

## CHAPTER 2 THEORETICAL FRAMEWORK FOR THE STUDY

What differentiates the writing of research of scholars from that of journalists is a well-developed and articulate theoretical framework (Caliendo & Kyle, 1996). This chapter deals with aspects of theoretical frameworks in general and in particular a theoretical framework for research investigating the pedagogical content knowledge of teachers teaching evolution.

### 2.1 THE ROLE OF A THEORETICAL FRAMEWORK IN RESEARCH

The term “theoretical framework” comprises two words, “theory” and “framework”. It is therefore appropriate to start by giving definitions of what a theory is and what a framework is. A theory, according to Kerlinger (1986:9), is “*a set of interrelated constructs, definitions, and propositions that present a systematic view of phenomena by specifying relations among variables with the purpose of explaining and predicting phenomena*”. A framework is “*a set of ideas that you use when you are forming your decisions and judgements*” (MacMillan English dictionary, 2002:561). According to Kerlinger (1986), a theory can be used to successfully make predictions and this predictive power of the theory can help guide researchers to ask appropriate research questions. On the other hand, a framework provides structure within which the relationships between variables of a phenomenon are explained.

Abd-El-Khalick & Akerson (2007) point out the difficulty of identifying an exact definition of a theoretical framework in the field of (science) education. Nevertheless, LeCompte and Preissle (1993) define a theoretical framework as a collection of interrelated concepts that can be used to direct research with the purpose of predicting and explaining the results of the research. Simply put, a theoretical framework is used to provide the rationale for conducting the research (Caliendo & Kyle, 1996; Radhakrishna, Yoder & Ewing, 2007).

In educational research, theoretical frameworks have a number of roles, which improve the quality of research (Caliendo & Kyle, 1996). According to various authors, theoretical frameworks:

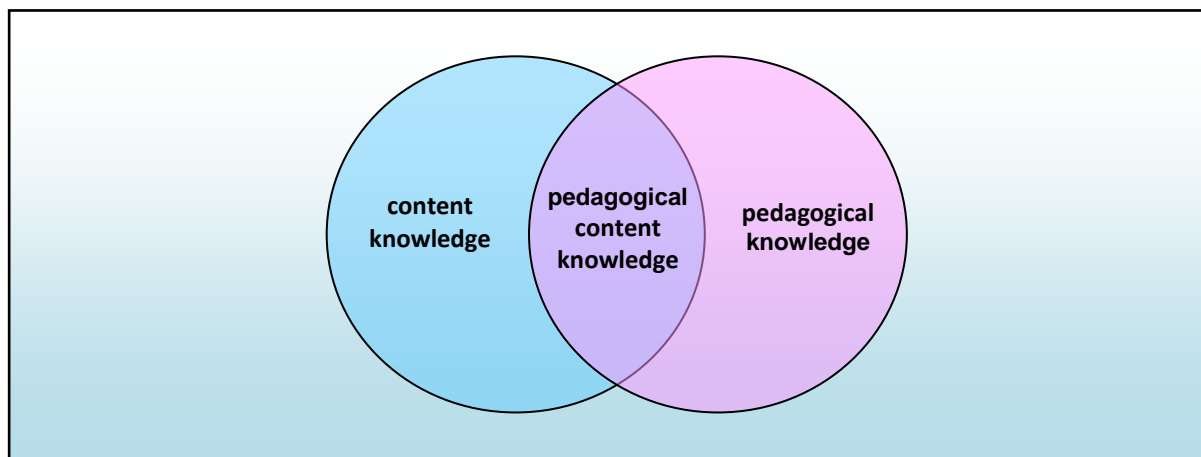
- connect the researcher to existing literature (Smyth, 2004; Herek, 1995).
- provide assumptions that guide the research (Miller, 2007).
- help the researcher to choose appropriate questions for the study (Miller, 2007).
- convince the reader of the relevance of the research question (LeCompte & Preissle, 1993; Mishra & Koehler, 2006).
- guide the choice of research design (LeCompte & Preissle, 1993).
- guide the researcher toward appropriate data collection methods (Miller, 2007).

- assist the researcher to make predictions of the outcomes and to interpret and analyse the results of research based on the existing literature. The results can be used “*to test and critically appraise a theory*” (Abd-El Khalick & Akerson, 2007:189).

Basing research on a theoretical framework is important, as research is theory driven (Abd-El Khalick & Akerson, 2007).

## 2.2 THE THEORETICAL FRAMEWORK FOR THIS STUDY - PEDAGOGICAL CONTENT KNOWLEDGE

This study aims to look at the nature and extent of the pedagogical content knowledge of a group of South African *Life Sciences* teachers having to teach evolution for the first time. The study is based on a modified model based on ideas of Shulman (1986; 1987) regarding pedagogical content knowledge, often abbreviated as PCK. Pedagogical content knowledge is described as a “*particular form of content knowledge that embodies aspects of content most germane to its teachability*” Shulman (1986:9). Shulman first introduced the PCK concept into the educational realm after he had noticed that policies in the 1980s that dealt with teacher competency ignored content and focussed largely on basic pedagogy. He also realised that there was a gap in research regarding subject matter content and that research literature on subject matter content teaching was lacking. This absence of content in research translated into policy makers also ignoring it when setting standards for teacher competency evaluations. “*No one asked how subject matter was transformed from the knowledge of the teacher into content of instruction*” (Shulman, 1986, p.6). This absence of content in research was termed the “*missing paradigm*” (Shulman, 1986:7). The missing content became a matter of serious concern to him such that when he and his research group conducted a study on knowledge growth in teaching, they focused on content knowledge. Their central question was “*how does somebody that really knows something, teach it to somebody who does not?*” (Berry *et al.*, 2008:1274). Shulman argued that ignoring content knowledge results in teacher programmes that emphasise either general pedagogy or content knowledge, thereby treating the two as separate entities which are independent of each other and this was not benefitting teachers, as pedagogy only “*is likely to be as useless pedagogically as content-free skill*” (Shulman, 1986:8). Shulman then proposed an amalgamation of the two types of knowledge (pedagogical knowledge and content knowledge) and said that at the intersection of this amalgamation lies pedagogical content knowledge (Shulman, 1987) as shown in Figure 1 below.



**Figure 1: Pedagogical content knowledge – the amalgamation of content and pedagogical knowledge (Mishra & Koehler, 2006)**

*“The foundation of PCK is thought to be the amalgam of teacher pedagogy and understanding of content such that it influences their teaching in ways that will best engender students’ learning for understanding”* (Berry et al., 2008:).

