulman that assessing teaching performance in the 1800's placed emphasis on the teacher's subject matter knowledge, but by the 1980s this emphasis shifted from subject matter knowledge to the teacher's methodological practices (Shulman, 1986).

Shulman (1986) identified three categories of content knowledge of expert teachers (see Figure 8) which are explained below.

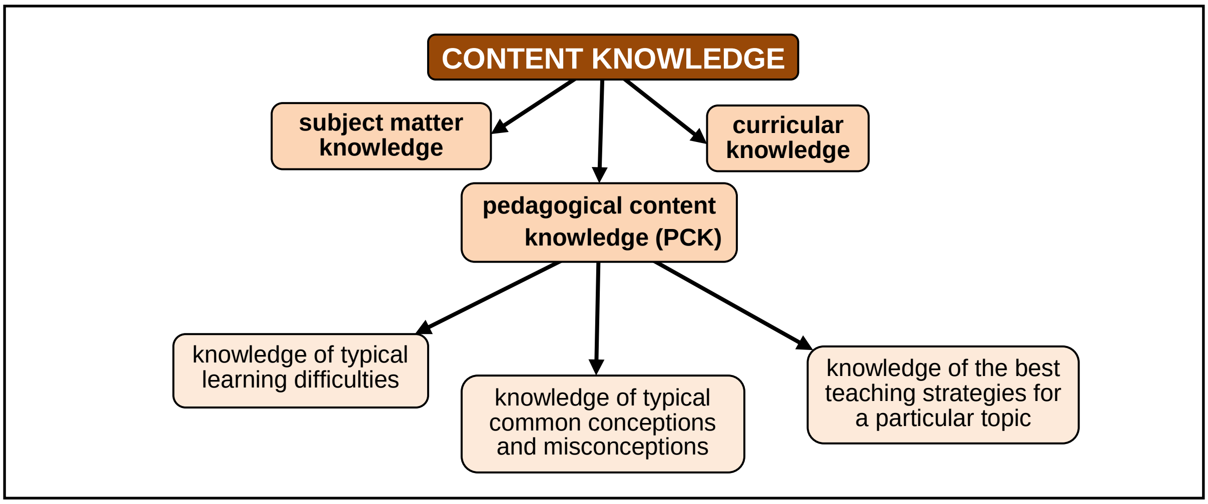

Figure 8. Shuman's categories and subcategories of content knowledge (Shulman1986)

Subject matter knowledge

According to Annetta and Dotger (2006, p. 44), "… *the most important component of PCK is science content knowledge. If a teacher is strong in pedagogy but lacks the science core knowledge to facilitate students beyond their misconceptions, then learning will most likely not occur"*.

Shulman (1986, p. 9) defines content knowledge[8] as *"…. the amount and organisation of knowledge per se in the mind of the teacher*". The subject content knowledge which teachers know has direct influence on what students learn (The National Commission on Teaching and America's Future, 1996). Shulman cited by Berry *et al.* (2008, p. 1276) pointed out in an interview that "… *a teacher who does not both understand and have a real affection for a subject will never be able to teach it well. …"* as this "… *leads to rigid pedagogy"* (Berry *et al.,* 2008, p. 1276). Through empirical studies, science educationists have come to realise that the way teachers understood the subject matter has a powerful influence on how they teach (Berry *et al.*, 2008). If teachers have an inaccurate understanding of specific concepts it is very likely they will pass on incorrect ideas to their students (Ball, 1990; Boyes, 1995).

Shulman explained, using the ideas of Schwab (1978), that subject matter knowledge can be thought of as substantive structures (ways in which major concepts and facts of a subject are organised) and syntactic structures (for determining what is acceptable or unacceptable, authentic or falsehood, in a given discipline).

Teacher pedagogical knowledge for teaching the topic of evolution has been identified by science educationists such as Sanders (2008) and van Dijk (2009). Teachers need to know specific evolution concepts (substantive knowledge and syntactic structures) because in order to teach the topic of evolution effectively, a teacher ought to have a sound grasp of how the process of biological evolution occurs (Sanders, 2008). This is because, according to Annetta and Dotger (2006), knowledge of the basic ideas about how evolution by natural selection happens is important for teachers to know if they are to do effective teaching. Substantive knowledge is about scientists' explanations of biological evolution, as contained in the evolutionary synthesis. Syntactic structures have to do, for instance, with the ideas that are acquired through the scientific method or careful observation of the phenomenon followed by rigorous testing and scrutiny by the scientific community. According to van Dijk (2009), teachers ought to know about the processes and products of evolution as depicted by the tree of life. Such knowledge is important to enable students to see the bigger picture of the topic of evolution which would in turn enable them to see it as a unifying theme across different biology topics (van Dijk, 2009). Thagard and Findlay (2009, p. 2) identify concepts which are essential for understanding evolution by natural. These concepts include "… *evolutionary change, genetic variation, struggle for existence,* and *natural selection".*

In this study, a teacher guide checklist was used to investigate if teacher guides helped teacher on how to a) deal with issues of evolutionary adaptation to environment, b) deal with issues of genetics as a source of variation, and c) deal with the issue of passing on of favourable traits from parent to offspring.

