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<u>Investigating an optimized approach to the teaching and learning of Genetics & Evolution in South African schools</u>

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DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

On the 24th day of March 2023 at Johannesburg, South Africa.

Abstract

This study explores teachers' experiences of teaching genetics and evolution according to the grade 12 Life Sciences CAPS curriculum in Gauteng Public High Schools. Research has shown that learners are only achieving a 40-50% average in the genetics and evolution sections of their final examinations (DBE, 2017,2018,2019,2020,2021,2022), however, few studies have been undertaken to explore how learners' conceptual understanding and performance could be improved. In this regard, this study investigates whether the enacted might be a contributing factor to poor performance. To address this, 3 teachers from three different quintile 5 and 2 teachers from 2 different quintile 4 public (1 teacher per school), CAPS abiding high schools, as well as 1 genetics and 1 evolution lecturer to pre-service Life Science teachers, were purposively selected and interviewed to evaluate the topics of genetics and evolution in the enacted curriculum. The data collected from the interviews, participant sequencing suggestions and participant concept maps was analysed through inductive and deductive thematic analysis. In terms of threshold concepts, the data showed conclusively that an understanding of certain genetic concepts (such as DNA, meiosis, mutations, variation, etc.) is essential to the understanding of certain evolution concepts. Regarding the annual teaching plans, it was found that although teachers abide by the proposed plan, they suggest that resequencing evolution to directly follow genetics may improve learner understanding. Lastly, the genetics and evolution lecturers agreed that while the university curriculum is tailored to cover the school curriculum, there are still some areas which are not adequately covered a university level which may result in teachers having some knowledge gaps regarding the school curriculum. Based on the data, a recommendation is made for the reconsideration of the sequencing of genetics and evolution for optimized linking between the topics. However, further research still needs to be done to determine the most effective pedagogical methods for teaching and learning genetics and evolution content in high school.

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To my supervisor, Professor Kershree Padayachee, thank you for your continuous guidance during my writing journey, for the spontaneous meetings when I needed them, the articles you made sure I had access to and the feedback on multiple drafts of this paper. I am truly grateful for your unwavering encouragement and support during the pandemic which placed a strain on my academics. You counselled me through many challenging days, including the day my mentor, Dr Ian McKay passed on.

When you are a master's student in a pandemic, it is easy to feel alone as the reality of independent study sets in, however, the late Dr Ian McKay was always willing to listen to my concerns, questions and even my fears. In the five years that I had known Dr McKay, I was always inspired by the dedication he had towards teaching. He invested his time and resources in trying to make paleo-education accessible and exciting. Dr McKay's passion for research and education was unmatched. He motivated me each and every day, prompting me to think deeper. He always had an "outside the box" way of analysing things which was interesting and inspiring. Dr Ian McKay strengthened my passion for teaching, learning, and research and for that, I will be forever grateful.

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List of Abbreviations

ATP: Annual Teaching Plan

CAPS: Curriculum Assessment Policy Statement

DBE: Department of Basic Education

IEB: Independent Board of Examiners

MKO: More knowledgeable other

NCS: National Curriculum Statement

PCK: Pedagogical content knowledge

SAGs: Subject Assessment Guidelines

SMK: Subject matter knowledge

TSPCK: Topic specific pedagogical content knowledge

CHAPTER 1: Introduction

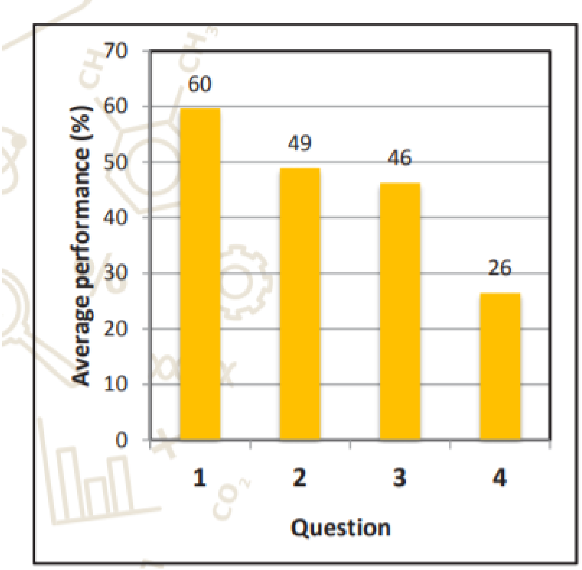
For many, the end of a 46-year apartheid legacy marked an optimistic beginning for the South African Education system (Spreen & Vally, 2010). A multitude of education policies were formulated under the assumption that a new democratic government would pioneer an improved education system (Spreen & Vally, 2010) which culminated in the establishment of various new curricula (Gumede & Biyase, 2016). Since 1995, there were several Life Sciences curriculum changes which attempted to reach an optimized curriculum (Johnson, 2009).

One of the major changes that was made concerned the teaching of evolution. Previously, Christian National Education, banned evolution from the school curriculum (Van den Heever, 2009) since the topic clashed with the religious ideologies (Dempster & Hugo, 2006) of National Christian Education (Lavin, 1965). It was only in the 2008 National Curriculum Statement (NCS) that taboo evolutionary related content was introduced and examined in grade 12 (Johnson, 2009, Sanders & Ngxola, 2009). It has been suggested by many authors (Dobzhansky, 1973, Dempster & Hugo, 2006, Sanders & Ngxolo, 2009 and Rutledge & Sadler, 2002) that evolution is the highest ordering principle in biology. Therefore, its inclusion in the school curriculum is essential to promote the learning and understanding of the development of organisms (McKay, 2017).

However, a multitude of studies, both in South Africa and abroad have revealed that evolution is one of the topics, which teachers and learners struggle to understand (Deniz & Borgerding, 2018). Many reasons have been proposed for this challenge, including the difficulty of the topic, poor content knowledge of the teachers, fundamentalist religious beliefs of learners and teachers, and essentialist and teleological reasoning of the teachers and learners (e.g., Kyriacou et al., 2015, Friedrichsen et al., 2018, p.273, Stern et al., 2018, p.4,5)

In South Africa, the National diagnostic reports (2017-2022) explicitly state that evolution and the closely allied topic of genetics continuously remain the two sections in which learner performance is the weakest, reaching only a 40-50% average in these sections (DBE, 2021). This is shown in Figures 1 a, b and c below.

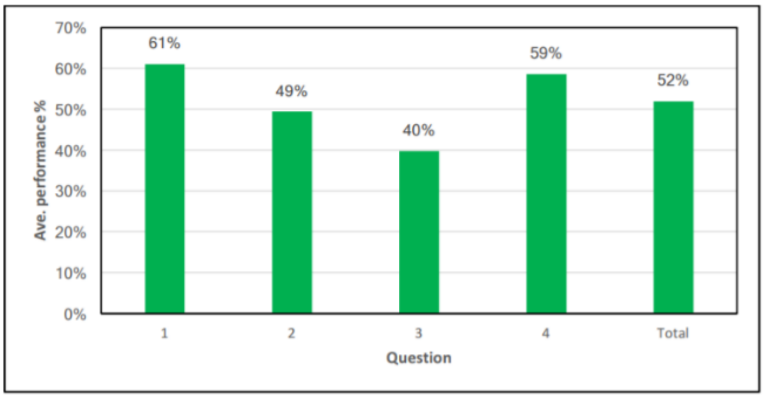
Average Marks per Question expressed as a Percentage in Paper 2



Q1	MCQ, Terms, AB Matching, Meiosis, Dihybrid cross
Q2	Protein Synthesis, Co-dominance, Monohybrid, Natural Selection, Scientific investigation
Q3	Human Evolution, Speciation, Variation
Q4	Sex Determination, Paternity Testing (Blood Groups and DNA Profiling)

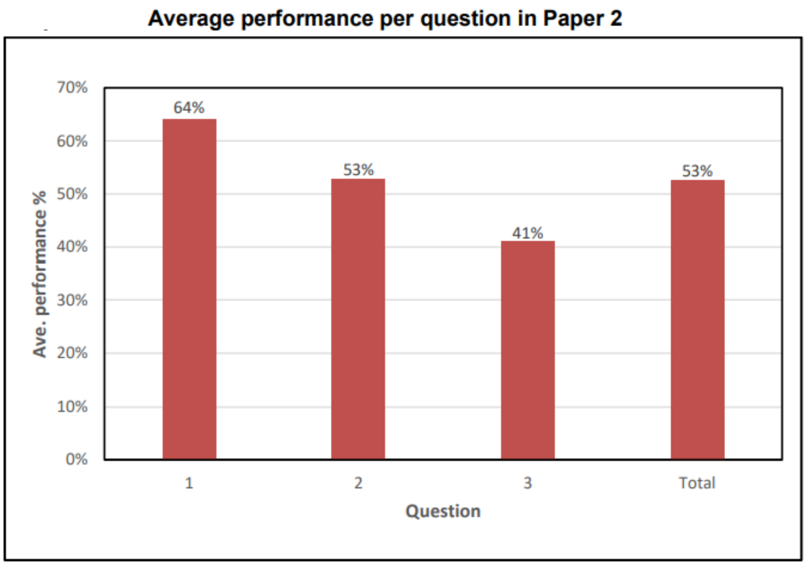
Figure 1a: 2019 average performance in the topics of genetics and evolution (adapted from 2019 National Diagnostic Report: Content Subjects)

Average performance per question in Paper 2



Q	Topic/s
1	Multiple Choice, Terminology, Matching Items, Meiosis, Dihybrid cross and Phylogenetic tree
2	DNA profiling, Cloning, Genetics (Pedigree diagram and sex-linked inheritance)
3	Evolution
4	DNA, DNA replication and Mitosis

Figure 1b: 2020 average performance in the topics of genetics and evolution (adapted from 2020 National Diagnostic Report: Content Subjects)



Q	Topic
1	Multiple choice, terminology, matching items, DNA, Meiosis, Dihybrid cross
2	Protein synthesis, Meiosis, Genetics
3	Genetics, Evolution

Figure 1c: 2021 average performance in the topics of genetics and evolution (adapted from 2020 National Diagnostic Report: Content Subjects)

Some curriculum related reasons that have been given for poor performance in genetics and evolution are learners' lack of understanding of basic terminology, inaccurate information in textbooks (DBE, 2020) and poor teacher training (Sanders, 2018). It is also possible that evolution may not be adequately covered by teachers as it is the last topic in the South African Curriculum Assessment Policy Statement (CAPS) and annual teaching plans (ATP) (DBE, 2020) which are the two documents that guide the teaching and learning process.

There are also other possible problems in the current curriculum. With a topic as controversial and seemingly inherently difficult as evolution, one would expect that a well laid out curriculum with appropriate curriculum support materials would be crucial (Ball and Cohen 1996; Hutchinson and Torres 1994; Ottevanger 2001 cited in Sanders & Makotsa, 2016). Unfortunately, this may not be the case with the CAPS curriculum (the national curriculum implemented since 2012) which is said to be "diluted" (Naidoo, 2017, p. 118,), with substantial gaps existing across grades. For example, in grade 10, learners are exposed only to the fossil record, grade 11 does not include any evolution related content except for learners to "draw phylogenetic tress showing evolutionary history of plant groups" (DBE, 2011, p.41) in the biodiversity and classification section, however, this falls within the "investigation" area of the

CAPS document which is not compulsory. Grade 12 presents evolution by natural selection and human evolution (Naidoo, dissertation, 2017, p.118). Bodhania (Hons, 2019) also analysed the curriculum in detail, interviewing experienced Life Science teachers regarding the sequencing of evolution in CAPS. The findings of that study concurred with Naidoo (2017) that the sequencing of topics from grade 10-12 may be flawed in that evolution related content is separated over grades and terms. Furthermore, the grade 12 curriculum separates the topic of genetics (taught in terms 1 & 2) from evolution (taught at the end of term 3), despite the important conceptual underpinnings that these topics share. Scaffolding of topics requires the use of prior knowledge to show the links between topics through conceptual progression. However, teachers do not always use learner's prior knowledge as a segue to introduce new topics which are linked to a previous section (Bodhania, Hons, 2019). Bodhania (Hons, 2019) concluded that part of the reason why evolution content is found difficult may be that for learners to have a good understanding of evolution, their understanding of genetics must be comprehensive.

Alters and Nelson (2002) explain that certain concepts need to be understood before other concepts can be understood. This is supported by Mead et al. (2017) who reported that a survey of over 300 14–16-year-old learners in the United Kingdom revealed that their evolution knowledge increased significantly if they were taught genetics before evolution, compared to the reverse situation. Mead et al. (2017) further argued that the coherent linking of these topics in the curriculum is crucial for deeper conceptual understanding.

Whilst Mead et al. (2017) were concerned with Biology education in the UK, their reference to the relationship between genetics and evolution is directly related to the South African Life Sciences curriculum since these are the topics of major concern in our national context too. There may be certain concepts in genetics which, when understood well, will assist learners to understand certain evolution concepts (Mead et al., 2017). For example, understanding foundational concepts of genetics such as: "DNA, mutation, inheritance, alleles" (Mead et al., 2017, p. 19), which are uncontroversial, might make it easier for learners to process evolution information, especially if the evolution content is introduced as "population genetics" (Mead et al., 2017, p.19). Other genetics concepts such as meiosis and Mendelian genetics are critical for understanding natural selection (Jing et al., 2019, Bergero et al., 2021). Additionally, mutations, mitochondrial DNA and Y-chromosomal DNA are essential evidence for understanding common ancestry between hominids and the "Out of Africa Hypothesis" (Dulik et al., 2012).

In South Africa, genetics is suggested to be taught before evolution in the CAPS curriculum which acknowledges the relationship between genetics and evolution but does not explicitly link the topics. This may be related to "threshold concepts" – which Meyer and Land (2003) suggest are crucial for "students, teachers and for curriculum designers" (Salwén, 2019, p. 36), since threshold concepts refer to "a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress" (Meyer and Land, 2003, p. 1). However, there have been many concerns about the precise definition of threshold concepts (Salwén, 2019), as discussed later.

Although often compartmentalized, genetics and evolution require integration to form a coherent understanding of the links between these biological concepts (Gilissen et al., 2019). It appears, however, that many Life Science curricula do not consider genetics as an essential aspect of understanding evolution (Homburger et al., 2019). Consequently, it is necessary to investigate if the current Grade 12 Life Science CAPS curriculum falls into this category of curricula and if so, perhaps the topics of genetics and evolution could be reorganised and intentionally linked, to enhance learning.

Nyamupangedengu (2016) suggests that teachers can only make effective links between topics if they possess "horizon knowledge" (p. 41) which makes teachers explicitly aware of how topics are related in the curriculum. This supports the proposition that: "teachers would be better equipped to link genetics and evolution concepts if the curriculum guiding their teaching directly and effectively connects these topics".

The focus of this study was therefore to investigate how the links between genetics and evolution in the enacted curriculum affects teaching and learning and identify possible ways of improving the teaching and learning of these topics by rearranging their current sequencing, scaffolding the topics to ensure direct links and integrating concepts when possible. While I acknowledge that the findings of this study will not result in any immediate changes in the current grade 12 Life Sciences curriculum, it is possible that the disconnect shown between these topics is contributing to learners' poor performance in these sections, and if so, the recommendations proposed in this study could improve new versions of the Life Sciences CAPS curriculum.

1.1 Problem and purpose statement

Grade 12 learners in South Africa consistently perform poorly in the genetics and evolution sections of the grade 12 final examination (DBE, 2017-2022). Part of the reason may be because the topics are not conceptually progressive in the CAPS curriculum (Naidoo, 2017; Bodhania, Hons, 2019). This study explores teachers' and teacher educators' views of the scaffolding of evolution in the CAPS curriculum, the extent and influence of linkages between genetics and evolution topics, and whether these linkages can be strengthened and consequently improve learner and teacher understanding.

1.2 Aim and Objectives

Aim

The aim of this study was to investigate if Grade 12 Life Science teachers and teacher educators consider genetics concepts to be prerequisite to understanding evolution concepts. Furthermore, the study investigates how evolution concepts in the grade 12 Life Sciences CAPS curriculum could be improved for enhanced conceptual understanding. The argument advanced in the present study is that teachers and teacher educators support the proposition that there is an incoherent sequencing and a lack of conceptual linking between genetics and evolution in the grade 12 Life Sciences CAPS curriculum, and that if the curriculum is organised in a way that shows how topics within genetics such as DNA and Meiosis can be used to explain the mechanism of evolution, the theory of evolution might be better understood by learners.

Objectives

The research was based on the following objectives:

1. To investigate what concepts Life Science teachers and teacher educators consider as threshold concepts in genetics and evolution.
2. To determine what Grade 12 Life Sciences teachers and Life Science teacher educators think about the way genetics and evolution threshold concepts are sequenced and interlinked.
3. To investigate, based on the answers to questions 1 and 2 above, whether the organization of genetics and evolution CAPS curriculum could be optimized for better teaching and student learning.

1.3 Structure of the dissertation

The chapters that follow provide a summary of the current research and literature on the teaching of genetics and evolution in the South African high school context (Chapter 2), a description of the methods employed to address the research objectives posed (Chapter 3), a presentation of the results (Chapter 4), and discussion of the findings (Chapter 5) and the conclusions and recommendations of the study (Chapter 6).

1.4 Potential contribution of this research

Comparison of the Grade 12 Life Sciences National diagnostic reports from 2017-2021shows that learners have continuously performed poorly in genetics and evolution. This study aims to address the poor performance trends by contributing to more effective teaching of these topics, by attempting to identify the relationships between genetics and evolution in the current CAPS curriculum and to identify solutions to bridge the gap between the topics for enhanced conceptual understanding. The outcomes and recommendations of this study may inform future improvements to the CAPS curriculum, particularly in the sequencing of topics in Life Sciences, with a strong motivation for bi-directional linking between the topics of genetics and evolution. This would scaffold the topics more effectively, potentially resulting in better conceptual understanding of both topics.

CHAPTER 2: Literature review

The literature review begins with an analysis of reported difficulties experienced in the teaching and learning of genetics and evolution in South African schools under the sub-headings of *fundamentalist religious beliefs, Genetics and Evolution in the Grade 12 CAPS curriculum, Preparation of teachers to teach Genetics and Evolution*. This is followed by explanations of concepts that were essential to this study, including: *Core concepts and threshold concepts in Genetics and Evolution* and *Documents guiding the teaching and learning of Life Sciences in South Africa. Lastly, the conceptual frameworks that informed the study are discussed.*

2.1.1 Fundamentalist Religious Beliefs

The theory of evolution unifies all topics in Life Sciences "Nothing in Biology makes sense except in the light of Evolution" (Dobzhansky, 1973, p. 125). While the significance of evolution lies in the evidence and explanatory power that it provides for the diversity of all life on Earth (Rutledge & Sadler, 2011), it is poorly understood and perhaps therefore, often rejected. Since the day Charles Darwin's theory of evolution was published, it underwent scrutiny and resistance, particularly from religious groups (Hildering et al., 2013). Whilst scientific doubt has decreased, much of the public still remain opposed to it (Hildering et al., 2013). This may be due to a lack of public interaction with science which results in a negative attitude towards scientific theories (Hildering et al., 2013). Religious beliefs and identities have been documented as one of the key contributors to evolution rejection (Barnes et al. (2021). The public are usually conflicted since it is assumed that evolution contradicts common sense and strongly engrained religious beliefs of many in South Africa (Dempster & Hugo, 2006, Kyriacou et al. 2015, Sanders, 2018).

Student opinions about the theory of evolution often reflect the generally sceptical views of the public (Deniz & Borgerding, 2018). Since most people in South Africa are likely to be exposed to the *scientific* explanation of evolution for the first time at school level, learners often enter the classroom with a multitude of misconceptions (Deniz & Borgerding, 2018). Consequently, Life Sciences teachers serve as the most important link in the transformation of the scientific understanding to public understanding of the theory of evolution (Yates et al., 2013). Transformation involves adapting subject-matter knowledge as a teacher into that which is accessible to learners (Geddis, 1993). This is necessary in education as transformation requires an exchange of transmitting and receiving information to for the purpose of modifying one's current knowledge or introducing new knowledge which can be retained and passed on (Wye et al., 2015). Consequently, teachers should be skilled in acquiring and adapting content knowledge and links between genetics and evolution for learner comprehension.