Shulman identified three categories of knowledge that constituted content knowledge, which he named subject matter knowledge, curricular knowledge, and pedagogical content knowledge (Shulman, 1986).

- **Subject matter knowledge**

*“Understanding of subject matter knowledge is a sine qua non in teaching; to help pupils to learn worthwhile academic content, teachers have to know the content ... especially when they seek to foster conceptual understanding”* (Feinman-Nemser & Parker, 1990:40). Shulman (1986) explained subject matter knowledge as the amount of organisation of knowledge *per se* in the teachers’ minds about the discipline. Shulman (1986) indicates that subject matter knowledge goes beyond knowledge of facts and concepts in the discipline, and involves understanding of the structure of the subject, which includes substantive and syntactic knowledge, as indicated by Schwab (1978).

**Substantive knowledge:** This involves knowing the different ways in which the basic concepts and principles of the discipline can be organised to incorporate its facts (Shulman, 1986). Abd-El-Khalick (2006:4) explains substantive knowledge as knowledge of *“how ideas within a discipline are inter-related and connected”*. For example, the three ways in which biology knowledge was organised in the Biological Sciences Curriculum Studies textbooks used in the U.S.A. in the 1960s, (in one textbook knowledge is organised from molecules to complex organisms; in the second knowledge is organised from ecological systems down to the simplest unit of life; and in the third from familiar structures and function to adaptation). *“The well-prepared biology teacher will recognise these as alternative forms of organisation and the pedagogical grounds for selecting one under some circumstances and others under different circumstances”* Shulman (1986:9). Shulman also points out that teachers need to understand which concepts and principles are central to the discipline and which are peripheral.

**Syntactic knowledge:** This involves knowledge of the ways in which experts decide what constitutes “legitimate” scientific knowledge in a field being investigated (Schwab, 1978).

- **Curricular knowledge**

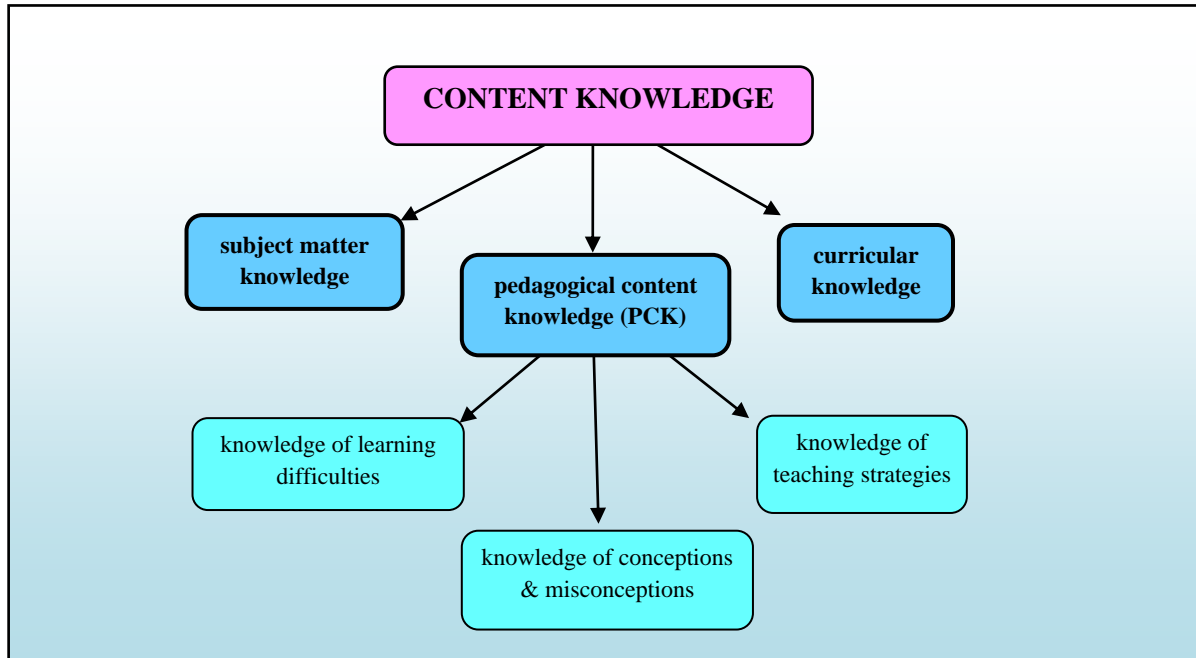
This knowledge includes knowing the breadth and depth at which it is appropriate to teach the topic for particular grade levels (Shulman, 1986). This includes the teachers’ knowledge about the different teaching programmes that are available to teach a particular topic, the variety of available alternative instructional materials (such as textbooks, visual aids, laboratory demonstrations, computer software) and knowledge about how the topic links to previous topics taught, and topics still to be taught, as well as how the topic integrates with other subjects (Shulman, 1986). Note that such lateral integration is one of the nine requirements for the new South African curriculum (Sanders & Kasalu, 2004). Magnusson, Krajcick & Borko (1990) define curricular knowledge of specific curricular programmes but say that knowing specific goals and objectives about the subject is an important aspect of curricular knowledge.

- **Pedagogical content knowledge (PCK)**

Shulman (1987:8) defines PCK as representing “*the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction*” (my emphasis). Shulman also indicates that pedagogical content knowledge applies to “*the most regularly taught topics in one’s subject*” (Shulman, 1986:9). It is the kind of knowledge especially associated with the teaching of specific topics and it goes beyond knowledge of subject matter *per se* (Shulman, 1986). Pedagogical content knowledge differentiates a teacher from a content specialist (Shulman, 1987) in the way it is organised and used as it (PCK) allows teachers to transform content in such a way that makes it easier for learners to understand [makes for effective teaching]. According to Shulman (1986), an expert teacher is able to teach effectively if the teacher has knowledge and understanding of:

- typical learning difficulties learners may encounter when learning the particular topic,
- the likely preconceptions and misconceptions learners may bring to class about that topic, as well as
- strategies needed to represent that particular content so that learners can understand.

Figure 2 below depicts Shulman’s categories of content knowledge and what constitutes PCK, which was an area he took special interest in and is the thrust of this study.