Knowledge of the curriculum

Shulman (1986) suggested that curricular knowledge involves two aspects. The first is knowledge about the breadth and depth of the content to be taught. This includes knowing: a) the subject content appropriate for teaching to a particular grade in order to enhance learning; b) what should have been taught in previous units or grades before the topic is taught; c) what will be taught in units or grades to come after the topic in question has been taught; and d) the relevant ideas which are taught in other subjects of the school curriculum so as to link from one subject to another for deeper concept understanding (Shulman, 1986). The second component of curricular knowledge is about knowledge of curricular resources available for the teacher to use to enhance effective learning.

8 Shulman was inconsistent when he used the label 'content knowledge' in his 1986 paper (on page 9). His argument shows he was talking about subject matter knowledge at this point, not the umbrella concept he had called 'content knowledge.' Shulman acknowledged his inconsistency on how he used these terms in his 1987 paper (see footnote on page 8).

In the case of the topic of evolution, curricular knowledge is about knowledge of evolution ideas that are taught in previous units and grades, and ideas that are taught in the following units and grades, and knowledge of all the resources which can be used for the effective teaching of evolution (van Dijk 2009). Examples include evolution-related textbooks, videos, fossil excavation simulation kits, museum and real fossil sites (as already mentioned above). In this study, teacher guides were investigated to find out if they helped the teachers to link the topic of evolution to what is taught in previous units and grades before evolution by natural selection can be taught.

Pedagogical content knowledge

Shulman (1987, p. 8) defines **'pedagogical content knowledge'** as a construct that:

> *… identifies the bodies of knowledge for teaching. It represents the blending of context and pedagogy into an understanding of how particular topics, problems, or issues are organised, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction.*

PCK is therefore about knowledge of how to teach particular science topics (topics which are regularly taught) for enhanced student understanding (Shulman, 1986).

Shulman identified three sub-categories of pedagogical content knowledge (domains of knowledge) outlined in Figure 8, which are needed by teachers in order to teach a particular topic effectively:

- **Knowledge of typical learning difficulties:** Shulman (1986) emphasises that for a given topic teachers ought to know typical difficulties students encounter so as to be in a position to plan in a way that assists students to overcome those difficulties. Such knowledge allows a proactive teaching style so that subject content can be taught in ways which promote conceptual change.

  Typical difficulties when learning the topic of evolution include a) handling potential emotional stress associated with the perceived evolution/religion controversy and decisions about whether to accept evolution (Sanders, 2008; James & Craig, 2000); b) the challenges which are associated with understanding the relatively abstract concept of evolution by natural selection (Taylor & Cope, 2007; Thagard & Findlay, 2009); c) interpretation of time scales on the phylogenetic tree in millions or billions of years (Decker *et al.,* 2007); d) understanding evolutionary ideas (those which have a lot of historical details to be learnt) as most students find such aspects difficult (van Dijk, 2009); e) difficulties in letting go evolution misconceptions despite having learnt accurate evolution ideas (Wandersee et al., 1994); f) seeing the link between the "*process of natural selection"* and the "*genetic underpinning"* that depicts variation in members of population upon which natural selection acts to bring about evolution (Taylor & Cope, 2007, p. 105); g) using ideas about evolution to make sense of other biology topics since most books present evolution as an isolated topic (Weiss & Dreesmann, 2014); and h) learner understanding how 'adaptation to the environment' occurs without bringing in aspects of teleological reasoning (Ross, Taylor, Hughes, Whitaker, Lutze-Mann, Kofod, & Tzioumis, 2010).

  Sanders (2008) points out that Shulman's original PCK does not address typical teacher difficulties associated with the teaching of a particular topic. For instance, difficulties teachers are likely to encounter when teaching the topic of evolution include: difficulties of handling the extreme controversy associated with the teaching of the topic of evolution; inability to teach evolution (due to having evolution misconceptions coupled with lack of adequate training); and omitting the topic of evolution or simply not teaching evolution (because of the perceived contradictions of evolution and the teachers' personal religious beliefs) and failure to teach evolution because of worries based on not knowing what evolution content to teach and how to teach it, and due to lack of resources (Sanders, 2008). I found Sanders model useful for my study as it goes beyond Shulman

(1986) by also including these difficulties teachers encounter when teaching the topic of evolution, not only student difficulties.