Barnes et al. (2021) suggest that teachers can increase transformation of evolution-related concepts by engaging in discussions which promote the idea that understanding evolution does not mean one has to reject their religious identity or belief in God. However, this can become a challenge in the classroom when the teacher's ability to transform the evolution content is hindered by their *own* religious beliefs (Siani & Yarden, 2021).

Chinsamy and Plagányi (2008) mention that even if teachers and learners do not accept the concept of evolution, their understanding of evolution is improved when factual information with supporting evidence is provided. Sanders (2018) noted that the few teachers who previously sought help from the National Professional Teachers' Organisation of South Africa (NAPTOSA), universities, individual academics and/or department of education (p. 416) benefited from workshops which equipped them with strategies to be able to transform the evolution subject-matter knowledge into that which is accessible to learners. However, the workshops and number of participating teachers was minimal (Sanders. 2018). Despite religious beliefs having an impact on the teaching and learning of evolution, there are also various evolution-related curriculum issues which may be contributing to the poor understanding of the topics. These obstacles are discussed next.

2.1.2 Genetics and evolution in the Life Sciences CAPS curriculum

Mnguni (2018) cites Gagne's (1967) definition of a curriculum as a "sequence of content units arranged in such a way that the learning of each unit may be accomplished as a single act, provided the capabilities described by specified prior units (in the sequence) have already been mastered by the student" (p. 3099). Simply, Hacohen and Weinshall (2019) explain this by stating that a curriculum organises concepts in increasing complexity, where prior knowledge links and facilitates new knowledge (p.1). According to the grade 10-12 Life Sciences CAPS curriculum, the curriculum content has been sequenced for progression "from simple to complex" (DBE, 2011, p. 4). While the Department of Basic Education (DBE) states that the CAPS curriculum is a guideline, it is a requirement for teachers to follow the Annual Teaching Plan (ATP) provided by the department of Education for each year. According to the DBE's circular S3 (2020), the ATP "outlines the minimum concepts, content and skills that are core per grade and per subject, that are to be taught, learned, assessed and prioritised" (p. 2) this serves as a limiting factor for teachers who remain bound to the sequencing and pacing of topics (Naidoo, 2017, p. 119). Furthermore, the centralisation of assessment (Naidoo, 2017, p.119) according to the ATP does not favour holistic learning since topics are tested according to their sequence in the CAPS curriculum which, previously mentioned, separates evolutionary and genetic content in grade 10-12, despite their direct connection: genetics is evidence that supports the theory of evolution. This problem of separating evolutionary related content was investigated in some detail by Bodhania (Hons, 2019) the findings: evolutionary content in the CAPS curriculum leaves gaps in conceptual progression from grade 10-12. The fossil record and biogeography are taught in grade 10, grade 11 omits evolutionary content, then evolution by natural selection and human evolution (including fossil evidence) is presented at the end of grade 12 (DBE, 2011). This results in a lack of continuity in the content; not only between topics in one year but also from one grade to the next. Table 1 below shows how the topics are arranged in grade 10-12 and the way in which they are linked according to the CAPS curriculum. However, the expected links are not always achieved since the topics are separated over three years in the Life Sciences curriculum. Table 1 therefore shows the prescribed links and the possible hinderance of conceptual progression due to the sequencing and timing of evolution-related topics

Johnson et al. (2015) claim that CAPS curriculum designers were concerned with making a better link between the strands and topics than in the previous NCS (National Curriculum Statement) document that was in place from 2006 to 2010. Yet, Grussendorff et al. (2014), who specifically examined the CAPS curriculum to determine the level of improvement from the NCS, showed that the CAPS curriculum presents no evidence that the sequence of topics leads to a better progression within a grade (p. 16). Table 1 shows that teachers are required to link grade 10 concepts to grade 12 concepts without any integration from grade 11, this means that learners are expected to compartmentalise what they learn about the “History of life on earth: Evidence of certain key events in life’s history” (Mavuru, 2019, p. 5) until they reach the topic of Human evolution in grade 12.

Table 1: Evolutionary topics in grade 10-12 Life Sciences CAPS curriculum

Grade	Term	Content	Links in CAPS
10	4	• Fossil formation and dating • History of life on Earth	• Link mass extinctions to grade 12 (DBE, 2011)
11			No links
12	end 3	• Evolution by Natural Selection	• Link to grade 10 fossil record (DBE, 2011) • Link to grade 10 modification by descent (DBE, 2011) • Link to grade 12 genetics (DBE, 2011)
		• Human Evolution	• Link to genetics (DBE, 2011)
	Beginning 4	• Human Evolution continued	• Link to grade 10 dating of fossils (DBE, 2011)

In a study carried out by Naidoo (2017), teachers suggested that life sciences topics such mitosis (grade 10) and meiosis (grade 12) should be studied in consecutively to enable learners to see how these processes are related (p. 180), similarly, it can be deduced that topics that rely on each other for conceptual progression, such as genetics and evolution should not be separated in the curriculum. Schmidt, Wang and McKnight (2005) explain this using the term "curriculum coherence" which they describe as the progression from concrete knowledge to abstract knowledge (Coleman et al., 2015). They expound the importance of making sensible links between related topics (Coleman et al., 2015).

This is a particularly noticeable issue in the grade 12 syllabus (Table 2), which shows how the sequencing of topics and the required links according to the CAPS document may not serve curriculum coherence. Grade 12 evolution topics are expected to be linked with genetic concepts. However, the topics of genetics and evolution are separated over time and between other unrelated topics. Table 2 below shows the topics (shaded in grey) which interrupt the conceptual progression between genetics and evolution. Since genetic concepts are not followed directly by evolution concepts, it may be challenging to link the topics as required by the curriculum and for holistic understanding.

Table 2: The current sequencing and linkages of Genetics and Evolution in the Grade 12 Life Sciences Curriculum.

Term	Topic	Content	Links made between genetics and evolution
1	DNA: The code of Life	• DNA • RNA • Meiosis	In order to understand species, speciation, biodiversity and change, it is essential to understand how DNA and chromosomes enable continuity and change" (DBE, 2011, p. 54).
	Reproduction in Vertebrates	• Diversity of reproductive strategies	None
2	Genetics and inheritance	• Genes • Inheritance and variation • Sex chromosomes	None
		• Mutations	"Mention mitochondrial DNA and the tracing of genetic links" (DBE, 2011, p. 57)
	Responding to the environment: Humans	• Human nervous system • Disorders • Injuries • Effects of drugs • Receptors	None
3	Human endocrine system	• Endocrine glands	None
	Homeostasis in humans	• Homeostasis	None
	Responding to the environment: Plants	• Plant hormones • Geotropism and phototropism • Plant defence mechanisms	None
	Evolution by Natural selection	• Origin of ideas about origins	"Link to genetics (grade 12)" (DBE, 2011, p. 61)
		• Artificial selection	None

		• Darwin's theory of evolution by natural selection	"Link to Genetics: depends on variation/gene pool of inherited characteristics" (DBE, 2011, p. 61)
		• Formation/emergence of new species	None
		• Mechanisms for reproductive isolation	None
		• Evolution in present times	None
	Human evolution	• Evidence of common ancestors for living hominids including humans	"Genetic evidence: mitochondrial DNA" (DBE, 2011, p. 63)
		• "Out of Africa" hypothesis	"Evidence African origins for all modern humans: genetic links, mitochondrial DNA" (DBE, 2011, p. 63)
4	Human evolution	• Importance of the Cradle of Humankind	None
		• Alternatives to evolution	None

The curriculum acknowledges some conceptual links between genetic concepts and human evolution, viz., how the fossil record, biogeography, genetic evidence and cultural evidence supports the theory of human evolution (DBE, 2020, p.163). However, the current sequencing and timing of content (genetics in term 2 and evolution in terms 3/4) poses challenges for the integration and optimization of these topics (Bodhania, Hons, 2019). Furthermore, it seems that despite the decade-long inclusion of evolution in the South African curriculum, the topic remains a challenge for some who teach it, causing a flawed transfer of knowledge to learners (Sutherland & L'Abbé, 2019). Furthermore, the curriculum is a crucial means of support for teachers, particularly for teachers who are poorly prepared (Ball and Cohen 1996; Hutchinson and Torres 1994; Ottevanger 200, cited in Sanders & Makotsa, 2016), consequently, it is necessary to examine how teachers become prepared to teach evolution and if the CAPS curriculum serves as an effective supporting material.

2.1.3 Preparation of teachers to teach Genetics and Evolution

Pre-service teachers

There is a direct relationship between the preparatory teacher curriculum and the school curriculum (Mpungose, 2020). For learning to occur, it is imperative that teachers possess certain knowledge domains, including: "contextual knowledge, curriculum knowledge, knowledge of the learners, pedagogical content knowledge and the subject matter knowledge" (Mavuru & Pila, 2021, p.106). Teachers should be able to integrate these knowledge domains to effectively transform knowledge (Botha & Reddy, 2011). However, it must be noted that many pre-service teachers enter their university programmes with misconceptions about biological concepts that they developed during high school (Mavuru & Pila, 2021). Many teachers have difficulties teaching topics such as genetics and evolution in grade 12 due to the complex nature of the topics, teacher's contradictory beliefs and poor pre-service preparation (Mavuru & Pila, 2021) may lead to ineffective teaching and learning. Pre-service teachers often state that evolution and, particularly human evolution is a controversial topic, which causes them to have a lack of confidence, negatively affecting the way in which the topic should be taught (Mavuru & Pila, 2021). Most teacher education courses are also content driven (Nyamupangedengu, 2015) with limited training and support on *how to teach* (Johnson et al., 2015). Teacher education courses should assist teachers in developing the ability to make curriculum content accessible, relatable, and meaningful to learners (Ngwenya, 2020), but this is not always the case.

Practicing teachers

A change in curriculum is a challenge to any practicing teacher (Keke, 2014). In addition to being confronted with new content, they are also required to develop their skills and methodologies to make the new content accessible to their learners (Keke, 2014). Competent teachers should be able to identify how their own thinking and the thinking of the learners in relation to the content can be used to overcome barriers (Sturts & Mowatt, 2012). As such, teachers should engage in continuous professional development programmes (Bell and Gilbert, 1994 cited in Keke, 2014) to enrich their pedagogical content knowledge (PCK). PCK is a framework described by Shulman (1987) in which a teacher is able integrate subject matter knowledge with appropriate teaching strategies for learners to achieve an understanding of the content at hand (De Rossi & Trevisan, 2018). In this study, the teacher's PCK is topic specific to genetics and evolution discussed further below.

Genetics

Genetics is often considered an innately difficult topic to learn (Banet and Ayuso, 2000). Learners have consistently struggled to answer genetic related questions (DBE, 2017-2022). Olanrewaju and Atagana (2012) state that one of the main contributors of learner poor performance in this topic is poor teaching. Teachers' understanding of genetics affects their lesson planning, delivery and activities (Hadiprayitno, 2019), and, in South Africa, classroom practices mainly involve traditional methodologies which encourage learners to be passive receivers of knowledge, possibly leading to the development of misconceptions (Ngwenya, 2020). Since teachers are at the centre of the problem (Olanrewaju & Atagana, 2012), teacher educators need to develop courses that enhance pre-service teacher PCK (Nyamupangedengu, 2015). In other words, teacher educators need to collaborate the content with *how to teach* in the classroom (Nyamupangedengu, 2015).

Evolution

As previously mentioned, many South African teachers hold strong religious beliefs, lack content knowledge of evolution related topics (Kyriacou et al., 2015) and have minimal training on evolution related topics (Coleman et al., 2015). These barriers may result in teachers having naïve conceptions about the theory of evolution, causing their teaching of the topic in an isolated manner, possibly leaving room for the development of misconceptions (Coleman et al., 2015, Kyriacou et al. 2015). The fundamentalist views of some Christian and Muslim teachers prevent them from understanding and accepting evolution, making their teaching ineffective (Naude, 2013). Furthermore, Sutherland and L'Abbé (2019) explain that the negative portrayals of African people as 'closer' to earlier Hominid species may leave teachers feeling unequipped to deal with heated conversations in the classroom and often lack skills to address racial misconceptions. Since evolution was only introduced in 2008, a tremendous challenge that some teachers faced, at least in the early years, was not having covered evolution education in their pre-service teacher programmes (Holtman, 2010). The implementation of CAPS resulted in teachers having to familiarise themselves with content and methodologies of which they had limited/no prior training (Holtman, 2010). While the curriculum states the concepts of evolution, it does not provide teachers with methods to effectively link these concepts with supporting evidences, hindering a holistic understanding of the topic (Dempster & Hugo, 2006). It is possible that the poor linkage in the CAPS curriculum accompanied by ill-designed teacher training may result in many South African teachers being unaware of *how* evolutionary concepts fit into the topics of "biodiversity and classification, and genetics" (Molefe & Sanders, 2009, p. 382). Despite the attempts to make evolution education inclusive, most teachers have not been equipped to teach the specialised type of evolutionary content (Holtman, 2010).

The results of a case study conducted by Keke (2014) in the Kwa- Zulu Natal Province with about 206 Life Sciences FET teachers, from 3 districts concluded that several teachers requested professional development courses in grade 10-12 evolution topics. Yet, little has been done in recent times to identify whether teacher training on evolution remains a problem or if there are other reasons for learners' poor performance in the section. Furthermore, teachers may not be aware of the: core concepts, threshold concepts, troublesome knowledge and bottlenecks in Genetics and Evolution, defined, differentiated and discussed below, according to their relevance in this study.

2.1.4 Core concepts and threshold concepts in Genetics and Evolution

Concepts refer to the way we think about something. They are the basic components of thought (Salwén, 2019, p. 37), helping to categorize knowledge according to the disciplines they belong (Salwén, 2019). As described next, concepts in science may be defined as either "threshold" (Meyer & Land, 2003) or "core" (Meyer & land, 2003). It is therefore important to distinguish between these, although it is equally important to note that these are often used interchangeably outside the academic space.

Core concepts

"A core concept is a conceptual 'building block' that progresses understanding of the subject; it has to be understood, but it does not *necessarily* lead to a qualitative different view of the subject matter" (Meyer and Land, 2003, p. 4). Simply, core concepts are established on existing knowledge, a core concept is any idea, process or principle that can be learned without explicitly transforming the way a person thinks about a topic (Meyer and Land, 2003). Examples of core concepts include: evolution, homeostasis (McFarland & Michael, 2020, p. 628) and the centre of gravity (Meyer & Land, 2003, p. 5). Core concepts are made up of explicitly defined constituent ideas and a thorough comprehension of any core concept requires an understanding of each component individually (Michael et al., 2017).

Threshold concepts

The notion of threshold concepts was first proposed by Meyer and Land in 2003, as a definition for concepts that open a “new and previously inaccessible way of thinking about something" (p. 1). Threshold concepts lead to a qualitatively different view of the subject, meaning that one develops an in-depth understanding of a particular area by becoming aware of interrelatedness that was previously concealed (Meyer & Land, 2003, p 5). However, reaching a transformed way of thinking is often difficult or as Meyer and Land (2003) cite Perkins (1999) who describes it as “troublesome”. Threshold concepts in their own form or in their application may invoke troublesome knowledge (Meyer & Land, 2006). It is suggested that “conceptually difficult knowledge is encountered as troublesome” (Perkins, 1999 cited in Meyer and Land, 2006, p. 8). Troublesome knowledge is conceptually difficult, counter-intuitive or ‘alien’ (Meyer & Land, 2003, p. 1). Troublesome knowledge simply means knowledge that is difficult to comprehend. Some troublesome knowledge can become bottlenecks. Pedagogically, the term “bottleneck” refers to a moment when students may face barriers to understanding content in the process of learning” (Sturts & Mowatt, 2012, p.1).

When students come upon certain knowledge that they simply cannot make sense of, knowledge that is difficult to assimilate or accommodate, bottlenecks occur (Middendorf & Shopkow, 2017). According to Piaget (1958), assimilation is the processes of interpreting the knowledge we encounter by adding new information to our current understanding which allows us to categorise information by using existing cognitive structures (Faizah, Nusantara & Rahardi, 2022). Accommodation refers to the modification of current schemas to alter or replace existing knowledge to transform one’s interpretation of reality (Faizah, Nusantara & Rahardi, 2022). Since students often use the same mental patterns when acquiring knowledge, they may experience similar types of mental blocks or “bottlenecks” because they tend to view all information in the same way (Middendorf & Shopkow, 2017). This creates a barrier to understanding of the concept or topic which leaves learners in a state of “liminality” (Meyer & Land, 2003, p. 13); a stage between a student’s old understanding and possible new understanding of a concept. Only once they reach assimilation and accommodation of the new concept, will they have understood a “threshold concept”.

Threshold concepts can also either be tacit or explicit (Ross et al., 2010) and may include abstract concepts which are required to understand the principles causing a phenomenon (Tibell and Harms (2017). Threshold concepts that are tacit are often interdisciplinary. Fiedler et al. (2017), for instance, explain that while randomness and probability are key principles in mathematics, they are threshold concepts which manifest in various other contexts, including evolution. Threshold concepts integrate subject matter to increase coherence (Davies, 2006) and holistic understanding of a topic (Meyer & Land, 2006). According to Meyer and Land (2003) "as a consequence of comprehending a threshold concept there may thus be a transformed internal view of subject matter, subject landscape, or even world view" (p. 1). As many learners have the weakest performance in this section in grade 12 (DBE, 2020), it can be deduced that the inherently difficult concept of evolution can be considered a threshold concept and will be referred to as such in the following chapters.

Evolution as a threshold concept

Evolution education should be scaffolded by organising relevant knowledge to form pivotal links that highlight evidences and similarities in complex biological concepts (Tibell & Harms, 2019). However, there has been a trend of misconceptions and misunderstandings of evolution in South African schools (DBE, 2017-2022). According to some literature, "bottlenecks" as defined under threshold concepts above, are evident in the teaching and learning of evolution. Consequently, it may be the core genetic concepts that underlie evolution which are poorly understood and as such, are the bottlenecks to understanding evolution concepts (Tibell & Harms, 2019). By way of example, Tibell and Harms (2019) explain that the core concept of natural selection is used to facilitate the understanding of the threshold concept of evolution. However, natural selection only leads to evolution if there is physical and genetic variation within a population (Ross et al., 2010). To understand this, one must understand three specific core principles: the variation principle, the hereditary principal and the selection principle (Tibell & Harms, 2019). Natural selection occurs from *random* genetic variation in a population which results in different inherited traits that offer different survival opportunities. However, survival is related to the environmental pressures placed on the individual (Elliot et al, 2014). Individuals that have advantageous phenotypes are more likely to be "selected" – to survive and reproduce (Elliot et al., 2014). The *probability* of an individuals' traits passing on to the next generation is dependent on their reproductive success rate in their given environment (Tibell & Harms, 2019).

Linking back to the notion of threshold concepts, Figure 2 below shows that understanding evolution, is dependent on the understanding of the tacit threshold concepts, viz., randomness and probability (Tibell & Harms, 2019). Only once learners understand how randomness and probability cause variation, inheritance and selection, can they understand the concept of evolution (Ross et al., 2010).