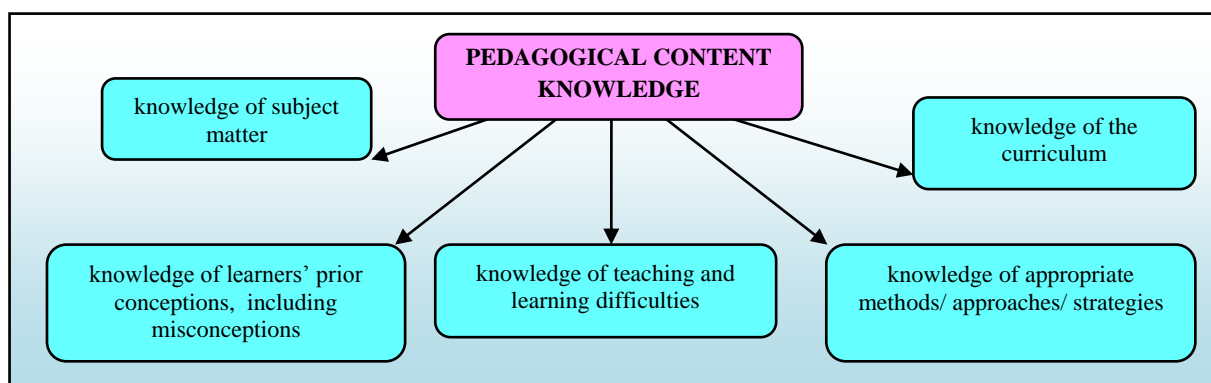
**Figure 2: Shulman's categories of content knowledge and sub-categories of pedagogical content knowledge (based on Shulman, 1986)**

Many researchers have used, in different ways, the various aspects of Shulman’s concept of pedagogical content knowledge to fill in the gaps identified in Shulman’s study of knowledge required for teaching (Smith & Neale, 1989; Marks, 1990; Cochran, DeRuiter & King, 1993; Carlsen,

1999; Halim & Mohd, 2002; Loughran, Mulhall & Berry, 2004; Abd-El-Khalick, 2006; Mishra & Koehler, 2006; Miller, 2007). Grossman (1989) modified Shulman's construct of PCK by identifying four categories of knowledge which constitute pedagogical content knowledge about teaching a particular topic (knowledge about the purpose for teaching; knowledge about students' understanding, conceptions and misconceptions; curricular knowledge; and knowledge about instructional strategies and representations). Cochran, *et al.* (1993) altered the Shulman PCK construct to **pedagogical content knowing (PCKg)**, citing the reason that in constructivism knowledge growth is an active and an on-going process.

Articulating the teaching process and the influences of teachers' knowledge in the process has proved to be a difficult exercise (Gess-Newsome, 1999). Researchers have come up with different cognitive models to reduce this complexity. Gess-Newsome (1999:10), however, outlines the following as attributes that constitute a good model "*organisation of knowledge, integration of previously disjointed data, suggestions of explanations, stimulation of research and revelation of new relationships*".

My study is based Sanders' model of PCK (Sanders, 2008) which consists of five sub-categories (Figure 3).



**Figure 3: Five sub-category model of pedagogical content knowledge, adapted from Shulman (1986) by Sanders (2008)**

Sanders (2008) modified Shulman's model in three ways. First, Shulman's category of "subject matter knowledge" was added as a sub-category to PCK. This was necessary because Shulman says that pedagogical content knowledge is about knowledge of matters associated with the teaching of a particular topic, and in order to teach any topic teachers must have knowledge of the particular subject content. Secondly, based on the same reasoning, Sanders included Shulman's category of curricular knowledge as a sub-category under pedagogical content knowledge, because curricular knowledge about a particular topic is essential to the teaching of that particular content. Geddis & Wood (1997) had already made such a move (without explaining why), although they split the curricular knowledge sub-category into curricular saliency and knowledge of curricular materials. Magnusson, Krajcik & Borko (1999:103) also made a similar move, citing the reason that curricular knowledge is "*knowledge that distinguishes a content specialist from a pedagogue – a hallmark of PCK*". For PCK about evolution, Sanders (2008) expanded the sub-category of learning difficulties by including difficulties that teachers may encounter when teaching evolution, due to its controversial nature.

Teachers need to be aware of the difficulties this causes, so they can take appropriate steps to deal with the potential controversy.

Data for this study was collected in 2008. In the same year, Abell (2008) asked in a journal article “does pedagogical content knowledge remain a useful idea?” For my study, the question is “have there been any new developments since then?” Recently (October 2012) there was a summit held in Colorado in the USA to explore the models and methods researchers use to capture PCK and to attempt to form a unified model of PCK that can be used for future research. I looked at the thirteen written summaries of views that were submitted by researchers for the summit. No significant new ideas seem to have emerged since I chose the model for my research. The model that is most frequently used (five research groups) is the one developed by Magnusson, Krajcik & Borko (1999), with two research groups using slight modifications. Of the eight remaining research groups, different models were used (none were the same), with four groups using their own models (not well publicised). The answer to Abell’s question is “yes” PCK is still relevant to this day, hence the 2012 Colorado PCK summit. The answer to my question is that because no new widely used model has developed in the last five years, the model I used remains appropriate.

## **2.3 PEDAGOGICAL CONTENT KNOWLEDGE AS A FRAMEWORK FOR TEACHING EVOLUTION**

I have only come across one research article which looks at the pedagogical content knowledge of teachers concerning the teaching of the evolutionary theory (van Dijk, 2009). Van Dijk used the *Education Reconstruction for Teacher Education* model (ERTE) as a framework to study the teachers’ PCK. She looked at subject matter knowledge for teaching evolution, the teachers’ knowledge of learners’ pre-scientific conceptions about evolution, and the teachers’ knowledge of different ways to represent evolution in class. The PCK model used in my study used as a framework for the research is more comprehensive, using two additional categories.

### **2.3.1 Subject matter knowledge for teaching evolution**

Evolution is a recently introduced topic in the *Life Sciences* in South African high school (grades 10-12). In order for teachers to make sound instructional decisions when teaching a topic like evolution, they must have a good grasp of the content knowledge of the topic. This does not seem to be the case in South Africa, as Stears (2006) claimed (at the time) that many South African teachers had no formal training to teach evolution. Even experienced teachers become novices when faced with new and unfamiliar content (Gess-Newsome, 1999) as was the case in the teaching of evolution in South Africa since it was implemented in the *Life Sciences* in 2008. A more recent South African study (Ngxola, 2012) found many teachers were worried about deficiencies in their content knowledge when they started teaching evolution, and that these concerns were justified as the content knowledge of many was poor, and many had misconceptions on the topic.