In this study, teacher guides were investigated to find out if they provided teachers with information on typical difficulties learners experience with the topic of evolution. Such knowledge is important for the teacher in order to align teaching strategies in ways that counter typical difficulties learners experience with the topic of evolution.

- **Knowledge of preconceptions, including misconceptions, which students typically bring to class:** Shulman (1986, p. 9) points out that knowledge of preconceptions is about the "… *conception and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons."* According to Ausubel, *"[t]he most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly"* (Ausubel, 1968, p. vi). Following this line of thinking, the teacher's knowledge of student's prior conceptions, particularly if they are misconceptions, is important for effective teaching of a particular topic. Burke (1969) points out that knowledge of students' prior conceptions can be used by teachers as cognitive anchor points on which to build new learning. Because misconceptions are difficult to overcome, and also interfere with new learning (Hamza & Wickman, 2007), the teacher needs to be aware of typical misconceptions so that teaching strategies can focus on identifying and rectifying misconceptions.
- **Knowledge of the best teaching approaches of the topic of evolution:** Teachers should avoid teaching approaches that make students devalue or discredit the theory of evolution by natural selection. van Dijk explains that a teacher should have knowledge of "*soft*" or "*hard*" aspects of the theory of evolution by natural selection (van Dijk, 2009, p. 262). Emphasis on the '*soft*' aspects includes dwelling on those aspects under evolution that are "… *long on speculation and short on evidence"* (Costa, 2003, p. 1030) as they are mainly theoretical and consequently open to multiple interpretations which may result in students discrediting the theory of evolution as being just a tentative guess. This may in turn compromise their learning of evolution ideas. The '*hard'* aspects comprise those facets of evolution that are difficult to dispute or deny because they are based on empirical evidence which can be verified, for instance Lamarckian ideas which can be proven to be scientifically inaccurate and Darwin's theory of evolution by natural selection which can be verified and supported empirically (van Dijk, 2009). Teaching approaches that places emphasis on the 'hard' aspects of evolution and presenting ideas "… *in the context of analogy and inductive inferences"* (Costa, 2003, p. 1030) may enable students to learn the topic of evolution (and experience conceptual change) because, according Posner et al. (1982), conceptual change happens more easily when students find the ideas or knowledge they are learning to be trustworthy and credible (plausible).

  Some of the teacher practices that may promote effective teaching of evolution include lessons that:

  - are learner-centred to an extent that they address the issue of the perceived religion and evolution controversy of different learners (Alters & Alters, 2001). Enshrined in the South African curriculum statement is the idea of learner-centred education which upholds a *"… teaching and learning milieu that recognises that the people of South Africa have a variety of learning styles as well as culturally influenced perspectives. Meaningful education has to be learner-centred"* (Department of Education, 2002, p. 22).
  - recognise the need to be sensitive to the students' cultural and religious beliefs. When teaching the topic of evolution, the teacher ought to acknowledge and be sensitive to the students' cultural and religious beliefs (Sanders, 2008; van Dijk, 2009). Furthermore,

Meadows, Doster and Jackson (2000) point out that failure to be sensitive to the differences in student religious and cultural background is unethical as it causes moral harm. Because the use of debates when teaching evolution emphasis the choice between religion and evolution, it is inappropriate because it can cause conflict (Sanders, 2008). An attempt to change students' cultural and religious beliefs shows lack of sensitivity to the students' diverse religions. Such careless attempts (by the teacher) may cause emotional harm, may lead to rejection of evolution, and may consequently hamper effective learning of evolution content (Meadows et. al., 2000). Religious difference and their impact on teaching evolution therefore require that teachers are aware that religious differences may have an effect on how students from diverse religious backgrounds learn a perceived controversial and sensitive topic such as evolution (James & Craig, 2000).

– emphasise practical ways of teaching of ideas about evolution. For instance, teaching involving field trips to museums (Spiegel, Evans, Gram, & Diamond, 2006); visiting fossil sites (Diamond & Evans, 2007) such as Sterkfontein in South Africa; use of fossil excavation simulations (Latham & Scully, 2008); use of suitable evolution videos; and the use of online evolution-related activities and websites (Sanders, 2008). All these help in bringing about effective teaching/learning of the topic of evolution in real and relevant contexts (Zane Education, 2015) or what Lave and Wenger (1990) term 'situated cognition'.

In this study, the teacher guides were investigated to see if they assisted teachers by suggesting appropriate teaching strategies for effective teaching of the sensitive (James & Craig, 2000) and difficult (Taylor & Cope, 2007) topic of evolution by natural selection.