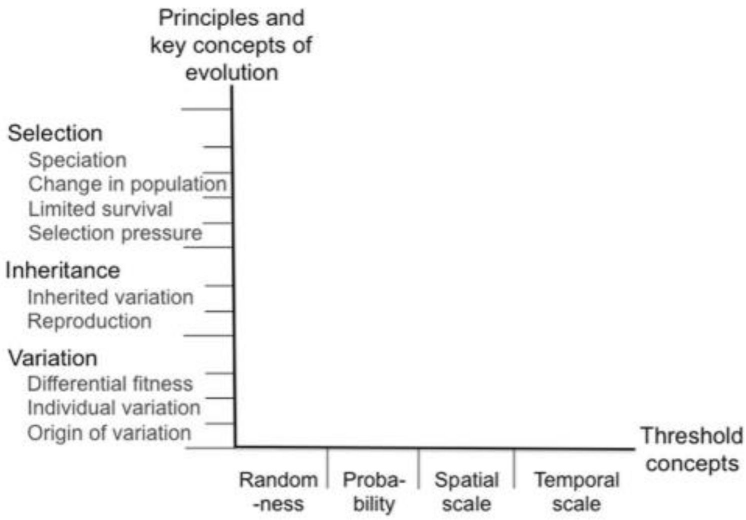


Figure2: Graph showing relationship between threshold concepts and key principles in evolution (Tibell & Harms, 2019)

It is often overlooked that a threshold or core concept in one discipline may be a key principle in another. Life Sciences teachers may assume that learners are able to understand random genetic variation and probability of hereditary traits being passed from one generation to the next if they understand these concepts in other disciplines (e.g., mathematics). Since threshold concepts are characterised as "troublesome" (Meyer & Land, 2003 and Tibell & Harms, 2019, p. 958), learners may fail to connect the concepts across the disciplines. Consequently, it may be that the "hidden" threshold concepts of probability and randomness as shown in Figure 2 above are impeding learner understanding of key evolution concepts such as those on the dependent axis of Figure 2. This may affect understanding of natural selection and consequently, evolution (Tibell & Harms, 2019). Although threshold concepts may be troublesome, once understood, they are transformative in providing deep insight into previously difficult key principles (Meyer & Land, 2003). Knowledge is transformed when critical reflection of a concept is achieved, allowing one to formulate meaning and construct perspectives about a particular topic (Dirkx, 1998).

While evolution may be troublesome, and may require much critical reflection, it is uniquely valuable in South African schools, since the country's rich fossil record illuminates the evidence of early humans, their evolution and their dispersal (Herries et al., 2020). South

Africa's vast biodiversity and fossil evidence such as the 1938 *Coelacanth*, the discovery of the *Taung child, Mrs Ples, Little foot, Karabo (A. Sediba) and Homo* naledi *and* major Fossil sites such as the Cradle of Humankind (Sanders, 2018) were included in the curriculum in an attempt to make evolution more accessible, hoping to increase learner knowledge about the complex diversity of living organisms (Sutherland and L'Abbé, 2019). However, as mentioned, learner performance in the final examination remains poor in the evolution section, particularly in the Human Evolution section (DBE, 2021), suggesting that while the content may be valuable, learner understanding is persistently rudimentary in the final NSC examinations.

2.1.5 Documents guiding the teaching and learning of Life Sciences in South Africa

The South African National Senior Certificate (NSC) Life Science examination is guided by two documents: the CAPS curriculum and the examination guidelines. According to the CAPS curriculum and the examination guidelines, the sequence of content topics for grade 12 Life Sciences shown in Figure 3a below (DB2,2021):

Life Sciences 5 DBE/2021
Examination Guidelines

3.3 SEQUENCE OF TOPICS FOR GRADE 12 (*CAPS* AMENDED)

The following sequence of topics is recommended for teaching in Grade 12 based on the progressive development of concepts through the different topics:

1. DNA: The Code of Life
2. Meiosis
3. Reproduction in Vertebrates
4. Human Reproduction
5. Genetics and Inheritance
6. Responding to the Environment (Humans)
7. Endocrine System and Homeostasis in Humans
8. Responding to the Environment (Plants)
9. Evolution

Figure 3a: CAPS sequence of topics for grade 12 Life Sciences

However, the examination sequence of topics does not follow the CAPS topic order but, rather aims to test conceptual progression (Figure 3b: Life Sciences examination guidelines (DBE, 2021))

Life Sciences 6 DBE/2021
Examination Guidelines

3.6 THE DISTRIBUTION OF TOPICS FOR THE TWO PAPERS (*CAPS* AMENDED)

PAPER 1

TOPIC	WEIGHTING	
	%	MARKS
Term 1:		
Reproduction in Vertebrates	5	8
Human Reproduction	27	41
Term 2:		
Responding to the environment (humans)	36	54
Term 3:		
Responding to the Environment (plants)	9	13
Term 2 and 3:		
Endocrine and Homeostasis (humans)	23	34
TOTAL	**100**	**150**

PAPER 2

TOPIC	WEIGHTING	
	%	MARKS
Term 1:		
DNA: Code of Life	18	27
Meiosis	14	21
Term 1 and 2:		
Genetics and Inheritance	32	48
Term 3:		
Evolution	36	54
TOTAL	**100**	**150**

Paper 2 tests all genetic and evolution concepts which shows that these topics have conceptual progression and are directly linked

Figure 3b: CAPS Life Sciences examination guidelines

The question thus arises: "why does the sequence of topics in the CAPS curriculum not follow the conceptual progression according to which learners are tested?"

According to the DBE (2021), the examination guidelines do not adequately cover the content yet it is imperative to engage in qualitative curriculum coverage as designated by the CAPS curriculum, however, the 2020 National Diagnostics Report suggests "Teachers should use the information provided by the Examination Guideline and not teach unnecessary content" (p. 146). If teachers are required to teach for examining purposes, then the current CAPS curriculum does not favour knowledge building (Weigel et al., 2020). This demands the fundamental analysis of what content is necessary to cover and how that content should be developed for effective learning to occur (Ramrathan, 2020). It is imperative for the Department of Basic Education to engage with teachers who are implementing CAPS, to determine if, perhaps, the content was taught according to the way in which it is tested, learner performance would improve.

Summary

The literature considered in this study thus identified the valuable evolution content in the CAPS curriculum along with the challenges that the document presents. One of the main issues appears to be the way in which the relationship between the topics of genetics and evolution is currently prescribed. The sequencing and timing of the evolution related content was another key element that emerged in the review of the available literature, showing that it is necessary to use genetic evidences to support the theory of evolution. However, *how* this can be optimally done requires further research, presenting a knowledge gap that the current study addresses.

2.2 Conceptual Framework

The complexity of science education makes it difficult to find a single *perfect* conceptual framework that underpins a study (Abd-El Khalick & Akerson, 2007, cited in Sanders & Makotsa, 2016). Consequently, derivatives of various frameworks are used to discuss the theories relevant to this study (Sanders & Makotsa, 2016). Science Education reform in South Africa continually encourages an understanding of the Nature of Science. Teaching about *how* scientific concepts were developed and *how* scientific topics, such as genetics and evolution, relate to each other (Klassen, 2006). The Nature of Science considers science as a way of coming to know (Abd-El-Khalick & Lederman, 2000) through logical thinking and cognitive methods (McComas in Kampourakis, 2016). This includes considering how philosophical and sociological theories impact the development of scientific knowledge. At the forefront of integrating philosophy and science education lies the teacher, referred to by Vygotsky (1978) as the 'more knowledgeable other' (MKO) (Schunk, 2012), and who Shumlan (1986) refers to as the 'pedagogical expert'. An MKO is a peer, adult or relevant to this study, a teacher who is cognitively more advanced than the learner (Doolittle, 1995). Interactions with MKO's are considered to advance learners from "simple perceptions, associative learning, and involuntary attention" (Doolittle, 1995, p. 3) to "higher mental functions such as language, counting, problem solving skills, voluntary attention, and memory schemas" (Doolittle, 1995, p. 3). Consequently, an effective science teacher is one who is able deliver pedagogical content knowledge (PCK) to learners in a way that allows learners to develop their own knowledge (Jacobs, Williamson, & Pretorius, 2015). In an attempt to create an "effective" science teacher, pre-service science education programmes usually encompass an education theory course, science content courses and science methodology courses (Ogunniyi and Rollnick, 2015). As such, what follows next is a discussion of the relationship between the constructs (Sanders &

Makotsa, 2016) relevant to the teaching and learning of genetics and evolution in South African schools, viz., *Piaget's* (1936) *theory of Cognitive Development*, *constructivism and socio-cultural constructivism (*Vygotsky, 1962), *Pedagogical Content knowledge (PCK)* (Shulman, 1987), *pedagogical link-making* (Scott, Mortimer, & Ametller, 2011) and the *Spiral curriculum* (Jerome Bruner, 1960).

Constructivism

The term "constructivism" was originally coined by Jean Piaget in 1952, where he described the ways in which children constructed knowledge by interacting with the surrounding environment (Harlow, Cummings, & Aberasturi, 2007). According to Piaget's theory, there are four stages of cognitive development from infancy to adolescence: Sensorimotor stage (age 0-2), preoperational stage (age 2-7), concrete operational stage (age 7-11) and the formal operational stage (age 11-onwards) (Ghazi et al., 2016, Jahoda, 1964). At each stage, an individual develops increased cognitive skills by assimilating and accommodating the information around them (Harlow, et al., 2007). In 1962, Lev Vygotsky extended on Piaget's constructivist epistemology (Harlow, et al., 2007) by introducing the theory of socio-cultural constructivism. Learners are required to make links between their schemes and structures at each cognitive stage based on their cultures, contexts and social interactions which facilitates knowledge formation (Schunk, 2012).

Vygotsky considered learning as a holistic experience during which an individual constructs knowledge through interactions with peers, adults and teachers in a contextual setting (Jaramillo, 1996). Vygotsky emphasized two aspects of the interaction, the first is the need for *mediation*; a process which suggests that children may acquire knowledge as they interact in social environments only once knowledge has been mediated for them by a more knowledgeable other (MKO) (Schunk, 2012). Each social environment may have a different MKO, in the classroom; the teacher is the MKO and thus the mediator of knowledge.

The second aspect is to cultivate an egalitarian setting: (Jaramillo, 1996, p. 136) a space which empowers learners to engage in their learning process by participating in the classroom. In the school setting, the curriculum serves as a tool for mediation which is designed to foster inclusion (César & Oliveira, 2005, p. 1) and consequently, egalitarianism. It is specifically designed as a tool for social mediation to make academic knowledge relevant to students in a particular space at a particular time (César & Oliveira, 2005). Although learners may have prior conceptions of genetics and evolution, when learners enter the classroom, the teacher becomes responsible as the MKO to deliver, mediate and scaffold the curricular knowledge about these concepts for the learners. However, this can only be possible if teachers actively scaffold curriculum concepts by providing them with knowledge and participatory tasks that are progressive to their previous encounters (Jaramillo, 1996, p. 136). Scaffolding is a process directly related to constructivism as it involves the teacher guiding learners towards solving tasks through motivation, interaction and direct and indirect forms of support in which recommendations which initiate deeper thinking within the learner, ultimately allowing them to draw their own conclusions and build their knowledge within the relevant context (van der Valk & de Jong, 2009). Since the South African Life Sciences CAPS Curriculum stipulates which scientific concepts are relevant to each grade; wherein genetics and evolution are only taught in the final year of schooling. Possibly insinuating that genetics and evolution are higher order concepts which require learners to be at what Piaget refers to as the formal operational stage during which learners are able to synthesize abstract concepts (Jahoda, 1964). Consequently, these higher order concepts require scaffolding and mediation by an MKO for learners in the classroom to develop concrete knowledge from abstract concepts (Jaramillo, 1996).

PCK and TSPCK

Pedagogical Content knowledge (PCK) described by Shulman (1987), provides a conceptual framework which teachers can use to mediate and scaffold knowledge for their learners in the classroom. PCK is defined as the reasoning behind the integration of content knowledge and pedagogy or teaching methodologies into an understanding of how content is organized, scaffolded and represented during instruction to make subject matter comprehensible for others (Shulman, 1987). Mavhunga (2014) furthers Shulman's study and expands on the components of PCK by introducing "Topic Specific" Pedagogical Content knowledge (TSPCK). TSPCK refines PCK by laying out five specific components (viz., student prior knowledge, curricular saliency, what is difficult to teach, representations and analogies, and conceptual teaching strategies). These components are derived from Shulman's PCK components with the addition of curricular saliency. Thus, in TSPCK, there is a particular focus on making use of Shulman's PCK components to make links between specific topics in the curriculum, thereby enabling the transformation of teacher's subject matter knowledge (SMK) into knowledge that is accessible to learners. TSPCK specifically acknowledges the necessity of understanding certain sub-concepts to understand a broader topic (Mavhunga, 2014). Thus, the components of TSPCK can be effective in making explicit links during the teaching and learning of genetics and evolution, to optimize the CAPS curriculum.

Pedagogical link-making

Pedagogical link-making refers to “the ways in which teachers and students make connections between ideas in the ongoing meaning-making interactions of classroom teaching and learning” (Scott, Mortimer, & Ametller, 2011, p. 3). Accordingly, three forms of pedagogical link-making have been proposed:

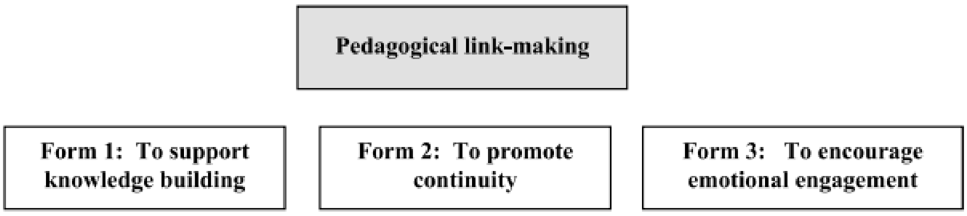


Figure 4: Forms of pedagogical link-making (Scott, Mortimer, & Ametller, 2011, p. 6)

There are several approaches to support knowledge building during the pedagogical link-making process (Scott, Mortimer, & Ametller, 2011), however, some of these are beyond the scope of this study and it seems necessary only to discuss: Making links between scientific concepts: (Scott, Mortimer, & Ametller, 2011) “learning scientific conceptual knowledge involves coming to recognise how the scientific concepts themselves fit together in an interlinking system” (Daniels, 2001 cited in Scott, Mortimer, & Ametller, 2011, p. 8). This is of particular interest in the relationship between genetics and evolution. Genetics concepts provide a mechanism for evolutionary processes. Consequently, an understanding of genetics may provide the opportunity for an understanding of evolution (Mead et al., 2017). Pedagogical link-making: to support knowledge building and continuity link: to develop the scientific story (Scott, Mortimer, & Ametller, 2011). This technique involves recapping events or concepts from previous lessons to develop new knowledge (Scott, Mortimer, & Ametller, 2011). Since the understanding of genetics is a basis for understanding the biological phenomenon of evolution (Johnstone and Mahmond, 1980; Finley et. Al., 1982, cited in Kindfield, 1994; Banet and Ayuso, 2003, Chi-yan and Treagust, 2003 cited in Olanrewaju and Atagana (2012), it has been stated that learners would have a better understanding of evolution if teachers clearly linked the underpinning genetic concepts of evolution to DNA (Kalinowski, Leonard, &

Andrews, 2010), ideally, this should be carried out in the CAPS curriculum (Kalinowski, Leonard, & Andrews, 2010). According to Johnson et al. (2015), the CAPS curriculum attempts conceptual progression across grades and topics to mimic the hierarchical structure of concepts in the biology discipline and achieve curriculum coherence (see Schmidt et al., 2005). However, a spiral curriculum is one that may promote pedagogical link-making.

Spiral Curriculum

A spiral curriculum involves reiterating concepts during the learning process (Harden & Stamper, 1999 cited in Mavuru, 2019), with the intention of building onto prior knowledge (Mavuru, 2019). The value of a spiral curriculum stems from the scaffolding of concepts according to the levels of cognitive challenge outlined in Bloom's taxonomy (1956), from simple to complex (Harden & Stamper, 1999 cited in Mavuru, 2019), to ensure progressive understanding (Mavuru, 2019). Since genetics is covered before evolution in the CAPS curriculum, perhaps it is the reiteration of the links between the topics that should be made explicit to learners. Teachers may possess the subject matter knowledge as shown in a study carried out by Mavuru (2019):

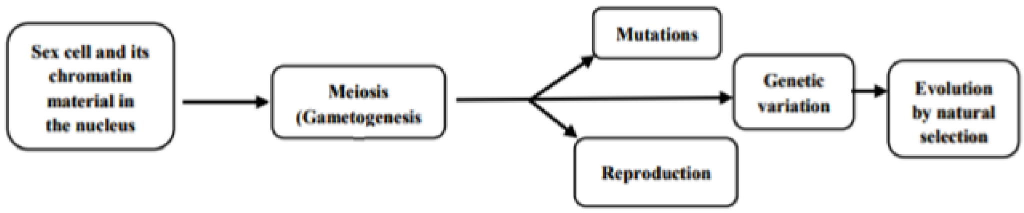


Figure 5: Pre-service teachers' understanding of the conceptual progression between genetics and evolution (Mavuru, 2019).

However, the poor performance in the genetics and evolution sections of the final examinations (DBE, 2021), may be a result of teachers being unable to transform the links between the topics as they are separated by time and other non-relating topics in the CAPS curriculum.

Summary

As previously mentioned, the science education discipline is not bound by a perfect framework and as such, the above frameworks were used to analyze the how the CAPS curriculum and classroom teaching work together. The classroom environment promotes Piaget's theory of constructivism and Vygotsky's social interaction theory as teachers act as mediators in the development of cognitive learning abilities, specifically when knowledge and activities are scaffolded for holistic learning (Jaramillo, 1996, Schunk, 2012). This means that teachers can facilitate the teaching and learning of genetics and evolution by integrating constructivist methods with TSPCK. However, this can only be achieved if the curriculum content in the genetics and evolution sections are coherently organized, i.e.: a spiral curriculum that facilitates pedagogical link-making in conjunction with workshops explicitly designed to enhance teachers understanding on the effective transformation of the content.

CHAPTER 3: Methods

The literature review provided insight on *fundamentalist religious beliefs, Genetics and Evolution in the Grade 12 CAPS curriculum, Preparation of teachers to teach Genetics and Evolution*; *core concepts and threshold concepts in Genetics and Evolution* and *Documents guiding the teaching*. However, the extant research does not explicitly address optimizing the teaching of genetics and evolution to grade 12 Life Sciences learners. This study sought to investigate this gap using a qualitative research approach involving a range of research methods including qualitative research analysis such as semi-structured interviews and document analysis, consequently, this chapter provides a detailed description of the methods implemented.

3.1 Qualitative Research

Qualitative research is described as a method that results in findings not reached through statistics or quantification but through experiences, behaviours, environments, culture, and interactions (Strauss & Corbin, 1998). According to Hoepfl (1997) "Qualitative research has an interpretive character, aimed at discovering the meaning events have for the individuals who experience them, and the interpretations of those meanings" (p. 49). It involves comparing cases to determine their similarities and differences and develop a conclusion from the analysis of the empirical data (Tumele, 2015). Since qualitative research is context dependent (Daniel & Harlan, 2017) using this method may allow us to understand how curriculum design shapes teaching and learning (Kozleski, 2017), providing possible solutions to optimize the genetic and evolution content in grade 12 Life Sciences.

Farghaly (2018) suggests that education research aims to improve education and qualitative research has been identified as "best-evidence" (p. 10) in informing the teaching and learning process. Qualitative research develops meaning from the experiences and views of participants (Farghaly, 2018). Specifically, grounded theory as a method of qualitative research seeks to develop a theory, cause or explanation based on data that has been collected and systematically analysed (Daniel & Harlan, 2017). The developed meaning is based on a series of coding and refining the collected data (Daniel & Harlan, 2017). Using qualitative research methods such as grounded theory in an educational setting *and* in this study was valuable in revealing contextually rich information (Heyink & Tymstra, 1993) about the teaching and learning of genetics and evolution.