According to Shulman (1986), subject matter knowledge incorporates substantive and syntactic knowledge. Substantive knowledge in evolution includes concepts and principles that are central to

the topic, like mutations, variation and adaptation. One of the central principles of evolution is Darwin's theory of evolution by natural selection, which explains that individuals in a population have genetic variations that allow some individuals to survive and reproduce better than others, so that the frequency of their favourable alleles increases in the gene pool of the population in later generations. These variations are a key element on which natural selection works. Teachers must understand how evolution interconnects and relates to other biology topics such as genetics, meiosis and reproduction. They need to understand how evolution provides a framework for understanding the principles and processes of life. A good understanding of why evolution is thought of as an explanatory and a problem-solving tool is also essential for effective teaching of evolution. Without this knowledge, understanding evolution becomes impossible.

Syntactic knowledge in evolution is knowledge that teachers must have about how scientific facts and theories relating to evolution were arrived at, in order to dispel the misconceptions that evolution is "just a theory", and to explain why scientists accept evolution. In other words, the teacher must have knowledge about the nature of science and how it relates to evolution. This would include knowledge about the evidence that supports the theory of common ancestry and descent with modification (macroevolution). This evidence includes information from the disciplines of palaeontology, comparative anatomy, comparative embryology, comparative biochemistry and biogeography. The teacher must have knowledge of why evolutionary theory is deemed a legitimate theory to explain diversity, and how this theory is supported by evidence. In the study conducted by van Dijk (2009) in Germany, she found that some of the teachers in her study have inadequate understanding of the nature of science (including views of what a scientific theory is). Teachers in her study focused mostly on micro-evolutionary processes and overlooked or ignored the product of evolution as represented in the phylogenetic tree that shows how living organisms relate in time (van Dijk, 2009).

### **2.3.2 Knowledge of the curriculum**

Based on the curricular knowledge discussion on page 13, *Life Sciences* teachers need to be aware of, and well conversant with, the three learning outcomes pertaining to the *Life Sciences* in the Further Education and Training phase of the school curriculum. They need to understand the progressive nature of these learning outcomes from Grade 10 up to Grade 12. Sources of such knowledge include the National Curriculum Policy Statement (Department of Education, 2003) and Learning Programme Guidelines (National Department of Education, 2005). They need to know about the different teaching programmes that are available to teach evolution, the variety of available instructional materials (such as textbooks, visual aids, laboratory demonstrations, computer software). Sanders (2008) supplies a list of some of different resources available in South Africa to teach evolution, their references and descriptions (See Appendix B).

Of particular importance, as well, is vertical and horizontal knowledge (Shulman, 1986) associated with evolution. Teachers must be aware of the evolution-related concepts in the lower grades (vertical knowledge) and how to link them to what is being taught in the evolution concepts they teach. For example, they need to be aware that concepts like "variation", "fossil record", "natural selection", "biodiversity", and "extinction" are already part of the *Natural Sciences* curriculum in the intermediate and senior phases (Grades 7-9). In *Social Sciences* Grade 7, a whole section is devoted to

human evolution. *Life Sciences* teachers should thus use these topics as prior knowledge and link them to their lessons in Grades 10, 11 and 12. They must also be aware of the interrelationships that exist between evolution and genetics and teach them as such and not as two separate concepts. Teachers in South African need to be aware of evolution concepts that are studied in other subjects in the same grade, so that these concepts can be related to the evolution content that is being taught. Shulman (1986) refers to this knowledge as ‘horizontal knowledge’. The evolution-related concepts that are studied in *Geography* are continental drift and plate tectonics. Such lateral integration is one of the nine requirements for the new South African curriculum (Sanders & Kasalu, 2004).

Concerning establishing the content depth and breadth, the available resources include the National Curriculum Statement, *Life Sciences* (Department of Education, 2003), and the Grade 12 *Life Sciences* examination guidelines (Department of Education, 2008a), which are updated annually; exemplar papers; examination papers; and textbooks. Table 1, on page 2 in Chapter 1, summarises the evolution content that appears in the *Life Sciences* examination guidelines.

### 2.3.3 Knowledge of teaching and learning difficulties associated with teaching evolution

Evolution is explained as a change that takes place over many generations in the gene pool of a population. The theory of natural selection is one of the ideas used to explain how evolution occurs. One of the key elements of natural selection is genetic variation, whose major sources are mutation, crossing over and random assortment of genes during meiosis (Raven *et al.*, 2005). Therefore, understanding of genetics is fundamental to the understanding of evolution. However, studies show that genetics is one of the most challenging topics to teach (Bahar, Johnstone, & Hansell, 1999). Evolution itself is an abstract concept (Besterman & Baggett la Velle, 2007). Thus, teachers need to be aware of the learning difficulties in these two topics in order to make pedagogically and instructionally sound decisions. The following are some of the learning and teaching difficulties associated with teaching evolution.

- **Teachers’ inadequate knowledge:** To be able to effectively transform subject matter knowledge into content that learners can understand, teachers must have a good grasp of the topic. However, within the South African context, teachers who had to teach evolution for the first time were ill prepared, as many were not formally trained in the principles of evolution and therefore lacked adequate content knowledge (Stears, 2006). Sanders & Ngxola (2009), in their South African study, reported that 49% of the teachers indicated that they had concerns related to lack of knowledge about evolution: one teacher was quoted as saying that it is difficult to teach something you yourself don’t understand. Lack of content knowledge in a particular topic is a factor in determining the level of confidence of teachers to teach that topic (Moolla, Rollnick, & Stanton, 2004). If this is the case, teachers resort to transmission of facts and learners respond by simply drilling and memorising disjointed facts (Geddis, Onslow, Beynon & Oesch, 1993). Rutledge & Mitchell (2002:25) say that teachers who do not have adequate knowledge and understanding about the theory of evolution are incapable of “*making professionally responsible instructional and curricular decisions regarding the teaching of evolution*”.