According to Buchmann (1982), a good science teacher is one who is able to integrate subject matter and pedagogy for easy understanding by students. A teacher will probably not be able to teach a particular topic effectively without subject matter knowledge and curricular knowledge (Berry, 2008). This has been cited as a shortfall of Shulman's PCK model because it does not include subject matter knowledge and curricular knowledge under pedagogical content knowledge (see Figure 8). Marks (1990) and Sanders (2008) argue that because subject matter knowledge is an important defining factor for PCK it should be a sub-category of PCK. Their PCK models (modified models based on Shulman's ideas) therefore involve the addition of subject matter knowledge as a sub-category of pedagogical knowledge (see Figure 9 for Sanders' modified model).

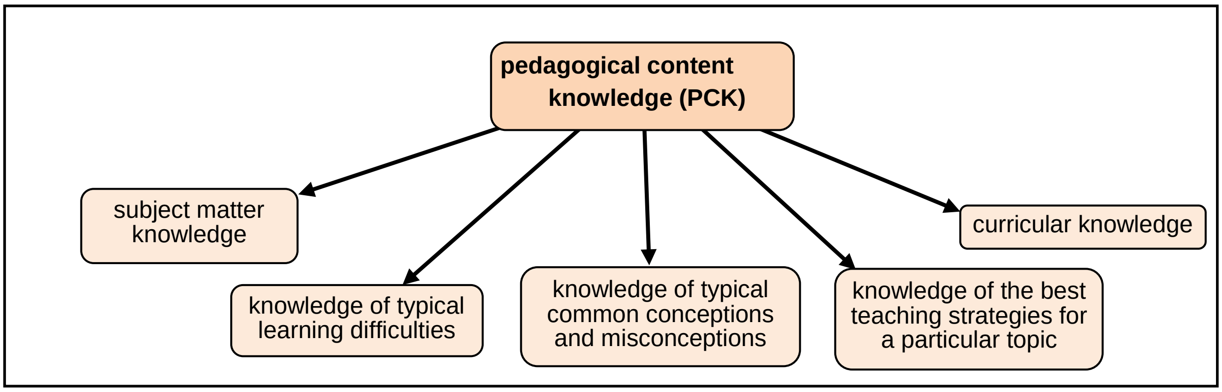

Figure 9. Categories of PCK, based on Shuman's ideas but hierarchically re-arranged by Sanders (2008)

Curricular knowledge is also an essential type of knowledge when teaching a particular topic – i.e. it should be part of PCK (Sanders 2008). It is probably because of this reason that many authors have placed curricular knowledge as a sub-category of PCK (Grossman, 1990; Marks, 1990; Magnussen, 1999; Sanders, 2008). Jing-Jing (2014, p. 422) explains that each of the proposed modifications of Shulman's PCK model follows a trend that helps clarify "*PCK components*" so that " … *the components become more and more comprehensive and specific."*

I have used the modified model proposed by Sanders (2008) as a framework to investigate teacher guides (how teacher guides assist teachers teach the topic of evolution and address the problem of misconceptions about evolution). She hierarchically rearranged the categories of content knowledge as shown in Figure 9. She shifted *subject matter knowledge* and *curricular knowledge* and placed them at the same hierarchical level as the other three sub-categories of pedagogical content (knowledge of typical learning difficulties; knowledge of typical common conceptions and misconceptions; and knowledge of the best teaching strategies for a particular topic) because, as she pointed out, they all constitute "… *essential knowledge for the teaching of specific topics"* (Sanders, 2008, p. 92). Figure 9 shows the hierarchical rearrangement of categories and sub-categories of Shulman's PCK model suggested by Sanders (2008).

2.8.2 Concluding remarks about PCK

In spite of criticism by some authors, the concept of pedagogical content knowledge has remained relevant for science educationists (Abell, 2008). This is evidenced by the many research studies on it for the past twenty-five years (Jing-Jing, 2014), its use by science teacher educationists to structure their teacher education programmes (Abell, 2008), and its use as a framework in structuring professional development workshops for practising novice and seasoned teachers (Sanders & Reiss, 2014). PCK has emerged as a lens through which we view, articulate and investigate types of teacher knowledge that enable teachers to teach a particular science topic to a particular group of students, in a particular school setup for their enhanced understanding (Berry *et al.*, 2008). In this study teacher guides were investigated to see if they are conduits for helping teachers with pedagogical knowledge for effective teaching of the topic of evolution.

2.9 CONCLUDING REMARKS ABOUT CHAPTER 2

The purpose of this chapter has been to provide a conceptual framework for the study. The literature review has enabled me to, firstly, get insights into the nature and extent of evolution misconceptions (central constructs in my study, which I investigated in curriculum support materials), and, secondly, to see the relationships between all the constructs relevant to this study so that I was able to see the link between my research questions, methods used, type of data collected, discussions carried out, and research conclusions drawn. Seeing the links between the constructs was useful in helping me come up with the coherence needed for report writing.