3.2 Sample

South African high schools have been quintile categorised "based on the socio-economic status of the community in which the school is located" (Ogbonnaya & Awuah, 2019, p. 1). Quintile 1-3 schools are situated in economically disadvantaged areas and are non-fee paying with increased government funding (Hall, & Giese, 2009). Quintile 4-5 schools are located in wealthier areas and are fee-paying schools with limited government intervention (Ogbonnaya & Awuah, 2019).

To study a distinct topic, I initially engaged in purposive sampling during which teachers from schools of various quintiles were invited telephonically and via email to voluntarily participate in this study. However, Covid-19 limited my access to quintile 1-3 schools as researchers were not allowed to enter schools during this time (as per the guidelines of Department of Education). Therefore, a mix of purposive and convenience sampling was undertaken, with 5 grade 12 Life Sciences teachers from CAPS abiding quintile 4-5 South African schools approached and voluntarily participating in this study. Purposive sampling was undertaken by contacting a variety of schools in Gauteng to invite those who met the pre-determined criteria: experienced (3+years) Life Sciences teachers who engage with the grade 12 Life Sciences CAPS curriculum. Such teachers were thus qualified to respond to the research objectives of this study (Palinkas et al., 2015). Additionally, two pre-service teacher lecturers - 1 genetics lecturer and 1 evolution lecturer from a school of education at a South African university formed part of the sample. The participants were emailed letters detailing the purpose of this study and the requirements of their participation (Appendix A). They were provided with confidentiality agreement letters (Appendix B) which each of them signed, thus committing to this study. Due to Covid-19 restrictions that prevailed during the data collection process, convenience sampling became necessary since there were few teachers who were accessible and available to participate in this study. All interactions during this study were conducted electronically via Zoom, Microsoft teams or telephonically as this was the preferred participant method.

3.3 Research instruments

This study involved the use of semi-structured interviews. In qualitative studies, this research instrument has proved to be a powerful tool to encapsulate the meaning of an individual's personal experience (Rabionet, 2011, Daniel & Harlan, 2017). Since the use of semi-structured interviews is deemed appropriate for small sample qualitative studies, its use herein was beneficial by allowing me to guide the themes and topics of the interview while capturing the experiences of the participants, ultimately enabling me to draw contextual conclusions relevant to the study (Rabionet, 2011). Document analysis is another tool particularly used in qualitative studies to produce rich, relevant comparisons and corroborations (Bowen, 2009). This instrument is used in conjunction with other research tools to triangulate data, promoting credibility of the research (Bowen, 2009). Lastly, concept mapping (Harden, 2001, Daley, 2004, Daley et al., 2016 and Latif et al., 2016. The purpose of concept mapping in this study was to draw meanings from participant responses within a particular context (Daley, 2004). Since linking words enable an individual to describe their understanding across disciplines, concepts and topics (Daley, 2004), this tool would have provided an accurate representation of the teacher's ability to scaffold topics within the Life Sciences CAPS curriculum. Consequently, each of these tools were used to generate the data required to address the research objectives of this study.

3.4.1 Semi-structured interviews

Interviews are the most common qualitative research method because they provide such rich data (Daniel & Harlan, 2017). There are three types of interviews: structured, semi-structured and open interviews (Daniel & Harlan, 2017). The main resemblance between these forms of interviews is their question-and-answer sequence (Roulston & Choi, 2018). To enhance mutual discovery, the participant should be comfortable, respected and valued during the interview (Daniel & Harlan, 2017). The semi-structured interview allows the researcher and participant to explore conversations around the topic *and* emergent ideas (Daniel & Harlan, 2017). Furthermore, semi-structured interviews allowed for follow up questions relative to participant responses to gather essential and comparable data (Roulston & Choi, 2018).

As such, semi-structured interviews (Daniel & Harlan, 2017) were conducted with the participants in my sample. Teachers and lecturers were asked different questions (Appendix C – interview schedule for teachers). Teachers were mainly asked questions about their own views on genetics and evolution concepts and the relationship between these topics in the CAPS curriculum. Since the pre-service teacher curriculum is tailored to cover the CAPS curriculum, the genetics and evolution lecturers were asked predetermined interview questions (Appendix D: interview questions for genetics lecturer and Appendix E: interview questions for evolution lecturer). The interviews were conducted at a convenient time for the participant, via Zoom, Microsoft teams or telephonically. The interviews were recorded with permission from the participants and subsequently transcribed for more detailed analysis.

The use of semi-structured interviews allowed room for flexibility during the interviews which gave the researcher the opportunity to ask relevant questions, request clarity and discuss participant responses (Heyink & Tymstra, 1993). These interviews exposed participants views on threshold genetic and evolution concepts and on the sequencing and linkages of genetics and evolution in the enacted curriculum.

3.4.2 Document analysis

Document analysis refers to the systematic review of an existing document (Bowen, 2009). As a qualitative research method, document analysis involves skimming, examining, and then interpreting (Mackieson et al.,2019). This process is conducted to elicit meanings and understanding, to develop knowledge from the empirical evidence (Bowen, 2009). It is important to note that policy documents are vast in their jargon, and it is important to isolate specific features during the analysis process (Cardno, 2018). This research was based on analysing two educational policy documents: CAPS curriculum and the 2019 Annual Teaching Plan (ATP) from the Gauteng department of Education. The ATP (2019) showed the concepts, outcomes, time for revision and examinations and the sequence and timing of topics for the grade 12 Life Sciences CAPS curriculum. Since I was concerned with investigating the links between genetics and evolution, I adapted the original ATP to highlight the sequence and timing of these topics by outlining these two topics in red brackets (Appendix F), with the expanded versions shown in Figures 6a and 6b).

Participants were sent the adapted 2019 ATP and asked to design their own ATP showing the sequencing and timing of topics that they would prefer. The 2019 ATP was used as my research began in 2020 and is based on the pre-covid CAPS curriculum. The 2020 and 2021 pace setters were flexible due to the lockdown periods and would not reflect a realistic experience. Subsequently, the 2022 CAPS curriculum adopted some changes in terms of assessment requirements, however, the content that is covered has remained the same as 2019. The document analysis was used as a secondary research method (Cardno, 2018) in conjunction with the concept maps and interviews as a curriculum mapping tool to evaluate curricular coherence and sequencing (Webb, 2020).

Term 2 51 days	Week 1 13 – 16 April (4 days)	Week 2 19 – 23 April (5 days)	Week 3 28 – 30 April (3 days)	Week 4 03 – 07 May (5 days)
CAPS Topic	**Genetics** (National Examination Guideline pg. 9) Genetics and Inheritance [32%]			
Core Concepts, Skills and Values	Concepts of inheritance, Monohybrid crosses, sex determination, sex-linked inheritance	Dihybrid crosses, Blood grouping	Genetic lineages/pedigree diagrams, mutations	Genetic engineering, paternity testing and genetic links

Figure 6a: expanded version of sequencing and timing of genetics according to the Life Sciences CAPS ATP (DBE, 2019)

Term 3 52 days	Week 1 13 – 16 July (4 days)	Week 2 19 – 23 July (5 days)	Week 3 26 – 30 July (5 days)	Week 4 02 – 06 August (5 days)	Week 5 10 – 13 August (4 days)	Week 6 16 – 20 August (5 days)
CAPS Topic	**Evolution** (National Examination Guideline pg. 13) Evolution [36%]					Data response questions, case studies, questions from past papers Revision-Mind the Gap Study Guide, past examination papers, videos and power points
Core Concepts, Skills and Values	Introduction to evolution e.g. biological evolution, hypothesis, theory. evidence for evolution and variation	Lamarckism, Darwinism and Punctuated equilibrium, Artificial selection and speciation	Reproductive isolation mechanisms evolution in present times	Evidence of common ancestors for living hominids, including humans	Out of Africa hypothesis	

Figure 6b: expanded version of sequencing and timing of evolution according to the Life Sciences CAPS ATP (DBE, 2019)

3.4.3 Concept mapping

A concept map is a visual depiction of one's understanding of a phenomenon, topic, or subject (Latif et al., 2016). Concept maps have been used as a curriculum design and planning tool in a variety of research projects: organisation of curriculum content (Cantú et al., 2004); examining and explaining ideas in curricula (Colli et al.,2004); curriculum evaluation (Paykoç et al., 2004); identification of missing links and unrecognised interrelations between curricular concepts (Vilela et al., 2004). According to Latif et al. (2016), educators should be able to plan, teach, analyse, and assess in ways that improves learning in the classroom and, while concept mapping can be an effective curriculum tool, it can also be used by teachers to explicitly show the links between genetics and evolution concepts for learner accessibility (Gabbay et al., 2020). There have been various ways of depicting concept maps, each quite similar: organised with the main concepts circled and arrow-tipped lines showing the direction of thought between concepts and, words along the lines to explain the meaning of the links between the concepts (Novak & Cañas, 2006 and Latif et al., 2016). Initially, a Knowledge Integration Map (KIM) on the connections between genetic and evolution concepts by Schwendimann and Linn (2016) (Figure 7) seemed appropriate, as it would have provided participants with concepts which they should have been able to link together.

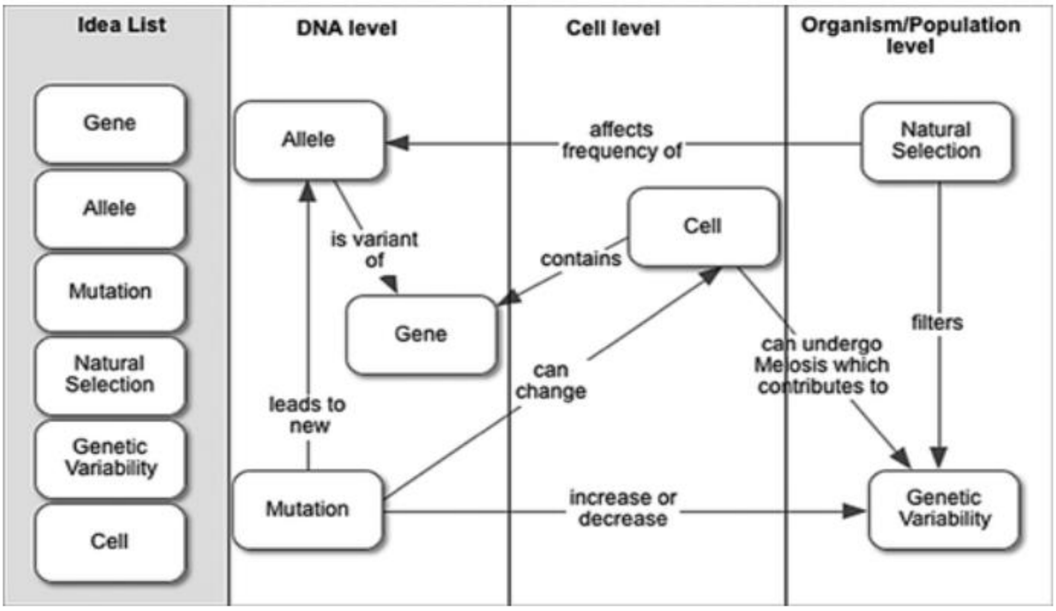


Figure7: Knowledge Integration Map showing the links between genetics and evolution (Schwendimann & Linn, 2016).

However, after further research, Harden's (2001) model (Figure 8) below reflected better in this study as it is a concept map that specifically depicts how concepts in a curriculum are connected and integrated (Daley et al., 2010).

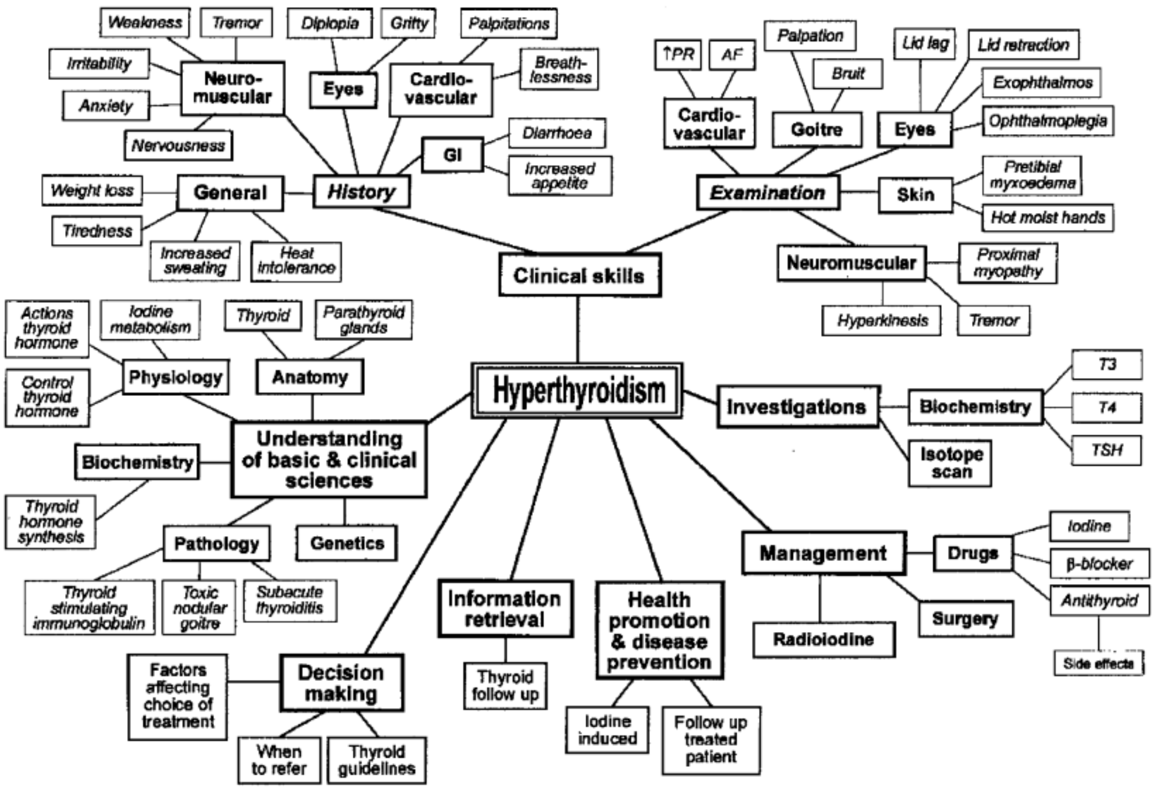


Figure 8: Harden's model of a section of the curriculum (Harden, 2001).

In this way, current curriculum content can be reviewed, and the links between concepts be made explicit (McDaniel et al., 2005). Consequently, Harden's (2001) model was adapted and used in the analysis of the CAPS curriculum, to develop a concept map showing the threshold genetics and evolution concepts and their links in the grade 12 Life Sciences CAPS curriculum (Figure 9 below). This mapping was used as it allows for the subject matter to be seen as a whole and through the connecting components of the topic (Harden, 2001). The resulting concept map was emailed to each participant as an exemplar, and they were asked to design their own concept maps to show *their* understanding of the links between the topics of genetics and evolution.

Figure 9: CAPS concept map developed using an adapted version of Hardens (2001) model

3.5 Thematic analysis of qualitative data

Thematic analysis is a meaning-making endeavour involving processes of identifying common patterns and constructing themes accordingly (Daniel & Harlan, 2017 and Kiger & Varpio, 2020). In this study, the transcriptions of the interviews together with the concept maps and ATPs were analysed using thematic analysis (Daniel & Harlan, 2017). Thematic analysis is preferred in qualitative studies due to its distinct features of accessibility and flexibility (Kiger & Varpio, 2020). Thematic analysis is accessible in the way it teaches researchers how to analyse and code qualitative data in a systematic way (Braun & Clarke, 2012), enabling the researcher to identify and isolate relevant information which can then be linked to the research objectives of the study (Braun & Clarke, 2012). Flexibility in thematic analysis refers to the various ways that analysis of qualitative data can be conducted, most commonly: inductively *and* deductively but not limited to one (Braun & Clarke, 2012)

This approach to data analysis was selected for this study given the interest in finding and analysing shared views of the participants regarding the teaching and learning of genetics and evolution. To provide a more nuanced understanding of the data, I employed a combination of deductive and inductive thematic analyses (Braun & Clarke, 2012 and Kiger & Varpio, 2020).

Inductive or "latent" (Daniel & Harlan, 2017, p.169) analysis is content-driven. Some themes were obvious (Daniel & Harlan, 2017) allowing the codes and themes to be derived directly from the content of the researcher's data (Braun & Clarke, 2012) and may not reflect the specific questions asked by the researcher (Kiger & Varpio, 2020). In contrast, deductive or "manifest" (Daniel & Harlan, 2017, p.169) analysis involved using existing literature, theoretical frameworks, or research objectives to purposely identify themes of interest (Kiger & Varpio, 2020). In other words, I used specific words in the interview questions and in the instructions of the concept map and ATP exercises to be able to use those same words to analyse and code the data. These included, but were not limited to: *links*, *integrate*, *sequence*, *scaffold*, *improve* and *optimize*.

The resulting qualitative dataset, including the interview transcripts, concept maps and ATP's presented various emergent themes which did not fully mirror the codes or the research objectives. Therefore, to analyse the data in a non-biased manner (Mohajan, 2017), combining deductive and inductive thematic analysis allowed for both "data-driven" and "data-emergent" themes to be developed and interpreted.

During the initial analysis, several themes were identified across the dataset using a deductive approach based on predefined themes I expected to identify, founded on the research objectives and questions that that were asked during the interviews, specifically about the participants knowledge of the relationship between genetics and evolution.

As a reminder, the objectives of the research were:

1. To investigate which concepts Life Science teachers and teacher educators consider as threshold concepts in genetic and evolution.
2. To determine what the Grade 12 Life Sciences teachers and Life Science teacher educators think about the way genetics and evolution threshold concepts are sequenced and interlinked.
3. To investigate, based on the answers to questions 1,2 and 3 above, whether the organization of genetics and evolution CAPS curriculum could be optimized for better teaching and learning.

Aligned to these objectives, there were 3 major themes initially identified: curriculum design, genetics and evolution and factors affecting the teaching and learning of genetics and evolution. Within these major themes, there was a vast number of sub-themes focussed on in the semi-structured interviews. However, by identifying and refining analogous terminology from the questions and responses, I was able to review the initial themes to produce the final themes which specifically addressed objectives 1,2 and 3 respectively. The thematic map below (Figure 10) reflects the deductive themes identified and the inductive themes which emerged during the analysis process. These are discussed with reference to the data in Chapter 4.

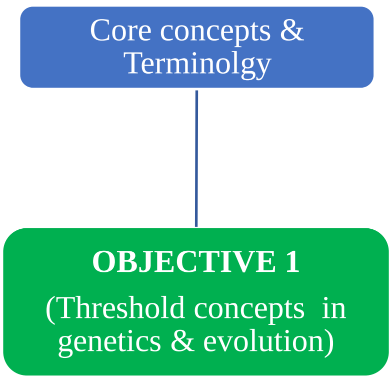


Figure:10a

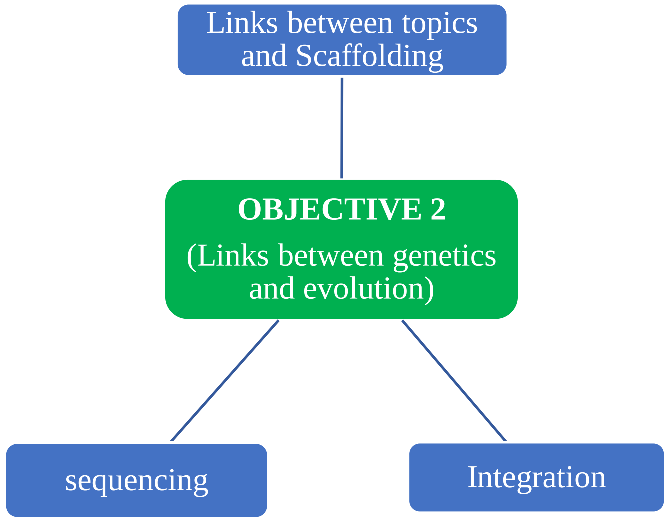


Figure:10b

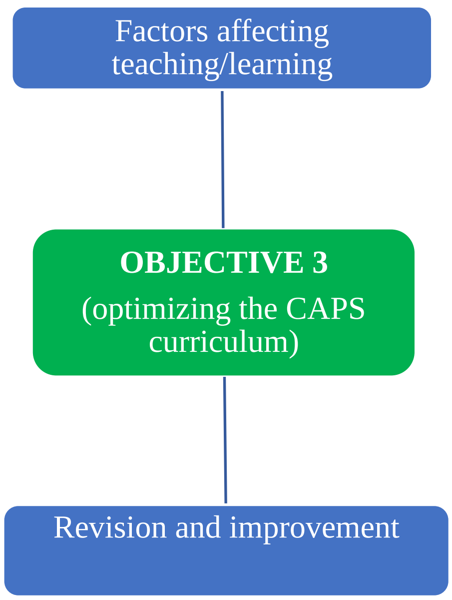


Figure:10c

Figure 10: Thematic map showing three final themes (10a: Objective 1: Threshold concepts in genetics and evolution in the CAPS curriculum, 10b: Objective 2: Links between genetics and evolution, 10c: Objective 3: optimization of CAPS curriculum)

3.6 Proposing an optimized curriculum

Lastly, during the analysis process, the literature and results foregrounded the concepts that the participants considered threshold concepts and when they should be taught. Accordingly, I designed a revised sequencing schedule which may act as a draft of an optimized grade 12 Life Sciences Curriculum, directly correlating with conceptual progression.