- **Teachers who don't or can't teach evolution:** Even though evolution is the cornerstone of biology, many are still opposed to its teaching in high school. Smith (2010) lists some of the factors that may negatively influence instruction in evolution, and one of them is the personal view of many teachers that evolution must be taught alongside creationism or intelligent design. A study conducted by Trani (2004) in Oregon, USA, showed that many teachers refused to teach evolution at all because of their religious convictions. However, he indicates that their rejection of evolution was often because of their inadequate understanding of the topic. This aspect has been discussed in more detail in Chapter 1; subsection 1.3.1, p 6-7.
- **The controversial nature of evolution teaching:** Evolution is a controversial topic as it deals (scientifically) with events in a way, which seems to counter religious beliefs about the creation of living things and their biodiversity (National Academic of Sciences, 2008). Teachers must be aware of potential conflicts that may come from the learners, their parents and the public, and must treat this topic with the utmost sensitivity but without compromising the science in evolution. Subsection 1.3.1 in Chapter 1 explains more about the controversy.
- **Problems with resources:** South African teachers tend to rely mostly on textbooks as a resource to teach content. However, concerning the teaching of evolution, content about evolution is organised differently in different textbooks, and sometimes the topic coverage is different. In cases where teachers do not have adequate content knowledge, this poses a problem for teaching, as teachers might not know where to start teaching and how to approach the topic. Teachers might also not be aware of the available teaching resources for evolution.
- **Problems associated with learning evolution:** Smith (2010) lists factors that can be barriers to learning evolution, which may be cognitive (learners' everyday approaches in explaining the world), affective (attitudes or emotions towards religion/ evolution), or pedagogical (teachers' attitudes, and misconceptions they hold and how these affect learners' ideas). South African teachers may anticipate problems with learners regarding evolution, should the learners come with negative attitudes from home, based on their religious beliefs. Brem, Renny & Schindel (2003:19) report that some students have the perception that evolution will influence their lives negatively by "*decreasing their spirituality, increasing selfishness and racism, and interfering with one's self of purpose and self-determination*". Our preconceptions about explanations about world, which we get from our environments, may become learning barriers when confronted with scientific explanations (Smith, 2010). Learners may also find learning evolution challenging because of the many new and difficult terms that come with evolution and because much of the evidence in evolution is inferred (macroevolution), making the concept abstract. When planning to teach evolution, teachers must take these perceptions and attitudes into consideration.

#### 2.3.4 Knowledge of learners' preconceptions (misconceptions)

##### The importance of knowing about misconceptions

Many researchers hold the view that acquisition of new knowledge depends on what the learner knows, and cite the well-known maxim by Ausubel that "*if I had to reduce all of psychology to just one principle, I would say this: the most important single factor influencing learning is what the*

*learner already knows. Ascertain this and teach him accordingly*” (Osborne & Freyberg, 1985:82; Lawson & Worsnop, 1992:145; Moore *et al.*, 2006:38). Based on Piaget’s theory of development, and theory about constructivist learning, we need to understand that learners have built existing cognitive structures for understanding and responding to experiences in their environment. Their construction of knowledge in class is based on their pre-existing knowledge constructs (schemata). In order for them to make sense of any new content, what they learn in class must be incorporated (assimilated) into what they already know (prior knowledge). *“This prior knowledge can facilitate, inhibit or transform learning”* (Hausfather, 2001). Sometimes these prior ideas are not in harmony with the mainstream science knowledge, and if they are deeply rooted in the learners’ minds, they may interfere with learning.

Osborne and Freyberg (1985) have identified the following five possible outcomes when teaching learners who hold incorrect prior ideas:

- The **undisturbed outcome**, where learners holding the scientifically incorrect ideas retain them regardless of being taught the correct scientific concept.
- The **reinforced outcome**, where learners misinterpret/ misunderstand the correct science taught, thus reinforcing the incorrect science ideas they hold.
- The **two perspective outcome**, where learners store the correct science idea and use it when answering questions in class or tests, but still retain the scientifically incorrect idea and use it in their everyday life outside the classroom.
- The **confused outcome**, where learners are taught the scientifically correct ideas but cannot comprehend, and become even more confused and thus lose confidence in their incorrect scientific ideas. They conflate the two ideas, their own and that they are taught in science.
- The **unified outcome**, where learners are taught the correct scientific idea and are able to lose the old and incorrect science idea and develop an understanding of the new science concept. This is the desired outcome to enable learners to construct correct science knowledge.

It is therefore important that teachers are aware of learners’ unscientific preconceptions and their effect on learning, when preparing to teach a particular topic, so that they can make informed decisions about which strategies or approach to use (Shulman, 1986).

### **Terminology used to name scientifically incorrect ideas**

Numerous terms have been used to describe these incorrect scientific ideas in the literature, and authors seem not to agree on the most useful and meaningful term to use to describe them (Abimbola, 1988). Abimbola (1988) has attempted to classify the terminology used by researchers based on the researchers’ philosophical orientation. He suggests that “empiricists” tend to judge these prior ideas as wrong and they use terms like “erroneous ideas”, “misconceptions” or “misunderstandings” to refer to these ideas. The second group of researchers, who subscribe to the “new philosophy of science” called the “conceptual change theory” use less judgemental terms and describe these prior ideas as “prior conceptions”, “existing schemata” or “alternative conceptions”.

Abimbola (1988) did not identify the types of preconceptions or how the learners got to know them. The scientifically incorrect ideas can be classified into two types. Firstly, there are those ideas that learners have actively constructed (Fisher & Lipson, 1986). These authors use the term “misconception”, but others may call them “alternative conceptions”. To describe scientifically incorrect mental constructs. Misconceptions are deeply rooted in the learners’ schemata and are thus often resistant to change. Secondly, there are those scientifically incorrect ideas that learners did not construct mentally, but have had passed on to them from various sources. These ideas are referred to “mistakes” or “errors”. An error is described as an observable performance, which differs from an expected “correct” performance (Fredette & Clement, 1980 cited by Fisher & Lipson, 1986:784). Abimbola (1988) explains that mistakes (ideas that are inconsistent with the correct scientific explanations, but not mentally constructed) are often not strongly held by learners, and if taught the correct conceptions, learners can usually replace them with the scientifically correct ideas. The learners are able to recognise the mistake when taught the correct conception. Sanders (1993) cautions researchers that they need to distinguish between **misconceptions** and **errors** when reporting their results.

In this study I will use the terminology as explained by Fisher and Lipson (1986), Abimbola (1988) and Sanders (1993). Although the teachers’ ideas are incorrect, I do not know for sure if they were mentally constructed, or if they are just errors. Whilst I am aware of the distinction between the two terms (misconceptions and errors), I will use the term “misconceptions” when referring to the scientifically incorrect ideas because it is easier for many people to recognise the term misconception as it is commonly used to describe unscientific ideas.

### **Evolution-related misconceptions**

*“Misconceptions about evolution are widespread and contribute significantly to the controversy about teaching evolution”* (Sanders, 2008:94). In this study, I have used the classification system that is used by the Biology Education Research Group at the University of the Witwatersrand to categorise common evolution misconceptions. The system consists of four categories, namely 1) scientifically incorrect ideas possibly associated with religious beliefs, 2) scientifically incorrect ideas associated with misunderstanding the mechanism of evolution, 3) scientifically incorrect ideas associated with a lack of understanding of the nature of science, and 4) other scientifically incorrect information about evolution. Common misconceptions that have been identified in the literature are listed in the tables below, with the correct scientific explanations.