3.7 Summary of research methods

According to Bryman and Bell (2011), a qualitative research study involves developing research questions or objectives, determining, and conducting appropriate research methods and analysing the data (Figure 11 below).

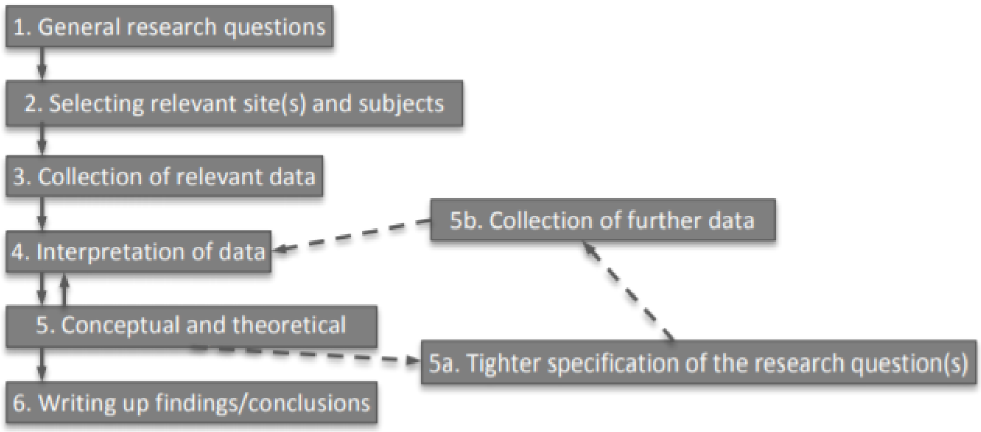


Figure 11: steps in qualitative research (Bryman & Bell, 2011)

Using an adapted version of this model, the methods undertaken in this study are shown in Figure 12 below.

Flow diagram showing process of methods:

1. Designed baseline concept map based on CAPS (genetics and evolution)

2. Document analysis to formulate adapted ATP highlighting sequencing and timing of genetics and evolution in CAPS

3. Semi-structured interviews with:
- Gr12 Life Sciences teachers
- Genetics lecturer to pre-service teachers
- Evolution lecturer to pre-service teachers

4. Each participant was sent
- Figure 9 (concept map) and asked to design a concept map showing the genetics and evolution concepts which they consider to be threshold concepts.
- Figure 6,b (adapted ATP) and asked to design their own ATPs showing their preferred sequencing and timing of genetics and evolution in Gr12.

5. Data analysis

A – Transcribing of interviews
B – Identification of common patterns & themes
C – Analyse concept maps
D – Analyse sequencing and timing suggestions
E – Identify overlaps, gaps and links between threshold concepts in genetics and evolution across the dataset (concept maps, ATPs, interviews).

6. Proposed optimized curriculum

Figure 12: flow diagram of methods

3.8 Validity and Reliability

In qualitative research, validity refers to the procedures that researchers use to increase the accuracy of their findings (Creswell, 2014). Using multiple methods of data collection to investigate the same problems (answer the same research questions) promotes validity in qualitative studies (Natow, 2020), therefore, this study included: interviews, concept maps and sequencing and timing analysis. During the interviews, validity checks were conducted by asking participants to rephrase or further explain statements which I did not think directly answered a research question, to ensure that the participants real-world experiences coincided with what was being researched (Stacks in Van Rensburg, 2009). Lastly, I promoted the validity of this study by transcribing and analysing the interview recording, verbatim, ensuring that I did not distort the information provided by the participants (Hayashi. et al, 2019).

Trustworthiness and credibility in a qualitative study increases reliability (Cypress, 2017). Trustworthiness and credibility both relate to the level of trust of a study based on the quality and authenticity of the study and the findings (Cypress, 2017). Therefore, I found it necessary to carefully select the methods of data collection as the methods chosen would directly affect the trustworthiness of this study. Consequently, the above-mentioned methods were essential to ensure credibility of the content. The intention was for the data collected to directly address the intended focus of the study (Elo et al., 2014). These research methods were piloted on a group of peers and my supervisors prior to the participants to express self-awareness and decrease bias, thus promoting credibility in the study (Elo et al., 2014).

Furthermore, administering different types of assessments to the same group of participants also serves as a measure of reliability (Mohajan, 2017). I ensured that all research instruments (semi-structured interviews, concept maps and sequencing and timing plans) were designed in a logical and coherent manner with similar questions regarding the links between genetic and evolution concepts allowing them to be comparable.

Validity, reliability and trustworthiness ensure transparency and decrease researcher bias (Mohajan, 2017), as such, the themes and coding systems used to analyse the data were agreed upon by myself and supervisors. Detailed transcription methods, including computer programs coupled with researcher and supervisor quality assurance and, systematic coding were modalities used to promote trustworthiness in this study. Furthermore, the data collected and my interpretations were verified by my supervisors who had access to the transcripts, concept maps and ATPs to ensure that I had analysed the data correctly, thereby promoting the reliability and dependability of the findings (Elo et al., 2014). By analysing data from different sources to answer the same questions, ensuring supervisor reviews and, detailed data collection methods with systematic coding and analysis, the data was effectively triangulated (Carter et al., 2014), thereby contributing to the trustworthiness of the research (Elo, et al., 2014).

With regards to the credibility of the study, I deemed it necessary for the participants to have at least 3 years of experience teaching grade 12 Life Sciences CAPS curriculum, to ensure that these participants had sufficient acquaintance with the curriculum for their experiences to be valuable to this study. To increase trustworthiness between myself as the researcher and the participants, I allowed the participants to choose the place, time and whether they would be comfortable with video chat during the interview which hopefully promoted sincere and relevant answers (Golafshani, 2003).

3.9 Ethics

As a researcher, I have an ethical responsibility towards all the participants involved in my research project, therefore, I obtained written permission (Appendix G) to conduct the study (non-medical) from the Human Research Ethics Committee of the University of the Witwatersrand (PROTOCOL NO. H20/03/03). I also received approval from Gauteng Department of Education prior to conducting the research. “Ethics is the attempt to arrive at understandings of human behaviour and values” (Farrow, 2016). Since this study focused on human experiences, I had an obligation to develop and open and trustworthy relationship with the participants. I drafted information (Appendix A) and consent letters (Appendix B) for each of the participants and the organizations in which they are admitted, ensuring that all parties were aware that participation was voluntary, and their identity will remain confidential and pseudonyms would be used during the recorded interviews. All non-digital material collected was and will remain kept in a locked filing cabinet and digital data will remain stored on a password protected computer.

3.10 Limitations of the study

The Covid-19 pandemic significantly impacted on the project. In particular, the sample size was significantly reduced compared with what was originally planned as access to schools was limited. In addition, and perhaps due to high pressure experienced by teachers to complete the school syllabus in the significantly reduced number of school days, many teachers did not respond to the invitation to participate in this study. In addition, while the 7 individuals in this sample all engaged in the virtual semi-structured interviews, only 4 of the participants partially completed the concept map activity and only 3 participants partially completed the sequencing and timing activity. The findings, presented next, reflect this.

CHAPTER 4: Results

4.1 Overview of results

Three research instruments, viz., interview transcripts ((Appendix C, D and E), concept maps (*Fig 9*) and sequencing and timing outlines (referred to as Annual Teaching Plans (ATPs) (Appendix F) in the CAPS curriculum) were used to investigate the research objectives of this study.

The interviews provided the most substantial data because there was a narrow response to the concept maps and ATPs. This made it necessary to analyse and interpret the entire dataset collectively. During the initial analysis, several themes were identified across the dataset using a deductive approach. These themes (chapter 3: thematic analysis) were based on predefined themes I expected to identify, founded upon the research objectives and questions that that were asked during the interviews, specifically about the participants knowledge of the relationship between genetics and evolution. The themes were then crossed analysed with the data from the concept maps and the ATPs to determine the final themes (*Fig 10*) and present a draft for an optimized grade 12 Life Sciences curriculum (Table 10).

4.2 Data analysis and interpretation

As mentioned previously, it was necessary to cross-analyse the interview transcripts against the concept maps and ATPs received in order to determine which concepts are considered as linking concepts between genetics and evolution, to reach an optimized approach to the teaching and learning of these topics. To do so, I explain the themes from the thematic map (*Figure 10*) under each of the objectives separately and discuss the combined findings in Chapter 5.

The themes that will be discussed within the objectives are:

1. Core concepts and terminology.
2. Links between topics and scaffolding, sequencing and, integration.
3. Factors affecting teaching/learning and, revision and improvement

Objective 1: Threshold concepts in genetics and evolution in the CAPS curriculum

Since this study was aimed at determining how teachers and experts view the relationship between genetics and evolution, it was necessary to determine which concepts the participants considered most vital. Whilst the term "threshold" is used in academic literature to refer to a particular type of knowledge, those outside the scope may refer to threshold concepts as "core" concepts. Furthermore, to the participants, core concepts were also categorised as "terms" or "terminology". Consequently, to avoid confusion, interview questions were framed in term of their perceptions of core genetics and evolution concepts, with the participants using the terms "threshold" and "core" interchangeably and often referred to certain "terms" as "core" concepts.

The theme addressed under this objective: threshold concepts in genetic and evolution was derived deductively from the participants responses to the following questions:

1. What are the threshold/core genetic concepts all learners should understand?
2. What are the threshold evolution/core concepts that all learners should know?

The responses to the questions were extracted from the recorded transcripts and are shown in Table 3 below. The shaded concepts are what teachers refer to as "core" concepts *but* some of these concepts may be academically defined as threshold concepts based on the nature of usage. For example: inheritance can be classified as a threshold concept since the understanding of evolution is fundamentally dependent on the understanding of variation (Walck-Shannon, et al., 2019), consequently it may be that once a learner understand variation, a new way of understanding evolution may come to light (Walck-Shannon, et al., 2019). Similarly, the topics highlighted in yellow in Table 3 below may lead to a transformed way of thinking while the terms highlighted in grey are considered core concepts since these topics are the monomers of particular topics but do not necessarily lead to new ways of thinking (Meyer & Land, 2003),

Table 3: Participants responses to questions about threshold concepts (highlighted in yellow) and core concepts (highlighted in grey) in genetics and evolution in the CAPS curriculum

Question	Participant	Quoted Response
What are the core genetics concepts that all learners should know?	1.	The inheritance factor is very important where… how do you get your genetic information. Then the still with inheritance of characteristics, how is this passed on, knowing those crosses, understanding homozygous, heterozygous and predicting the offspring. They have to understand the different types of dominance. They have to understand sex-linked because different characteristics are inherited in different ways.
	2.	I explain all of the terminology, what is phenotype, what is genotype, what is an allele, a gene and so forth. The different genetic crosses. First the monohybrid crosses then the dihybrid crosses. I would say the core is the…the terminology.
	3.	I think that something core to genetics is the basic terminology, things like dominant, recessive, like, homozygous, heterozygous, uh, a gene, an allele. Co-dominance and incomplete dominance…complete dominance…
	4.	Mendel's laws, meiosis and DNA.
	5.	5. We do genetic engineering. But at the same time, there is absolutely nothing about CRISPR and CRISPR is that the biggest thing at the moment.
What are the core evolution concepts that all learners should know?	1.	Natural selection is the biggest part to it.
	2.	Natural selection, I think that's quite important, and I think that part where we do Lamarck's theory.
	3.	I think natural selection. Darwin's views…Aside from natural selection as a main mechanism for evolution, that we should cover concepts of genetic drift.
	4.	The proof of evolution. So, things like modification by descent, biogeography, all of those, that is incredibly important to the actual human evolution.
	5.	No, well, in regards to evolution 100% it has to be Lamarckism, Darwinism and punctuated equilibrium., But the key concept is natural selection.

By cross analysing the responses of the participants against the CAPS document, it was clear that the shaded terms are the compulsory concepts to be taught in the genetics and evolution sections of the curriculum. There were a few foregrounded core concepts, such as terminology, gene, alleles and Lamarckism, amongst others, however, the dominant concept that all participants mentioned was natural selection. Teachers may consider this as a “core” concept because it is a concept prescribed in the CAPS curriculum. Since the participants may not have been familiar with the definition of a threshold concept, many described threshold concepts i.e., natural selection, as core concepts. However, due to the transformative nature of the terms in yellow, which leads to conceptual progression (Meyer & Land, 2003), some core concepts can be categorised as threshold concepts.

While some core and threshold concepts were mentioned, it seems that some participant knowledge is limited to what is stated in the CAPS curriculum. The interview questions in Table 3 above were open-ended and did not specifically ask participants about concepts in the CAPS curriculum, yet the participants stated concepts only from the CAPS syllabus. Only one teacher was able to identify an outlying concept: CRISPR, a genetic engineering technology tool (Vidyasagar, 2018). It is worth mentioning that although CRISPR does not explain past evolution or human evolution, it is a concept that relates to “evolution in present times” which is a topic covered in the CAPS curriculum.

Despite the ever-changing nature of science, the science syllabus tends to remain the same without introducing new concepts that could better explain genetics and evolution to teachers and learners. However, even the participant who appreciates the value of CRISPR, and all the other teachers, did not specify any implicit “threshold” concepts such as probability or randomness (Ross et al., 2010), which underpin much of the concepts that they did mention. This shows the influence of the CAPS curriculum in guiding teaching and perhaps because the genetics and evolution are separated in the curriculum and teachers are required to follow the ATP, they are unable to alter the syllabus to make those links for learners, even if they are aware of the direct links between the topics.

Objective 2: Links between genetics and evolution

Under the umbrella of this objective, I explore the themes: links between topics as well as scaffolding, sequencing and integration, to show which genetic and evolution concepts the participants viewed as interlinked, how these links were made during teaching and learning, and how they would possibly optimize the links outside the recommendations of the curriculum.

Links between topics and scaffolding:

All of the participants were asked if they thought there are genetics and evolution concepts which overlap, and if they could mention any. Their responses to the question were extracted from their interview transcripts and are shown in Table 4 below, with the links highlighted in grey.

The participant responses in Table 4 below above show that they are aware of the relationship between genetic and evolution concepts. Five of the 7 participants identified variation as the leading link between genetics and evolution, while 4 of the participants agreed that meiosis is linked to evolution since it directly influences variation. The link between meiosis and evolution is interesting because meiosis is not considered a genetics concept in the CAPS curriculum, yet the participants were able to identify meiosis as a genetic concept that influences the understanding of evolution. However, only 2 participants mentioned mutations as a link between genetics and evolution, yet mutations also contribute to variation and in turn, evolution. While these 7 participants were able to identify some links, to determine whether the participants were able to clearly show their understanding of the relationship between the links they recognised, the concept map illustration was encouraged. However, only participants 4,6, and 7 attempted the exercise while participant 4 did not illustrate any links between genetics and evolution at all. Consequently, only concept maps from participants 6 and 7 were compared and contrasted to the exemplar provided (Figure 9). This analysis is presented by quoting words or descriptions that show the links (shaded in grey) each participant illustrated on their concept map (Appendix H, I and J) in Table 5 below: links shown between genetic variation, natural selection and evolution.

Table 4: Participants responses to questions about links between genetic and evolution concepts in the CAPS curriculum. The terms shaded in grey represent genetic and evolution concepts that participants consider as linked.

Question	Participant	Quoted Response	Links (drawn conclusions, not direct responses from participants)
Do you think that there are genetic and evolution concepts which overlap or are linked? Could you mention some of these concepts?	1.	One would be that when you talk about mitochondrial DNA… In evolution, you talk of variation, what's the source of variation? So that has a bit of links, even with a small portion of evolution to say, meiosis would be the first one, which is another section on its own, that they link with evolution. And then mutations is part of genetics, which they link with evolution also.	mtDNA is a genetic concept that has a direct link to mitochondrial eve, an evolution concept. Since mtDNA is passed from mother to child, it is possible to use mtDNA as a tool to determine evolutionary paths.
	2.	…The gene, the types of genomes. The organism carrying many genes, but only with certain characteristics. Then we can link with mutations, helpful mutations or mutations that are harmful, and then you can link that to natural selection and natural selection is possible. And the further you can speak about speciation, when things like gene flow, then the gene pool become smaller or more limited. So, yes, you have to speak about certain genetic information while teaching evolution.	Mutations (genetic concept) are the driving force of evolution since it causes the genetic variation that initiates the evolutionary process.
	3.	I think that students understanding of …sources of variation within the context of genetics, that links up with the theories of evolution. For example; natural selection as being…operating on variation is present. Uhm, I think the concept of alleles in a population, that also relates to an understanding of evolution.	
	4.	…Modification by descent, like how do those characteristics get passed on from generation to generation… Mitochondrial eve and the Y chromosome.	
	5.	I don't think genetics, what; what massively overlaps is meiosis.	Meiosis (although listed under DNA in the CAPS curriculum and not under the section of genetics) is ultimately a genetic concept since it is responsible for

		In genetics, you have to learn about variation, you have to learn about mutations, you have to learn about, you know, how the variation comes about…	combining genetic material in the division process of gametogenesis which explains chromosomal inheritance which can be used as evidence of evolution.
	6.	6. Well, the obvious one is natural selection, right? And heredity and meiosis. I mean, so there's this link from DNA to RNA to proteins, and then the production of enzymes, but then there's just how these control development… So, maybe there's another link there, another stream from, from…So, what would it be? DNA, RNA, enzymes, development, forming of a new creature, of a new… of a new individual? And then, how if you play around with mutations and things like that, you're getting a different product at the other end, you getting that…that variation? And by playing around with the development, you get completely new features, you know, and like the bigger brain, for example, that would be just a developmental thing.	
	7.	7. There's no overlapping. There's linking. They are linked, not that they overlap. You can't teach evolution without talking about variation and you can't teach meiosis without talking about variation… So, if you teach meiosis first, then you talk about genetic variation and what it is and causes, you can immediately tell students, in this concept of genetic variation, we are going to be dealing with it again in…in…when we are looking at evolution.	

<u>Table 5: analysis of participant responses showing their understood links between genetic variation, natural selection and evolution (genetic concepts and evolution concepts shaded in grey)</u>

Question	Participant	Quoted Response
Do you think that there are genetic and evolution concepts which overlap or are linked? Could you mention some of these concepts?	1.	One would be that when you talk about mitochondrial DNA… In evolution, you talk of variation, what's the source of variation? So that has a bit of links, even with a small portion of evolution to say, meiosis would be the first one, which is another section on its own, that they link with evolution. And then mutations is part of genetics, which they link with evolution also.
	2.	…The gene, the types of genomes. The organism carrying many genes, but only with certain characteristics. Then we can link with mutations, helpful mutations or mutations that are harmful, and then you can link that to natural selection and natural selection is possible. And the further you can speak about speciation, when things like gene flow, then the gene pool become smaller or more limited. So, yes, you have to speak about certain genetic information while teaching evolution.
	3.	I think that students understanding of …sources of variation within the context of genetics, that links up with the theories of evolution. For example; natural selection as being…operating on variation is present. Uhm, I think the concept of alleles in a population, that also relates to an understanding of evolution.
	4.	…Modification by descent, like how do those characteristics get passed on from generation to generation… Mitochondrial eve and the Y chromosome.
	5.	I don't think genetics, what; what massively overlaps is meiosis. In genetics, you have to learn about variation, you have to learn about mutations, you have to learn about, you know, how the variation comes about…
	6.	Well, the obvious one is natural selection, right? And heredity and meiosis. I mean, so there's this link from DNA to RNA to proteins, and then the production of enzymes, but then there's just how these control development… So, maybe there's another link there, another stream from, from…So, what would it be? DNA, RNA, enzymes, development, forming of a new creature, of a new… of a new individual? And then, how if you play around with mutations and things like that, you're getting a different product at the other end, you getting that…that variation? And by playing around with the development, you get completely new features, you know, and like the bigger brain, for example, that would be just a developmental thing.
	7.	There's no overlapping. There's linking. They are linked, not that they overlap. You can't teach evolution without talking about variation and you can't teach meiosis without talking about variation… So, if you teach meiosis first, then you talk about genetic variation and what it is and causes, you can immediately tell students, in this concept of genetic variation, we are going to be dealing with it again in…in…when we are looking at evolution.

The CAPS concept map (Figure 9) shows that the link between evolution through Natural selection is limited to the term “variation” but the sources of variation are explained under the topic of genetics and inheritance which is split apart from the topic of evolution in the CAPS document. However, the genetics and evolution lecturers were able to illustrate on their concept maps how genetic variation is linked to evolution by natural selection. Participants 3, 4 and 5 suggested that the chromosome structure covered in meiosis can be built on immediately by exploring genetic concepts. With variation being the substance on which evolutionary mechanisms operate, teaching variation after genetics and meiosis allows for logical continuity in understanding variation. With an understanding of variation, evolutionary mechanisms like natural selection can be better understood. Consequently, it was necessary to investigate whether the sequencing of topics according to annual teaching plan (Appendix F) that is prescribed by CAPS favours conceptual progression between genetics and evolution.

Participants were required to consider the 2019 ATP (Figure 5) to decide whether they agree with the current sequencing of topics in the Grade 12 Life Sciences curriculum or if they felt, on reflection, that they would alter it in any way. Participants 3,4 and 5 responded by listing their preferred topic sequence. Participants 3, 4 and 5’s responses contradict the CAPS ATP sequencing as they suggested they would prefer teaching evolution directly after genetics for conceptual progression rather than having unrelated topics between the two. Their responses are shown in Table 6 below.

<u>Table 6: Participants preferred sequencing of genetic and evolution related topics for grade 12 Life Sciences</u>

Participant	Suggested sequencing of topics
3.	1. Meiosis 2. Genetics and inheritance 3. Introduction to evolution ➢ Evidence for Evolution ➢ Variation ➢ Origin of ideas ➢ Artificial selection ➢ Origin of an idea about origins (A historical development) ➢ Lamarckism (Jean Baptiste de Lamarck – 1744 – 1829) ➢ Darwinism (Charles Darwin – 1809 – 1882) ➢ Punctuated Equilibrium (Eldredge and Gould – 1972) ➢ Formation of new species ➢ Mechanisms of reproductive isolation ➢ Evolution in present times.
4.	1. Meiosis 2. Genetics and inheritance (Directly following Genetics and inheritance 3. Introduction to evolution: ➢ Biological evolution, hypothesis, theory, evidence for evolution and variation. ➢ Lamarckism, ➢ Darwinism ➢ Punctuated equilibrium ➢ Artificial Selection ➢ Speciation. ➢ Reproductive isolation mechanisms, ➢ Evolution in present times.
Participant 5	Term 1 and majority of term 2: 1. DNA: The code of Life 2. Meiosis 3. Genetics and inheritance 4. Evolution by Natural Selection 5. Human Evolution

All three participants agree that the sequence of topics should be as follows:

1. DNA: The code of Life
2. Meiosis
3. Genetics and inheritance
4. Evolution by Natural Selection

Sequencing

The rationale behind the suggested progression of topics (above) is that it follows a logical build up through which prior knowledge facilitates the understanding of new knowledge. The CAPS ATP prescribes that DNA (including meiosis) should be taught in term 1, followed by reproduction in vertebrates and genetics is taught in term 2, by separating DNA from genetics already decreases learners' ability to form links between meiosis, variation and mutations. Furthermore, genetics is separated from evolution which is taught at the end of term 3 or beginning of term 4 with human responses to the environment (human nervous system, human endocrine system, homeostasis in humans) and plant responses to the environment (plant hormones, geotropism and phototropism and plant defence mechanisms) between genetics and evolution. The participants agreed that the current ATP limits their ability to link genetics and evolution and would prefer to have genetics followed directly by evolution. On the premise that the topics needed to successively sequenced, the possibility of integration of genetics and evolution was investigated. Integration refers to combining genetic concepts with evolution concepts which are directly related, for example, linking mtDNA to mitochondrial eve or variation to speciation.

During the interviews, the teachers were asked if they thought genetics and evolution could be taught in an integrated way. All 5 of the teachers used the word "integrate" synonymously with "sequencing" which resulted in each of them having similar responses, some of which are quoted from their transcripts in Table 7 below.

Table 7: Participants inclination to integrating genetics and evolution in the Grade 12 Life Sciences curriculum

Question	Participant	Quoted Response
Could genetics and evolution be taught in an integrated way? Do you think this would enhance learner understanding of the topics?	1.	I think there is already, we don't have to maybe teach it in the sequence of one after another for that integration to be there. I think the teacher needs to be aware and make those links in class.
	2.	That could definitely help if the evolution followed genetics…for me, it doesn't matter when I do the work, but I have to integrate the work with one another.
	5.	100% definitely…teach DNA, then they go straight on to meiosis, then they go to genetics, then they go to evolution. And I've actually adapted it that way.

Integration

The responses in Table 7 suggest that the participating teachers are aware of the need to integrate the teaching of these topics and may be better equipped to make links between genetics and evolution if the topics followed each other. Two of the participants suggests that the teacher should be able to make the links despite the separation in CAPS. While this may be true, I would argue that it is often overlooked as teachers are focused on completing the content heavy syllabus rather than being able to backtrack to previous content that has been interrupted by unrelated concepts. Furthermore, participant 5 has adapted the curriculum to allow for the direct link between genetics and evolution, however, it must be remembered that since public schools are bound by the ATP, it is not possible for the majority to adapt the syllabus.

Since the pre-service teacher curriculum prepares teachers to teach the CAPS curriculum, the lecturers were asked if the pre-service teacher curriculum could accommodate an integration of genetics and evolution and if it would improve the teaching and learning of these topics which could filter into schools. Their responses, extracted from the transcripts, are presented in Table 8.

Table 8: Lecturers' opinions about integrating genetics and evolution in the pre-service teacher curriculum

Question	Participant	Quoted Response
Could genetics and evolution be taught in an integrated way to pre-service teachers? Do you think this would enhance pre-service teacher understanding of the topics and ability to teach these topics at school?	6.	You should maybe talk about meiosis and natural selection, you, you actually integrate the topics instead of having just genetics and evolution. So, you kind of take topics and you integrate them.
	7.	It doesn't really matter. It depends on how the teacher teaches. You can't integrate. You need to teach genetics and then maybe evolution should immediately come in.

In comparison to the teachers, the lecturers' responses are somewhat contradictory as the evolution lecturer proposes an integration of genetics and evolution while the genetics lecturer suggests that rearranging the topics to have evolution follow genetics is a more appropriate approach. While integration may be beneficial for wholistic learning as suggested by participant 6, perhaps at school level, topic progression could be the first step to improving the understanding of genetics and evolution as stated by participant 7. Furthermore, considering all the tabulated responses, it is evident that these participants would sequence evolution to follow genetics, thereby scaffolding the topics rather than integrating them.

The theme discussed under objective 2 was thus specifically aimed at determining participants inclination towards an integrated approach to the teaching and learning of genetics and evolution. However, an emergent theme that arose during the analysis of this theme was: *teacher understanding*, which will be discussed under objective 3 below.

Objective 3: optimizing the grade 12 Life Sciences CAPS curriculum

Optimizing the links between genetics and evolution can only be achieved if factors hindering this are acknowledged and addressed. The following challenges were identified within this theme:

Teacher understanding & ongoing professional training

As shown in Tables 5, and 7, all 7 participants acknowledge that forming links between genetics and evolution is imperative. In Table 7 and 8, participants 2 and 7 respectively, stated that the responsibility lies with the teacher to create the links, despite the topic order in the curriculum. However, there was a teacher who stated that they did not receive teacher training to do this at all, while another teacher stated that the training that was received did not equip them to scaffold the topics of genetics and evolution, as illustrated in the quotes below:

Participant 2: "*I didn't actually work with evolution before. I studied education and Life Science education, but no one ever told me anything about evolution ever. So, the evolution that I know is due to information that I've gathered myself*"

Participant 3 "*They pitch the training at such a low, elementary level …the training never addresses the aspects of intellectual discourse around the contents*".

The other teachers did not comment on their training experience as this was not a question that they were explicitly asked, but was brought up during the interview by participants 2 and 3.

Content load & timing

The volume of curriculum content and timing are two factors that emerged from the data, resulting in participants 4 and 2 specifically stating that they had difficulties with the amount of grade 12 content to be covered in the stipulated timeframe. Participant 2 further stated that evolution being the very last topic in the syllabus results in not having sufficient time to thoroughly cover the content. Since the university curriculum is aligned with the school curriculum, participant 6 also suggested that evolution being at the end may have an effect on pre-service teacher understanding. Table 9 below shows participant's concerns about the amount of content to be covered in the grade 12 year.

Table 9: Participants' statements regarding the content load and time constraints in the grade 12 Life Sciences CAPS curriculum (interview questions in Appendices G, H and I)

Participant	Interview question set	Question	Evidence from interview transcript
4	1	2: What are your thoughts about the current CAPS curriculum for Grade 12 Life Sciences?	The one thing I would say is that there's a real issue with timing. So, concepts like DNA are expected to be sure…expected to be taught in a specific amount of time where in reality, if they don't understand DNA, then pretty much the rest of the year is a write-off.
		5: Are there any new topics or concepts that you think should be introduced into the curriculum? Why?	I think we cover a lot… we cover a lot in matric, and that's completely new to them.
2	1	2: What are your thoughts about the current CAPS curriculum for Grade 12 Life Sciences?	And I've always been complaining about how large the CAPS curriculum is, in regards to matrics, that there's not enough time to actually cover everything.
		12: Are there evolution concepts you would remove from the curriculum? Why?	I would like to teach them a bit more or actually spend a little time on it (evolution), but because of the time constraints, because it's one of the last chapters, it's so close to exams and yes, the pace setter says we have three weeks to work on it, but we actually don't. So, it's really time. Time is a factor there.
6	2	9: Do you think that the prescribed content of your subject prepares student teachers to teach the topic of genetics according to the grade 12 CAPS curriculum	So, part of the problem might be it's like, right at the end of fourth year… And…I think they're overloaded with all the other courses that they're doing

The statements recorded in Table 9 above, were from teachers (participants 4 and 2) and a lecturer (participant 6). The teachers' testimonies suggest that the CAPS school curriculum is content heavy with little time to question the links within the current curriculum. This is in line with the findings of Naidoo (2017). Since grade 12 is the last year of schooling, it is an exam driven year, consequently, teachers are focused on ensuring that the overloaded curriculum is covered to equip their learners to write their final examination (Cimer, 2012; Naidoo, 2017). This reiterates that teachers who are bound by the curricula and the ATP's have limited agency to change the course in order to link the concepts. Furthermore, participant 6 suggested that abstract concepts like evolution are left to the end of pre-service teachers' final year of their programmes, at a time when they are inundated with other courses which may cause them to have inadequate evolution subject matter knowledge (Mavuru & Pila, 2021), possibly reducing their ability to teach such concepts once they become qualified teachers (Mavuru & Pila, 2021). However, a possible way to optimize the teaching and learning of genetics and evolution is through revision of the sequencing of topics in the Life Sciences CAPS curriculum which will consequently adjust the pre-service teacher curriculum. Some suggestions for revisions are discussed next.

Revision and improvement

When teachers were asked their views on the need to revise or improve the CAPS curriculum, two of the teacher's stated that there is always room for improvement and that the curriculum should be continuously upgraded:

Participant 1: "*I think there's always a need for improvement…So, we need to keep up with times*".

Participant 2: "*I think with regard to content, the also needs to be upgrading and updating some of the more recent findings should be included in the syllabus*".

It is worth noting however, that since the pre-service teacher curriculum is aimed at preparing Life Sciences teachers for classroom teaching, revisions in CAPS curriculum may necessitate revisions to the pre-service teacher curriculum. In addition, the evolution lecturer also highlighted the need for programme level review and revision, involving regular discussions between lecturers teaching evolution and genetics, to ensure that nothing is inadvertently left out or duplicated, and that the curriculum remains conceptually coherent. This is illustrated in the quote below.

Participant 6: "*I would work closely with the geneticists and see what they cover, and then make sure that what we do dovetails with what they teach…we're teaching content and methodology separately, sometimes by different people, I would also take a look at integrating them as well".*

While the need for programme level review was identified, it was not clear from the interview data whether this was actually achieved, and why or why not**.** Bernstein (1975) suggests that only if a consensus is reached by stakeholders, can a successful and integrated curriculum favour learning and assessment. Consequently, to develop a curriculum that is constructive to learning, further research is necessary to determine if school curriculum advisers should inform the pre-service teacher curriculum or if university research regarding the school curriculum should inform the structure of CAPS.

Summary

In this chapter, the themes and subthemes were analysed. Themes included: threshold concepts in genetics and evolution in the CAPS curriculum, Links between genetics and evolution and optimization of CAPS curriculum. The subthemes analysed were: core concept and terminology, links between topics & scaffolding, sequencing, integration, teacher understanding and training and revisions and improvement. Conclusions drawn were as follows:

1. Genetic concepts directly contribute to the understanding of evolution concepts, therefore:
2. The topic of evolution should directly follow the topic of genetics
3. Participants encourage scaffolding the topics of genetics and evolution rather than integrating them at school level.

The themes and conclusions are discussed with reference to the literature in Chapter 5 below.

CHAPTER 5: Discussion

The Life Sciences curriculum has been revised a number of times (Donnelly, 2006; Coleman et al., 2015), yet learner understanding and performance in the subject remains mediocre, particularly in the genetics and evolution section of curriculum (DBE, 2017-2022). According to the DBE (2011), the purpose of introducing the CAPS curriculum was to assist teachers by providing them with guidelines on the stipulated content, sequencing and the timeframes in which each section should be taught. Assumingly, this was aimed at improving teaching and learning. However, the results herein show that the specifications within the CAPS curriculum may not favour conceptual progression and holistic learning. Thus, suggesting a restructure of the curriculum to favour curriculum coherence (Schmidt, Wang & McKnight, 2005). The aim of conducting this study was to determine if Life Sciences teachers would see benefit in explicitly linking genetics and evolution in grade 12 Life Sciences rather than separating the topics as is currently in the CAPS curriculum. This study explored teacher's lived experiences of teaching the topics of genetics and evolution according to the Life Sciences CAPS curriculum to grade 12 learners. The study was conducted in 5 public schools (1 teacher per school) under the guide of the CAPS curriculum and included one genetics and one evolution pre-service teacher lecturer. It explored teacher's understanding of the links between genetics and evolution and the possibilities of resequencing genetics to immediately precede evolution for prior knowledge could facilitate the understanding of new knowledge. The results of the study revealed that teachers had a few challenges regarding the topics of genetics and evolution according to the CAPS curriculum. Firstly, genetics and evolution are abstract concepts which requires teachers and learners to thoroughly grasp the terminologies for the core and threshold concepts to become accessible. Secondly, although the CAPS curriculum states that teachers may expand on the content according to their learners' context, teachers remain bound by the curriculum which is overloaded and possibly prevents teachers from being able to form links between related concepts such as genetics and evolution. Lastly, for revision and improvement to result in an optimized Life Sciences curriculum, the sequencing of genetics and evolution, level of teacher training in these topics and pacing needs to be addressed. It was found that teachers may be able to effectively form links between genetics and evolution of the topics were respectively sequenced. These finding and the implications of the results with reference to the literature which informed this study are further explored in this chapter.

5.1 Threshold concepts, Core concepts and Terminology

As mentioned in the previous chapter, in science education terminology is fundamental to understanding core concepts (McComas, 2013). Consequently, when participants were asked which genetics and evolutions concepts were key concepts for learners to understand, they asserted that terminologies are essential to their understanding of the content and if not well understood, their understanding of principles and processes suffers (DBE, 2020). They further stated that terminology should be made explicit for students to develop a *scientific* understanding of the content, concurring with Wandersee (1988) and Gilissen et al. (2019) that understanding phenomena is dependent on understanding terminologies. However, it must be remembered that learning is enhanced through interaction with more knowledgeable others (MKO) (Schunk, 2012), therefore, in the classroom, the teacher who is expected to act as the MKO, should be able to make the relevant terminologies accessible to learners through scaffolding exercises (Jaramillo, 1996 and Scott, Mortimer, & Ametller, 2011). Learners could be asked leading questions with specific terminologies that allow them to develop inquiry skills leading them to a transformed way of understanding (Meyer & Land, 2003).

However, a challenge that is presented in this study is that teachers appear to be unaware of the notion of "threshold" concepts since there have been differing conclusions about what constitutes a threshold concept (Salwén, 2019 and Townsend, Hofer, Lin Hanick & Brunetti, 2016). It is also important to note that certain threshold concepts may be included and addressed in completely different and seemingly unrelated subjects. For instance, Fiedler et al. (2017) suggests that concepts such as randomness and probability are explicit threshold concepts in mathematics but implicit in genetics and evolution. It therefore seems appropriate to use this argument to draw awareness to the finding that the teachers in this sample seem to bound by the siloed nature of the CAPS curriculum and did not consider that concepts such as randomness and probability could be the reason behind learners' difficulty in understanding genetics and evolution.

Since the very definition of a threshold concepts includes that learners cannot progress without reaching a transformed way of understanding (Meyer & Land, 2003), the implications of teachers not recognising genetic threshold concepts may result in learners failing to comprehend evolution concepts which are directly dependent on understanding genetic concepts. Failing to understand concepts such as DNA, meiosis and variation which can be considered a threshold concept to understanding natural selection (Kindfield, 1994) may result in deficient understanding of evolution.

5.2 Links between genetics and evolution

The teachers in this study generally support the findings of Mead et al (2017) and Alters and Nelson (2002) that having a prior understanding of genetic concepts facilitates the learning of evolution is almost impossible to dispute. However, the study did not reveal the depth of data required to determine if integration of genetics is possible since teachers were unable to explicitly state how they understood the links between genetics and evolution. Perhaps it can be deduced that these teachers are not concerned with link-making pedagogies but rather with ensuring they cover the required content for examination purposes. Link-making is limited in the classroom as it is clear that these participants are restricted by the CAPS document and annual teaching plans (ATP).