#### ***Misconceptions potentially associated with religious beliefs***

Table 2 on the next page, summarises common misconceptions in this category. One of the most common misconceptions about evolution is that evolution challenges the existence of God by disagreeing with the biblical account of creation (Rutledge & Warden, 2000; Hokayem & Boujaoude, 2008). This gives the impression that evolution and religion are incompatible and people have to choose to believe one of the two. People, who believe the literal interpretation of the biblical accounts of creation, as outlined in the book of Genesis, tend to see conflict between

evolution and religion. The same problem occurs amongst fundamentalist Jewish and Muslim people who take their religious texts, in which a similar creation story exists, literally.

**Table 2: Scientifically incorrect ideas associated with religious beliefs**

Misconception	Scientific explanation
Life appeared on Earth less than 10,000 years ago	The Earth is estimated to be between 4.5 billion and 4.6 billion years old. Scientists think that the earliest forms of life appeared 3.4 billion years ago (McCarthy & Rubidge, 2005). Dated fossils the cyanobacteria are estimated to be 3.4 billion years old (Campbell <i>et al.</i> , 2008)
Life began when the Earth was formed	
Evolution explains how the Earth was formed	The central focus of the theory of evolution by natural selection is to explain how life changed after its origin (Campbell <i>et al.</i> , 2008). The origin of the universe, our galaxy and the solar system produced conditions necessary for evolution (National Academy of Sciences, 2008). Other theories like the big bang theory suggest how life started (Campbell <i>et al.</i> , 2008).
Evolution and religion are incompatible (people who believe in evolution cannot believe in God)	Evolution and religion are very different realms. They are based on different aspects of human experience. In science, explanations are based on empirical evidence drawn from the natural world. If the observations and experimentation are in conflict with an explanation this may then lead to modification or even abandonment of that explanation. Religion, on the other hand, is not based on empirical evidence, but on faith and beliefs that are beyond the natural world. Many religions and individuals accept the theory of evolution by natural selection as one of the most successful theories in the biological sciences (Freeman & Herron, 2004). Many religious denominations have issued statements that evolution and their faiths are compatible (National Academy of Sciences, 2008).
Evolution denies the existence of God.	
Organisms (including humans) exist today in the same form as they always have (i.e. have not evolved)	The implication of this misconception is that all life was created during the week of creation as outlined in religious texts such as the Bible and that evolution does not occur. Scientist no longer question whether evolution happened (Rutledge & Warden, 2000; Ridley, 2004). There is overwhelming evidence in support of common ancestry and evolution by natural selection. There is evidence that that species change over time on a small and a larger scale (Freeman & Herron, 2004; Ridley, 2004). Life has been evolving on Earth for billions of years resulting in vast diversity of past and present organisms (Reece <i>et al.</i> , 2011).
All individuals of a species evolved simultaneously	This misconception may be due to the literal interpretation of creation as depicted in the book of Genesis. The implication of this misconception is that all individuals of a species are the same. In a population individuals vary, and these variations are genetic and they are a result of mutation and sexual reproduction (Ridley, 2004).

Young Earth Christians believe that God created the Earth in six twenty-four-hour days (Freeman & Herron, 2004). They believe that the Earth is less than 10,000 years old, and that all living organisms were created as they appear today. A study conducted by Rutledge and Warden (2000) in the USA revealed that 27% of the teachers in their sample had indicated that life appeared on Earth at the same time the Earth was formed. That species do not change or evolve was an orthodox belief during Darwin's time (Ridley, 2004). Young Earth Christians also tend to believe that believing in evolution nullifies the existence of God and therefore brings about immorality. Their source of morality is the Bible, and since they see evolution as challenging God and/or the

Bible, it challenges morality as well (The University of California Museum of Palaeontology, Berkeley, 2006). This argument is about morality and has nothing to do with science (Freeman & Herron, 2004). Many religions accept the theory of evolution as an explanation of biodiversity (National Academy of Science, 2008; Freeman & Herron, 2004). The clergy letter project indicates that the purpose of religious truth *“is not to convey scientific information but to transform hearts”* (The Clergy Letter Project, 2006). In this letter, the Christian clergy from different churches come in support of the theory of evolution as a foundational scientific truth and state *“to reject the truth ... is to deliberately embrace scientific ignorance”*.

### ***Misconceptions associated with a lack of understanding of the nature of science***

At the heart of science is the development of an accurate understanding of the world around us, using observation and reasoning (Raven, Johnson, Mason, Losos & Singer, 2005). Science follows certain rules, guidelines and principles to explain phenomena in the natural world. Scientific truth relies on evidence from the natural world. Understanding how science works helps us to distinguish between science and non-science. The process of developing scientific ideas involves logical reasoning based on testing explanations against observation of the natural world and rejecting those that fail the test. Scientific claims are subject to peer review. Science is defined as *“the use of evidence to construct testable explanations and predictions of natural phenomena, as well as the knowledge generated through this process”* (National Academy of Sciences, 2008:10). Lombrozo, Thanukos & Weisberg (2008) indicate that even though “the nature of science” is part of the curriculum in many schools, teachers and learners still hold robust misconceptions associated with it. *“Students believe that theories can simply be read off from the world, that scientific claims can be definitely proved, and that theories have not yet achieved the status of facts or laws”* (Lombrozo *et al.*, 2008:291). Table 3 on the next page summarises misconceptions about evolution which could be linked to people’s misunderstanding of the nature of science.

Understanding the nature of science is crucial to an understanding of science and its terminology and to the reduction of misconceptions. For example, a “scientific theory” should not be confused with the everyday use of “theory” as a guess or hunch. Theories are central to scientific thinking. They are overarching explanations that make sense of some aspect of nature, based on evidence allowing scientists to make predications, and have been tested in many ways. As such, a scientific theory is reliable as it is supported by scientific evidence, but it is also provisional because it can be modified or replaced as new evidence appears. Thus, the theory of evolution is not a hunch but it is *“an evidence-based, internally consistent, well-tested explanation of how the history of life proceeded on Earth”* (The University of California Museum of Palaeontology, Berkeley, 2006). The theory of evolution was used to confirm a prediction made by an evolutionary biologist that an intermediate fossil between fish and limbed terrestrial animals, would be found in the 375 million year old sediment (National Academy of Sciences, 2008). The discovery of Tiktaalik in such rock confirmed the prediction.