The data revealed a variety of contrasting opinions regarding the sequencing of the topics in the curriculum. Only 2 teachers agree with Johnson et al. (2015) that the topics are arranged logically in the CAPS document, noting however, that it remains the responsibility of the teacher to make links between related topics. The rest of the participants suggest that the sequencing of genetics and evolution has implications on how well the topics are understood. These participants agree with Ngema (2016) that the ATP is prescriptive and, separating genetics and evolution causes fragmentation and the development of misconceptions. Their responses also concur with Nyamupangedengu's (2016) explanation that separating linked topics leaves room for the development of misconceptions within concepts, in this case: genetics and evolution they suggest that sequencing the topics in a scaffolded manner can form a unified understanding of the content. This is necessary since teachers can only make effective links between concepts if they understand the relationships between concepts in the curriculum (Nyamupangedengu, 2016).

The results herein concur with Kyriacou et al. (2015), Coleman et al. (2015) and Sanders (2018) that some teachers have not been adequately trained on the evolution section of the curriculum. Consequently, teachers struggle to make links beyond sequencing evolution to follow genetics. Therefore, it is unlikely that without training and prescriptive instructions, that they would be able to integrate genetics and evolution. However, if there is openness to rearranging the content, there is a possibility to begin optimizing the teaching and learning of genetics and evolution.

5.3 Optimizing the CAPS curriculum

Teacher training

Despite limited literature on teacher training, the data revealed that teachers and experts view genetics and evolution as the two most difficult sections in the curriculum and this is supported by the candidate results shown in Figures 1a, b and c in chapter 1.

The data from this study and findings from the National Diagnostic reports concurs with Tibbitts & Weldon (2017) and Sanders (2018) that poor teacher training may affect learner performance in the examined topics of genetics and evolution. While most teachers use CAPS to guide their teaching, workshops that enhance their content knowledge and skills may facilitate a deeper understanding of the links between concepts in the curriculum (Nyamupangedengu, 2016). Sanders (2018) suggests that teachers who attend workshops designed to improve their pedagogical content knowledge (PCK) are able to reduce their concerns and misconceptions about the teaching and learning of evolution-related content. Furthermore, teachers must become concerned with the ways in which their teaching unfolds (Shulman, 1987). They must be able to reason through their understanding and be able to consider various other possible ways that learners may understand a particular concept (Shulman, 1987). This requires them to engage with the 5 components of Topic Specific Pedagogical Content Knowledge (TSPCK): student prior knowledge, curricular saliency, what is difficult to teach, representations and analogies, and conceptual teaching strategies. Although these components are implicit, they directly affect the way in which the content is transformed for learners, since the teacher becomes aware of what to emphasize, how to sequence content and which topics to link (Mavhunga & Rollnick, 2015). Consequently, it can be assumed that the teaching and learning of evolution-related topics, may improve if teachers become aware of the TSPCK in the relationship between genetics and evolution.

Furthermore, the pre-service teacher programme serves as a form of teacher training since it is meant to prepare teachers for classroom engagement. Statements made by the genetics and evolution lecturers conclude that the pre-service teacher curriculum is aligned to the school curriculum. Consequently, these participants support Ogunniyi and Rollnick's (2015) opinion that the pre-service teacher education seeks to develop teachers who are able to competently teach the existing school curricula. However, it is also evident from their statements that the pre-service teacher curriculum does not cover all content for genetics and evolution and may not develop expert Life Sciences teachers (Mpungose, 2020), with potential gaps in content knowledge and implications for their PCK too. Furthermore, as school curricula change, teachers who were educated under the previous curriculum may not have the adequate training to adapt their teaching, this results in teachers who are not empowered to successfully implement curriculum change (Mnguni, 2018). Yet, teachers are the most important agents of change in curriculum reform as it is their willingness to adopt the new curriculum and review their teaching methods to transform the content for learners (Alsubaie, 2016). It is therefore imperative to determine if the curricula that guides Life Sciences teacher's knowledge of content – particularly evolutionary topics is appropriate and efficient, as this does not only shape teacher understanding but also learner understanding of the theory of evolution (Mead et al., 2017).

5.4 Overcrowding and timing

As previously mentioned, the current curriculum is content heavy (ref) and the sheer volume of content required to be covered in the stipulated timeframes places strain on the teacher to achieve learning through the linking of genetic and evolution concepts. The data from this study supports Tibbitts et al.'s (2017) observation of an oversaturated curriculum being a problematic aspect in the teaching and learning of genetics and evolution. Further, and perhaps more problematic is the anecdotal recommendation mentioned by some participations that the Examination Guideline document be used as a more definitive guide for what to teach rather than the CAPS document (DBE, 2021), thus circumventing the challenge of the overloaded curriculum. However, if this is indeed the case, then the purpose of the content in the CAPS document becomes questionable. It is therefore necessary to evaluate the purpose of the Life Sciences curriculum at school and to determine how best to arrange content to ensure understanding is achieved for lifelong learning rather than for examination purposes.

5.5 Revision and improvement

The data collectively focused on the possibility of linking the topics of genetics and evolution to optimize the teaching and learning of these topics. However, it is possible that we have neglected the ever-changing nature of science. As science changes, science education must also change, but as (Mpungose, 2020) suggests; teachers can only be empowered to discuss new findings, new teaching methods and new resources if they are provided with knowledge updates in the scientific world in relation to school knowledge. This requires specific teacher training in which the ideologies that inform the curriculum are explicitly explained to teachers, since pre-service teacher programmes and the enacted curriculum focus heavily on content and minimally on methodologies to transform scientific content (Mnguni, 2013).

Teachers can only optimize teaching and learning if the curriculum becomes optimized. An optimized curriculum may only be possible with input from the teachers since they may not always agree with the intended curriculum which may result in effective teaching and learning (Mnguni, 2018). According to Fuller (2007), the intended curriculum which is the formal document does not always match the enacted curriculum which is the way in which teachers deliver the curriculum content in the classroom. This was evident in this study as teachers did not fully agree with the sequencing of topics according to the intended curriculum and stated that they often change the way in which they link topics and concepts. Thus, a proposed outline for the sequencing of topics in the Life Sciences CAPS curriculum follows this chapter, as a recommendation, with consideration to the limitations and strengths of this study.

CHAPTER 6: Limitations, Strengths and Recommendations

This chapter presents the concluding remarks about this study by considering the limitations of the study, the positive outcomes, and recommendations for future research.

6.1 Limitations

There were four dominant spheres of limitations in this study. The first being the lack of literature on how genetic and evolution concepts can be linked to improve teaching and learning in South African schools. Consequently, it was challenging to compare the results of this study to other related studies.

The second limitation resulted from the small sample group. The sample was much smaller than expected and it only included 1 teacher per school and it was limited to quintile 4-5 schools. The third challenge arose as I began this research in 2020 when covid was at its peak, this meant that most teachers, especially in quintile 1-3 schools could not be contacted. Multiple attempts to contact quintile 1-3 schools were made by myself and my supervisor. However, our attempts were unsuccessful as we could not reach these schools electronically and were prohibited by Covid-19 lockdown laws to visit the premises.

Furthermore, grade 12 teachers were under pressure to complete the syllabus (often remotely) to prepare their learners for the matric examinations which continued, despite the pandemic. This means that teachers were focused on dedicating their time to the learners rather than engaging in a research study. An increased sample size, including teachers from all the quintile school would have been beneficial as it would have produced a more realistic picture of teachers experiences in enacting the grade 12 Life Sciences CAPS curriculum.

Lastly, the research instruments used presented some challenges. Some teachers may have felt as if their content knowledge and methodologies were being questioned during the semi-structured interview which may have resulted in their responses not reflecting the true reality of their experience. Furthermore, only 3 out of the 7 participants engaged in the concept map activity which meant that the data for the study was thin.

6.2 Strengths

The data collected in this study presented an opportunity for a draft of an optimized curriculum for genetics and evolution education in grade 12 Life Sciences although reliant on a small sample provides a platform for the discussions about the revision and improvement of genetic and evolution education in South African education institutions. Furthermore, participants were open about their need for topic specific training and resources to develop their pedagogical content knowledge and teaching methodologies, thus, this research could probe the beginning of these types of workshops.

6.3 Recommendations

Based on the findings regarding teachers' lack of familiarity with the notion of threshold concepts, and well as the issues identified with the sequencing and pacing of the content in the topics of Genetic and Evolution, it may be necessary to review the in the structure of the CAPS curriculum. Perhaps amending the CAPS curriculum towards the IEB (Independent Examination Board) curriculum which is remains governed by CAPS but attempts to provide teachers with agency through a SAGs (Subject Assessment Guidelines) document which provides teachers with content guidelines from grade 10-12 but does not stipulate the order in which topics should be taught nor bounds them with ATP's. This may allow teachers to engage in TSPCK practices more openly in the Life Sciences classroom.

Since the results of this study suggested that teachers would prefer to teach evolution directly after genetics in order to form conceptual links between these topics it may be beneficial that the next revisions to the CAPS curriculum includes a change in topic sequence as follows:

1. DNA: The Code of Life
2. Meiosis
3. Genetics and Inheritance
4. Reproduction in vertebrates
5. Evolution
6. Responding to the environment (humans)
7. Endocrine system and homeostasis in humans
8. Responding to the Environment (plants)

The content that could be covered in each topic is summarised in Table 10.

Table 10: Recommended ATP for Grade 12 Life Sciences:

Term	Topic	Content	Threshold concepts
1	DNA: The code of Life	• DNA • RNA • Meiosis	Meiosis can be considered a threshold concept since its understanding directly opens an understanding of variation and natural selection
2	Genetics and inheritance	• Genes • Inheritance and variation • Sex chromosomes • Mutations	An understanding of inheritance and variation and mutations may improve learner understanding of evolution and particularly human evolution.
	Reproduction in Vertebrates	• Diversity of reproductive strategies	
	Evolution by Natural selection	• Origin of ideas about origins • Darwin's theory of evolution by natural selection • Formation/emergence of new species • Mechanisms for reproductive isolation Artificial selection	It is fundamental to understand natural selection in order to understand the formation of new species and in tun, evolutionary theory. Each of these concepts depends on a transformed understanding of meiosis and variation.
	Human evolution	• Evidence of common ancestors for living hominids including humans • "Out of Africa" hypothesis • Importance of the Cradle of Humankind • Evolution in present times • Alternatives to evolution	Evidences of common ancestors includes genetic evidence: mtDNA and Y-chromosomal DNA – genetics concepts which impact the understanding of human evolution.
3	Responding to the environment: Humans	• Human nervous system • Disorders • Injuries • Effects of drugs • Receptors	
	Human endocrine system	• Endocrine glands	
	Homeostasis in humans	• Homeostasis	

	Responding to the environment: Plants	• Plant hormones • Geotropism and phototropism • Plant defence mechanisms	

It is suggested that the CAPS curriculum is reorganised to have evolution follow genetics and explicitly show the links between the topics. While reproduction in vertebrates is listed as a topic separate to DNA and genetics, the concept of reproduction shows how genes are passed from parent to offspring, as such it can be considered part of genetics which can later be linked to evolution and human evolution. Although the table above is an extremely simplified version of the possible curriculum, it was necessary to discuss the threshold concepts bound in the curriculum, since a curriculum is built on the premise of hierarchical knowledge (Bernstein, 1996), conceptual progression and curriculum coherence (Schmidt et al., 2005).

Conclusion and future research

Genetics and evolution are the two largest examined sections in the grade 12 Life Sciences examinations. However, literature in this study has shown that performance in these two areas has been recorded as poor since 2017, it may well be that the poor performance has occurred since their inclusion in the curriculum. This study proposed and showed the possibility that the reason for the poor performance may be due to the sequencing and pacing of the topics. A key recommendation is therefore to have a review of the curriculum to address and change the sequence of the teaching in which genetics directly precedes evolution, with points of integration and made more explicit for teachers. There was an indication of the impact of gaps in teachers' TSPCK which may also be linked to teachers' lack of strong content knowledge. Therefore, it is recommended that the Life Sciences CAPS curriculum for grades 10-12 explicitly provides teachers with clear links between threshold concepts and core concepts (clearly outlining the links between related topics).

Including specific links in one document – the CAPS document, may reduce the number of documents teachers have to consult and may effectively contribute to their own understanding and learners understanding of content that is conceptually progressive.

Since teachers use the curriculum to guide their teaching, it may result in teachers being able to transform their PCK into an accessible form of knowledge for the learners. However, it must be remembered that teachers are informed by the curriculum that guided their degree/diplomas, therefore, reviews of the Life Science content and methodology courses in teacher education programmes must occur to ensure that newly qualified teachers are adequately equipped to teach these challenging topics. In this respect, the findings of this study should be shared with Life Sciences district facilitators to investigate the challenges with current workshops to find ways to ensure that ongoing professional development initiatives address challenges by enhancing teachers' TSPCK. To conclude, the Life Sciences CAPS curriculum in South African schools has proved to include important topics which encourage lifelong learning, however, this study considers that the sequence and pacing of topics may be a contributing factor to weak understanding of these topics. There is a plethora of factors to consider in determining the revision of any curriculum, as such it is encouraged that further research is conducted at a larger scale to determine if these recommended changes would benefit the Life Sciences community.

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Appendix A: Participant Information sheet

Dear ___________________ Date:___________

My name is Aneesa Bodhania, and I am Masters in Science (Palaeontology) student, under the supervision of Dr Ian McKay and Professor Kershree Padayachee at the School of Geosciences at the University of the Witwatersrand.

I am currently researching a project entitled: ***Investigating an optimized approach to the teaching and learning of Genetics & Evolution in South African schools***

I am inviting you as a Life Sciences teacher to voluntarily participate and contribute to my research project.

The aim of my research is to investigate the current conceptual links between genetics (meiosis and sex-linked concepts) and evolution (human evolution and natural selection) in the grade 12 Life Sciences CAPS document and to determine whether they can be optimized for learning. To investigate if there is a link between a poor understanding of genetic concepts and a poor understanding of evolution concepts; and if an integrated approach to the teaching and learning of these topics would improve learner performance in both sections.

I, therefore, need to interview grade 12 Life Sciences teachers about the ways in which key genetic concepts and key evolution concepts are linked in the CAPS document and taught in the classroom. The interviews will be semi-structured and will need to take place using a platform that is suitable for the participant, such as Zoom, Microsoft teams, telephonic interviews or online questionnaires. Should the need arise, I may request further elaboration or clarification on some responses. I request that I may audio-record the interviews so that I can ensure an accurate recollection of the data and results. I anticipate that these interviews will take a maximum of 60 minutes to complete and may therefore be required to take place after school hours. The information that the teachers provide will be used to draw conclusions about the relationships between core genetic and evolution concepts both in the curriculum and during teaching.

I also require each participant to draw concept maps showing the genetic and evolution concepts you would add or remove from the grade 12 Life Sciences curriculum and the links between them. Lastly, I will require the participants to draw a sequencing and timing table derived from their concept maps showing when they would teach each of the genetic and evolution concepts (templates will be provided)

Participant's identities will be kept strictly confidential at all times and in all academic writings and publications regarding the study. All research data will be stored electronically on password protected devices and may be used in future studies.

I sincerely request your participation in my research project by engaging in a one-on-one interview with me and drawing the concept maps and sequencing and timing table.

You will not be advantaged or disadvantaged in any way. Your participation is voluntary; you can withdraw your permission at any time during this project without any penalty. There are no foreseeable risks in participating and you will not be paid for this study.

Please contact me directly if you require any further information.

Thank you for your assistance in my research project.

Yours sincerely,

Name: Aneesa Bodhania Signature: _______________________

Address: 19 Abdul Hassan Crescent, Azaadville. 1750. Johannesburg. Gauteng

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Contact: 0833825764

Supervisors: Dr Ian McKay: Ian.mckay@wits.ac.za & Professor Kershree Padayachee: Kershree.padayachee@wits.ac.za

HREC: University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrec-medical.researchoffice@wits.ac.za

Appendix B: Participant consent form

Please fill in and return the reply slip below indicating your willingness to participate in my (ANEESA BODHANIA,1076560) research project entitled

Investigating an optimized approach to the teaching and learning of

Genetics & Evolution in South African schools

I, ____ give my consent for the following:

Please Circle

I agree to be interviewed for this study.	YES NO
I agree that this interview can be used for secondary studies	YES NO
I acknowledge that I can stop the interview at any time and do not have to answer questions I am not comfortable with.	YES NO
I agree to be audio-recorded during the interview and allow notes to be taken.	YES NO
I acknowledge that my participation will remain anonymous.	YES NO
I agree that the researcher may use anonymous quotes in her research report.	YES NO
I agree that the information I am providing may include my own opinions which will be used anonymously in this research report.	YES NO
I agree that the information I provide may be used anonymously by other researchers following this study.	YES NO

Informed Consent

I understand that:

- my name and information will be kept confidential and safe and that my name and the name of my school will not be revealed.
- I do not have to answer every question and can withdraw from the study at any time.
- I can ask not to be audio-recorded.

Signature_____________________________ Date ___________________________

Appendix C: Semi-structured interview questions for teachers

This interview schedule consists of 16 questions in 3 sections and will be piloted before the interviews are conducted. Length of interview: ± 60 mins

Section 1: General Questions

1. How long have you been teaching Grade 12 Life Sciences?
2. What are your thoughts about the current CAPS curriculum for Grade 12 Life Sciences?
3. Do you have knowledge of prior South African Curricula? How does CAPS compare?
4. Do you think there is a need for revision and improvement of the curriculum? Why?

Section 2: The Specifics

5. Are there any new topics or concepts that you think should be introduced into the curriculum? Why?
6. Are there any topics or concepts you think should be removed from the curriculum? Why?
7. What are your thoughts on the prescribed content of the topics of genetics and evolution in the curriculum?
8. What are the threshold/core genetic concepts all learners should understand?
9. Are there genetic concepts you would remove from the curriculum? Why?
10. Are there additional genetic concepts you think should be included in the curriculum?
11. What are the threshold/core evolution concepts that all learners should know?
12. Are there evolution concepts you would remove from the curriculum? Why?
13. Are there additional evolution concepts you think should be included in the curriculum?

Section 3: in-depth

14. Are there genetic and evolution concepts which overlap? What are these concepts?
15. To what extent does the understanding of key genetic concepts affect the understanding of evolution concepts?
16. Could genetics and evolution be taught in an integrated way? Do you think this would enhance learner understanding of the topics?

Appendix D: Semi-structured interview questions for genetics lecturer

Semi-structured interview schedule: Genetics expert lecturer to pre-service teachers

This interview schedule consists of 15 questions in 3 sections and will be piloted before the interviews are conducted. Length of interview: ± 60 mins

Section 1: General Questions

1. What is your subject speciality in the Education faculty?
2. How long have you been teaching/lecturing your subject?
3. In which year of student study does your subject become compulsory?
4. How does the pre-service teacher curriculum (of your subject) relate to the school curriculum?

Section 2: The Specifics

5. What are your thoughts on the prescribed genetics content in the Life Sciences curriculum of pre-service teachers?
6. What are your thoughts on the prescribed genetics content in the grade 12 CAPS curriculum?
7. Are there any new topics or concepts that you think should be introduced/ removed from the Life Sciences curriculum of pre-service teachers? why?
8. Are there any new topics or concepts that you think should be introduced or removed from the grade 12 CAPS curriculum? Why?
9. Do you think that the prescribed content of your subject prepares student teachers to teach the topic of genetics according to the grade 12 CAPS curriculum?

Section 3: in-depth

10. Does the education discipline align with the science discipline regarding the topic of genetics?
11. Do you think the scientific content of genetics is effectively contextualised in the CAPS curriculum?
12. Do you think that there are genetic and evolution concepts which overlap? Could you mention some of these concepts?
13. In your expert opinion, to what extent does the understanding of key genetic concepts affect the understanding of evolution concepts?
14. Could genetics and evolution be taught in an integrated way to pre-service teachers? Do you think this would enhance pre-service teacher understanding of the topics and ability to teach these topics at school?
15. Do you think that a school curriculum which specifically explains the relationships between concepts such as genetics and evolution would enhance teaching and learning?