**Table 3: Misconception about evolution potentially associated with a misunderstanding of the nature of science**

Misconception	Correct explanation
Evolution is not a science because it is not observable or testable	This misconception is based on the idea that because evolution cannot be studied using controlled laboratory experiments it cannot be science. However, not all science investigation involves direct observations and experiments. This misconception may be due to what is in many textbooks that scientists follow a single fixed process to develop experiments (Lombrozo <i>et al.</i> , 2008). Evolution by natural selection can be scientifically tested in the many fields of science like embryology, biochemistry, molecular genetics, palaeontology (Ridley, 2004). Each of Darwin's four postulates about evolution by natural selection has been independently tested (Freeman & Herron, 2004).
Evolution is "just" a theory	The everyday use of the word "theory" has led to confusion in the public understanding of evolutionary theory. The word "theory" in everyday language means unsubstantiated speculation. Whereas in scientific theory is the body of interconnected concepts, supported by scientific reasoning and evidence that explains the facts in some area of study (Raven <i>et al.</i> , 2005). The hypothesis that evolution has occurred is an accepted scientific fact that is supported by an overwhelming body of evidence.
Evolutionary theory is invalid because it is incomplete and cannot totally explain the biodiversity around us.	All scientific ideas are works in progress. As more evidence is discovered ideas are changed to accommodate the new evidence.
Gaps in the fossil record disprove evolution	Gaps in the fossil record do not disprove evolutionary theory. They are expected because soft-bodied organisms do not fossilise well, and sometimes conditions for fossilisation are not present. Furthermore, palaeontologists have discovered, and are still discovering, new fossils, including transitional fossils which connect ancient species with their ancestors and descendants. The fossil record reveals major changes in the history of life and how they may have occurred (Reece, Urry, Cain, Wasserman, Minorsky & Jackson, 2011). A large number of transitional fossils have been discovered since Darwin's time, the most famous of which is <i>Archaeopteryx</i> (Freeman & Herron, 2004). Not all organisms fossilise, e.g. if soft-bodied or if environmental conditions are not favourable for making fossils.
Evolution is a theory in crisis and is collapsing as scientists lose confidence in it	Scientists agree that evolution took place; they debate about how evolution occurred and occurs in different circumstances. This could be a misinterpretation by anti-evolutionists that the debates are about whether evolution did occur or not (The University of California Museum of Palaeontology, Berkeley, 2006).
Most scientists no longer agree with the ideas put forward by Darwin & Wallace.	Modern advances in the understanding of genetics and fossils do not overturn the basic principles of evolution by natural selection as proposed by Darwin and Wallace, but simply add to them (The University of California Museum of Palaeontology, Berkeley, 2006).
Evolutionary theory is flawed	The flaws that are mentioned by the antievolutionists have been found to be based on their misunderstandings of the evolutionary theory and misinterpretations of the evidence. As new evidence is gathered, the theory is refined (The University of California Museum of Palaeontology, Berkeley, 2006).

An American study conducted by Rutledge & Warden (2000) showed that 37% of the teachers in their sample did not accept that evolutionary theory could be tested. Lombrozo *et al.* (2008) say that science does not have a universal path for discoveries and testing. Several other studies found the misconception that evolution is a theory supported by weak evidence (Robbins & Roy, 2007; Rutledge & Warden, 2000; Moore *et al.*, 2006; Nehm & Reilly, 2007; Hokayem & BouJaoude, 2008).

### *Scientifically incorrect ideas associated with misunderstanding the mechanism of evolution*

Darwin was among scientists who argued that species change over time and that fossilised and living organisms have descended from a common ancestor (Freeman & Herron, 2004). Darwin called this evolution “descent with modification”, explaining that there is a relationship between species that evolved from a common ancestor (descent) and diversity as species branched from the common ancestor (Reece *et al.*, 2011, Raven *et al.*, 2005). Table 4 summarises misconceptions related to misunderstanding the mechanisms of evolution.

**Table 4: Misconceptions associated with the mechanism of evolution**

<b>Misconception</b>	<b>Correct explanation</b>
Natural selection involves organisms trying to adapt	Adaptation refers to characteristics of an organism that increase its fitness relative to individuals without the trait (Freeman & Herron, 2004). Natural selection favours the individuals with existing traits that enable them to survive and reproduce. Adaptation does not occur at will. They already exist in the genetic makeup of an individual and the genes cannot alter during the individual's lifetime. Those individuals with the favourable traits will be naturally selected (Bishop & Anderson, 1990). Hence, individuals cannot try to develop new traits. Either they have those traits or they do not.
Natural selection gives the organisms what they need to survive	Natural selection does not have intentions. If individuals in a population do not have the genetic variation, they may survive or may die, but they will not be granted what they “need” by natural selection (The University of California Museum of Palaeontology, Berkeley, 2006). New traits that arise through random mutations during meiosis exist in individuals and can be passed on to the offspring. Existing variations within populations are an essential condition for evolution (Gregory, 2009; Bishop & Anderson, 1990)
Natural selection is about survival of the physically fittest individuals in a population	In everyday language “fitness” means health, strength and stamina (Bishop & Anderson, 1990; Gregory, 2009). However, in the evolutionary sense fitness is any genetic trait that increases an organism's ability to produce offspring (Freeman & Herron, 2009; Gregory, 2009; Bishop & Anderson, 1990). Individual members of a species and members of different species compete for the limited resources in order to survive. Struggle for existence is a metaphorical expression, which refers to ecological competition (Ridley, 2004).
Individual organisms evolve by adapting to their environment and pass on their acquired characteristics to their offspring.	Natural selection acts on individuals, but its results occur in a population (Freeman & Herron, 2004). Hence, populations evolve, not individuals (Gregory, 2009). In this case, adaptation is used in the everyday language context. In addition, this erroneous idea is indicative of Lamarckian ideas about evolution that acquired characteristics are passed on to the offspring (Bishop & Anderson, 1990).

Evolutionary change by natural selection is a chance process	Changes in alleles (mutations) are random. However, evolution by natural selection is a non-random process because it increases adaptation (Freeman & Herron, 2004). Existence is not determined by chance, although, it is biased by some heritable differences that exist between organisms (Gregory, 2009).
Organisms are always getting better through evolution. Evolution results in progress to a particular end point.	Even though the mechanism of natural selection results in the evolution of improved abilities to survive and reproduce, it does not mean that evolution is progressive and leading to some predetermined goal. Evolution makes organisms “better” only in the sense of increasing their adaptation to their environment (Freeman & Herron, 2004). It does not lead to more advanced forms of life. Organisms like sharks have not undergone evolution in a very long time but they still successful (The University of California Museum of Palaeontology, Berkeley, 2006).
Evolution of new species has never been observed	Although speciation is a slow process in larger organisms, scientists have directly observed it, e.g. the divergence of the apple maggot flies into two separate host races (Freeman & Herron, 2004). Furthermore, it is argued that scientific knowledge does not always have to be directly observed, and that science inferences can be used to make claims.
Evolution explains that people evolved from apes, chimpanzees or monkeys	Fossil records, comparative anatomy, and molecular studies have evidence suggesting that humans and apes share a common ancestor but evolved separately from that ancestor, hence they are found on different “branches” of phylogenetic trees (Reece et al, 2011; National Academy of Sciences, 2008; Freeman & Herron, 2004).
Evolution results in an increase in variation within organisms.	Evolution does not result in individual variation. In fact, genetic variation provides raw material for evolutionary change (Reece, 2004). Phenotypic variation often is a reflection of genetic variation which is a product of mutation and sexual reproduction and may result in the production of new alleles and new genes (Reece, 2004). Evolution (by natural selection) depletes genetic variation within populations (Gregory, 2009) but many result in new taxonomic groups on the world.

Darwin also indicated that individuals in a population have an inherent ability to reproduce exponentially (Gregory, 2009). This implies increased competition for resources among individuals of a population, thus there is a “struggle for existence” (Ridley, 2004; Gregory 2009). Darwin proposed a plausible mechanism of how descent with modification occurred, which he called “natural selection”. This mechanism of natural selection was based on the following four postulates, which can be rigorously tested in natural populations (Ridley, 2004; Freeman & Herron, 2004):

- Individuals within a population vary.
- These variations are heritable and are passed from parents to offspring.
- In every population generation, some individuals survive and reproduce better than others.
- Survival and reproduction of individuals in a population is not random, but is based on genetic variation among individuals which is random. Those individuals with favourable variations (variations that allow them to survive successfully) are naturally selected.

If there are heritable (genetic) differences in the individuals of a population, these differences will be passed on to the offspring. If these differences allow the individuals to successfully survive and



reproduce in the struggle for existence (competition), these differences will be passed on more frequently than others, resulting in the characteristics of the population changing slightly with each successive generation as the “favourable” alleles accumulate in the gene pool of the population (Freeman & Herron, 2004). Variation is usually a product of mutation (a random process). Darwin referred to the individuals with variations that allowed them to survive and reproduce better as “fit” (Freeman & Herron, 2004). Biological fitness describes the ability of an individual to survive and reproduce. Evolution depends on the environment that a population happens to live in and the genetic variants that are there in that population (Ridley, 2004).

One other crucial concept of evolution is “adaptation”. Adaptation has meaning in everyday language that differs from the scientific meaning (Bishop & Anderson, 1990). In everyday language, adaptation means “*individuals altering, through their own efforts, their form, function or behaviour*” (Bishop & Anderson (1990:423). Scientific adaptation refers to “design” – those characteristics that enable an organism to survive and reproduce (Ridley, 2004). Contrary to popular belief, natural selection does not allow organisms to adapt, but it favours those organisms that already have the characteristics that enable them to survive. Natural selection is responsible for the evolution of adaptive features (Gregory, 2009). “*Evolution by natural selection is a blend of chance and “sorting”: chance in the creation of new genetic variations (mutation) and sorting as natural selection favours some alleles over others*” (Reece *et al.*, 2011:526).

Gregory (2009) asserts that an understanding of natural selection is crucial to the understanding of how and why living things have come to display their diversity and complexity. However many people poorly understand the process of natural selection, probably because of the misconceptions they hold regarding this process (Bishop & Anderson, 1990; Gregory 2009).

### Other scientifically incorrect ideas about evolution

The misconceptions in Table 5 are probably based on lack of knowledge of the history of life, and may be errors rather than strongly held misconceptions.

**Table 5: Misconceptions about evolutionary theory**

Misconception	Correct explanation
Evolution is about the origin of life	The origin of life is not the central focus of evolution. Evolutionary theory deals with how life changed after its origin (The University of California Museum of Palaeontology, Berkeley, 2006).
Ancient humans (cave dwellers) once hunted dinosaurs.	The geological time-scale clearly indicates that the earliest direct human ancestors first appeared on Earth about 5.3 million years ago, whilst the dinosaurs became extinct about 65 million years ago (Reece <i>et al.</i> , 2011). Humans could not possibly have hunted dinosaurs
Evolution only occurs slowly and gradually	Evolution can occur slowly and gradually, as is the case of gradual evolution whales from their land dwelling mammal ancestor (The University of California Museum of Palaeontology, Berkeley, 2006). However, it can also occur rapidly like many microbes have evolved resistance to drugs, as have a fish species that has evolved resistance against toxins dumped in the Hudson river (The University of California Museum of Palaeontology, Berkeley, 2006).The speed of evolutionary changes depends on the length of a species life cycle. The shorter the life cycle, the faster the evolutionary change.

- Knowing about the different common misconceptions associated with evolution has allowed me to gain valuable knowledge, which enabled me to design the misconception questionnaire and to interpret the results. What was the nature and extent of the pedagogical content knowledge of *Life Sciences* teachers teaching evolution for the first time in South African high schools?

### 2.3.5 Knowledge of appropriate teaching strategies for evolution

*“Teachers need knowledge of strategies most likely to be fruitful in reorganising the understanding of learners”* (Shulman, 1986:9-10). One of the nine requirements of the new South African curriculum is that teaching should be learner-centred (Sanders & Kasalu, 2004). Learner-centredness means that teachers need to recognise the differences between learners (Sanders & Nduna, 2007). In the case of evolution, teachers need to be sensitive towards learners’ religious and cultural beliefs. According to Smith (2009), trying to change people’s beliefs can lead to serious emotional problems, so teachers need to help learners understand that learning about the science of evolution is not an attempt to change their belief systems.

In addressing misconceptions, teachers need to be aware of the types of misconceptions that are associated with evolution, so that they are able to select appropriate approaches and instructional activities that will help address these misconceptions (teaching for conceptual change). One approach suggested by Farber (2003) is to use evolution as a historical case study focussing on scientific problems. Teachers need to be made aware of the vast resources that are available for teaching evolution, and where they can source valuable activities and information. These include science education journals and the internet. It is also of vital importance that teachers attend in-service workshops and symposia, to keep abreast with the developments in evolution.

## 2.4 CONCLUDING REMARKS

Using the five categories in the theoretical framework helped me to realise what the areas were that I needed to probe, and therefore helped me to design the research questions this study is based on. In addition, this conceptual framework was useful for organising and interpreting the findings of the study.