Appendix E: Semi-structured interview questions for evolution lecturer

Semi-structured interview schedule: Evolution expert lecturer to pre-service teachers

This interview schedule consists of 15 questions in 3 sections and will be piloted before the interviews are conducted. Length of interview: ± 60 mins**Section 1: General Questions**

1. What is your subject speciality in the Education faculty?
2. How long have you been teaching/lecturing your subject?
3. In which year of student study does your subject become compulsory?
4. How does the pre-service teacher curriculum (of your subject) relate to the school curriculum?

Section 2: The Specifics

5. What are your thoughts on the prescribed evolution content in the Life Sciences curriculum of pre-service teachers?
6. What are your thoughts on the prescribed evolution content in the grade 12 CAPS curriculum?
7. Are there any new topics or concepts that you think should be introduced/ removed from the Life Sciences curriculum of pre-service teachers? why?
8. Are there any new topics or concepts that you think should be introduced or removed from the grade 12 CAPS curriculum? Why?
9. Do you think that the prescribed content of your subject prepares student teachers to teach the topic of evolution according to the grade 12 CAPS curriculum?

Section 3: in-depth

10. Does the education discipline align with the science discipline regarding the topic of evolution?
11. Do you think the scientific content of evolution is effectively contextualised in the CAPS curriculum?
12. Do you think that there are genetic and evolution concepts which overlap? Could you mention some of these concepts?
13. In your expert opinion, to what extent does the understanding of key genetic concepts affect the understanding of evolution concepts?
14. Could genetics and evolution be taught in an integrated way to pre-service teachers? Do you think this would enhance pre-service teacher understanding of the topics and ability to teach these topics at school?
15. Do you think that a school curriculum which specifically explains the relationships between concepts such as genetics and evolution would enhance teaching and learning

Appendix F: Grade 12 Life Sciences Pacesetter (2019)

Term 1 45 days	Week 1 27-29 January (3 days)	Week 2 1-5 February (5 days)	Week 3 8-12 February (5 days)	Week 4 15-19 February (5 days)	Week 5 22-26 February (5 days)	Week 6 1-5 March (5 days)	Week 7 8-12 March (5 days)	Week 8 15-19 March (5 days)	Week 9 23-26 March (4 days)	Week 10 29-31 March (3 days)
CAPS Topic	(National Examination Guideline pg. 5) DNA: The code of Life [18%]			(National Examination Guideline pg. 6) Meiosis [14%]		(National Examination Guideline pg. 7) Reproduction in vertebrates [5%]	(National Examination Guideline pg. 8) Human Reproduction [27%]			
Core Concepts, Skills and Values	DNA: location, chromosomes, genes and extra-nuclear DNA and discovery of DNA	Structure, role and replication of DNA, DNA profiling (Extract DNA and observe and examine the threads)	RNA: Types, location, structure Genetic code Protein synthesis (transcription and translation)	Structure of a chromosome and associated terminology, process of meiosis, importance of meiosis (Observe diagrams/micrographs of cells in selected stages of meiotic division)	Abnormal meiosis and consequences, similarities and differences between meiosis and mitosis	Diversity of reproductive strategies	Structure of male and female reproductive systems, Puberty, gametogenesis	Menstrual cycle, fertilisation and development of zygote to blastocyst	Implantation, gestation and the role of the placenta	

Term 2 51 days	Week 1 13 – 16 April (4 days)	Week 2 19 – 23 April (5 days)	Week 3 28 – 30 April (3 days)	Week 4 03 – 07 May (5 days)	Week 5 10 – 14 May (5 days)	Week 6 17 – 21 May (5 days)	Week 7 24 – 28 May (5 days)	Week 8 31 May – 4 June (5 days)	Week 9 07 – 11 June (5 days)	Week 10 14 – 18 June (4 days)	Week 11 21 – 25 June (5 days)
CAPS Topic	Genetics (National Examination Guideline pg. 9) Genetics and Inheritance [32%]				(National Examination Guideline pg. 10) Responding to the environment (humans) [36%]			(National Examination Guideline pg.12) Human endocrine system and Homeostasis in humans [23%]		(National Examination Guideline pg.13) Responding to the environment (plants) [9%]	
Core Concepts, Skills and Values	Concepts of inheritance, Monohybrid crosses, sex determination, sex-linked inheritance	Dihybrid crosses, Blood grouping	Genetic lineages/pedigree diagrams, mutations	Genetic engineering, paternity testing and genetic links	Human nervous system – central, peripheral and autonomic, nerve, reflex arc, disorders	Human eye	Human ear	Endocrine and exocrine glands, glands, hormones and functions of hormones, Negative feedback mechanism involving TSH and thyroxin (and the result of an imbalance: thyroid disorders), Insulin and glucagon (and the result of an imbalance: diabetes mellitus)	Negative feedback mechanisms – glucose, carbon dioxide, water, salts, thermoregu-lation	Plant hormones, Tropisms, Plant defence mechanisms	Consolidation and Revision

Term 2 51 days	Week 1 13 – 16 April (4 days)	Week 2 19 – 23 April (5 days)	Week 3 28 – 30 April (3 days)	Week 4 03 – 07 May (5 days)	Week 5 10 – 14 May (5 days)	Week 6 17 – 21 May (5 days)	Week 7 24 – 28 May (5 days)	Week 8 31 May – 4 June (5 days)	Week 9 07 – 11 June (5 days)	Week 10 14 – 18 June (4 days)	Week 11 21 – 25 June (5 days)
Informal Assessment	Past examination paper questions, practice questions on genetic crosses, pedigree diagrams, scientific investigations, tests				Questions from past papers, tests, scientific investigations				Questions from past papers, tests, scientific investigations	Past examination papers questions, tests	Past examination papers questions, tests

Term 3 52 days	Week 1 13 – 16 July (4 days)	Week 2 19 – 23 July (5 days)	Week 3 26 – 30 July (5 days)	Week 4 02 – 06 August (5 days)	Week 5 10 – 13 August (4 days)	Week 6 16 – 20 August (5 days)	Week 7 23 – 27 August (5 days)	Week 8 30 Aug. – 03 Sept (5 days)	Week 9 06 – 10 Sept (5 days)	Week 10 13 – 17 Sept (5 days)	Week 11 20 – 23 Sept (4 days)
CAPS Topic	Evolution (National Examination Guideline pg. 13) Evolution [36%]					Data response questions, case studies, questions from past papers Revision-Mind the Gap Study Guide, past examination papers, videos and power points					
Core Concepts, Skills and Values	Introduction to evolution e.g. biological evolution, hypothesis, theory. evidence for evolution and variation	Lamarckism, Darwinism and Punctuated equilibrium, Artificial selection and speciation		Reproductive isolation mechanisms evolution in present times	Evidence of common ancestors for living hominids, including humans	Out of Africa hypothesis					

Term 3 52 days	Week 1 13 – 16 July (4 days)	Week 2 19 – 23 July (5 days)	Week 3 26 – 30 July (5 days)	Week 4 02 – 06 August (5 days)	Week 5 10 – 13 August (4 days)	Week 6 16 – 20 August (5 days)	Week 7 23 – 27 August (5 days)	Week 8 30 Aug. – 03 Sept (5 days)	Week 9 06 – 10 Sept (5 days)	Week 10 13 – 17 Sept (5 days)	Week 11 20 – 23 Sept (4 days)
Informal Assessment	Past examination papers questions, tests	Questions from past papers, tests, scientific investigations		Questions from past papers, tests, scientific investigations							

Term 4 47 days	Week 1 05 – 08 October (4 days)	Week 2 11 – 15 October (5 days)	Week 3 18 – 22 October (5 days)	Week 4 25 – 29 October (5 days)	Week 5 01 – 05 November (5 days)	Week 6 08 – 12 November (5 days)	Week 7 15 – 19 November (5 days)	Week 8 22 – 26 November (5 days)	Week 9 29 Nov – 03 Dec (5 days)	Week 10 06 – 08 Dec (3 days)
CAPS Topic	Revision-Mind the Gap Study Guide, past examination papers, videos and power points Data response questions, case studies, questions from past papers				STUDY LEAVE FOR GRADE 12/NSC CANDIDATES			FINAL EXAMINATIONS		

Appendix G: University of the Witwatersrand Ethics approval letter

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Bodhania

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H20/03/03**
PROJECT TITLE	Investigating an optimized approach to the teaching and learning of Genetics & Evolution in South African schools
INVESTIGATOR(S)	Miss A Bodhania
SCHOOL/DEPARTMENT	School of Geosciences/
DATE CONSIDERED	13 March 2020
DECISION OF THE COMMITTEE	Approved Risk Level: Minimal
EXPIRY DATE	05 August 2023

DATE 06 August 2020 **CHAIRPERSON** ______________________________
(Professor J Knight)

cc: Supervisor : Dr I McKay and Dr K Padayachee

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

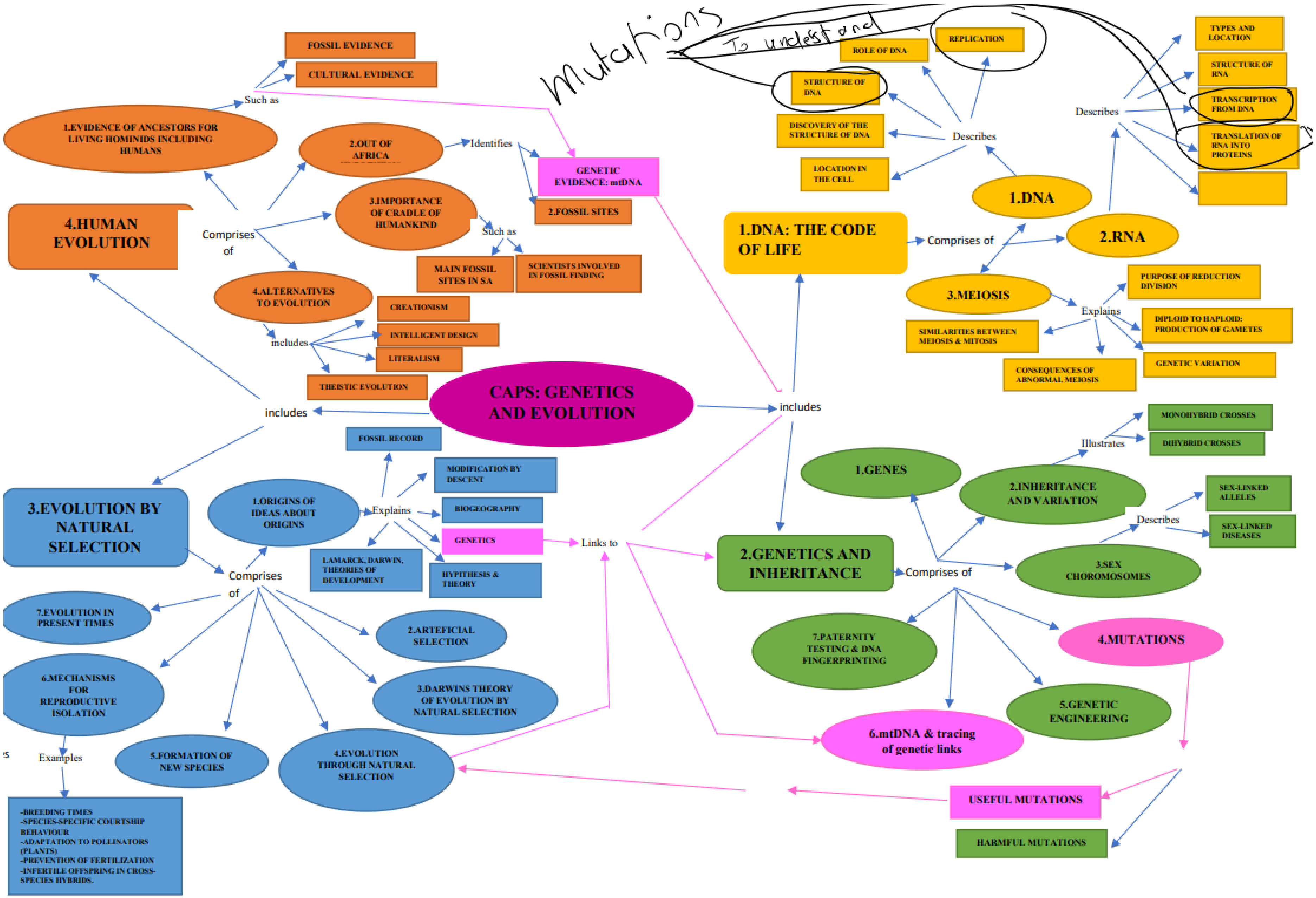
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

____
Signature

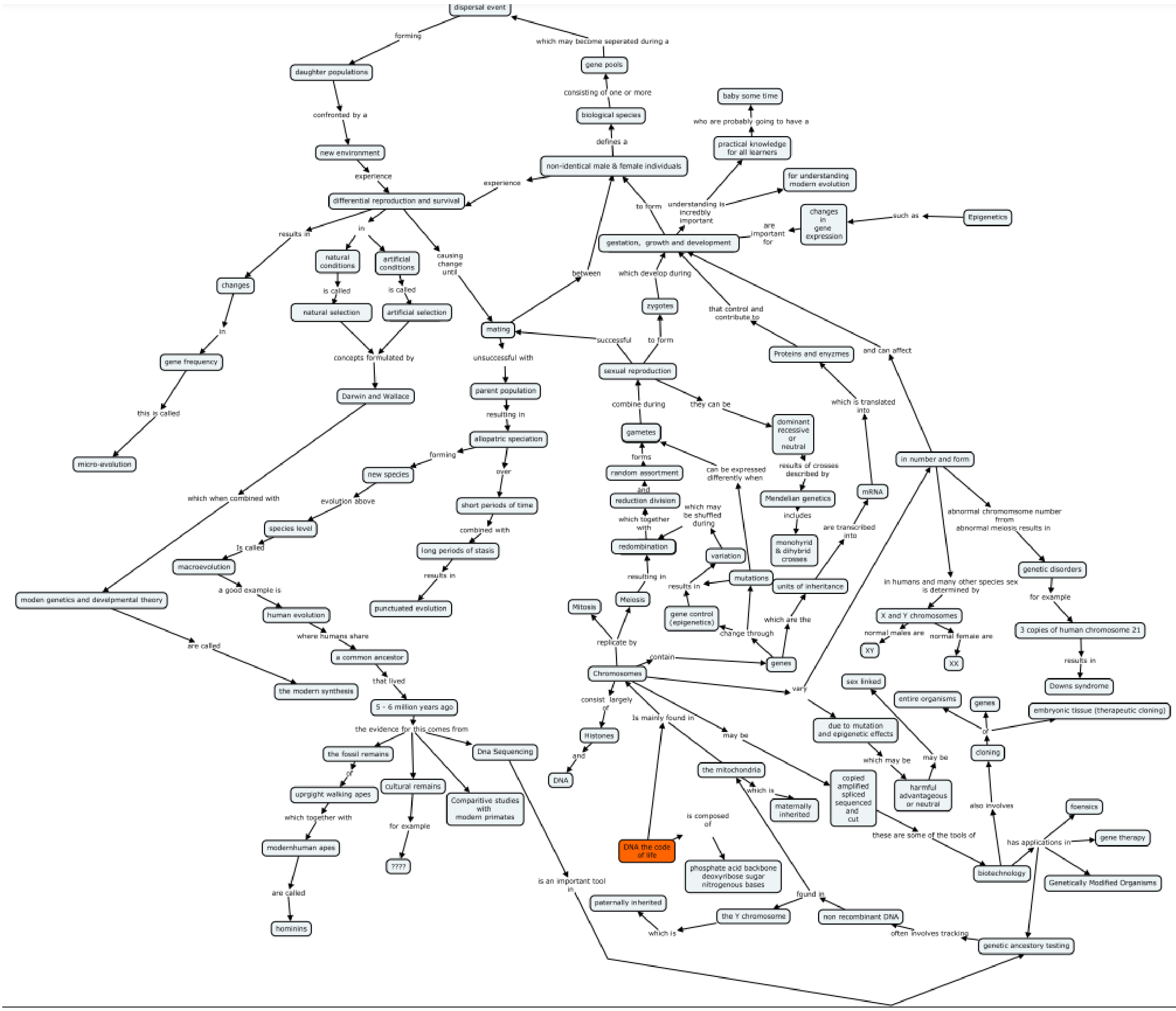
Date 15 / 03 / 2020

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

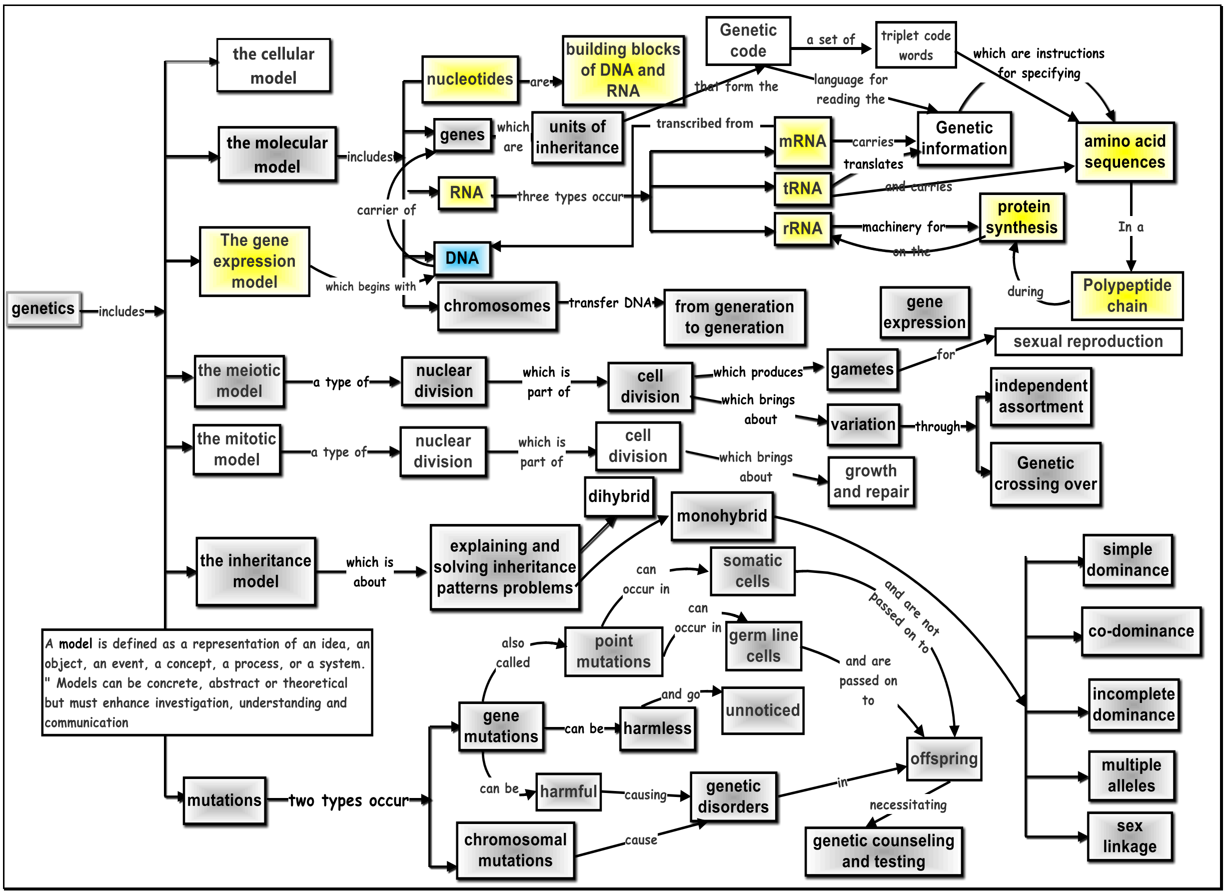
Appendix H: Participant 4's concept



Appendix I: Participant 6's concept map



Appendix J: Participant 7's concept map



Source: Nyamupangedengu (2016)

Below are the links

Meiosis is a source of genetic variation

Gene mutations are a source of genetic variation

Genetic variation drives natural selection

Natural selection drives evolution