Biology and its recontextualisation in the school curriculum: a comparative analysis of post-apartheid South African life sciences curricula

by

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ABSTRACT

This study explored the way biological knowledge is transformed when it moves from its disciplinary form to a high school biology curriculum, and how this occurred in successive versions of the life sciences curriculum implemented in post-apartheid South Africa. Bernstein's (1996, 1999) conceptualisation of biology as an hierarchical knowledge structure, the recontextualisation of knowledge, and the implications for social justice formed the theoretical framework to the study, as did Aikenhead's (2006) distinction between traditional and humanistic approaches to science education, and Schmidt, Wang and McKnight's (2005) concept of curriculum coherence.

Firstly, I attempted to elicit core concepts and conceptual organisation in biology from the writings of the distinguished biologist Ernst Mayr, two foundational biology textbooks, and interviews with two professors of biology. Seven concepts emerged: *the cell, inheritance, evolution, interaction*, *regulation, energy flow* and *diversity,* which I arranged in a hierarchy according to Mayr's "three big questions", "what?", "how?" and "why?". The theory of evolution was highlighted as the key integrating principle of the discipline.

Secondly, I considered biology in the school curriculum by means of a literature review and synthesis of the changing goals of a school science education. Five broad categories of objectives were derived: *knowledge*,

skills, *applications, attitudes and values*, and *science as a human enterprise*. Aikenhead's (2006) terminology captured the shifts in emphases of these objectives over time.

Thirdly, I analysed the stated objectives and content specifications of the three most recent versions of the South African life sciences curricula – the Interim Core Syllabus (ICS), the National Curriculum Statement (NCS) and the new NCS. The NCS represented a dramatic swing away from the traditional approach of the ICS, while the new NCS reverts to a more traditional approach, though with more humanistic content than in the ICS. Both the ICS and the NCS were found to be deficient in one of the three key conceptual areas of biology. The conceptual progression of the material is strongest in the new NCS, and weakest in the original NCS. The conclusion was drawn that, of the different curricula, the new NCS has the greatest potential to induct South African learners into the hierarchical structure of biology, and represents a positive contribution to the goal of transforming education in South Africa.

As the candidate's supervisors we agree to the submission of this dissertation.

SIGNED: .... DATE: ....

DR. E.R. DEMPSTER

SIGNED: .... DATE: ....

DR. W. HUGO

DECLARATION

I, Kathryn Barbara Johnson, declare that

(i) The research reported in this dissertation, except where otherwise indicated, is my original work.

(ii) This dissertation has not been submitted for any degree or examination at any other university.

(iii) This dissertation does not contain other personsô data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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KATHRYN BARBARA JOHNSON

dedicated to my parents, Stanley and Barbara Fish

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ABBREVIATIONS

AS	Assessment Standards
C2005	Curriculum 2005
DoE	Department of Education
ES	Elaborated Syllabus
FET	Further Education and Training
GET	General Education and Training
ICS	Interim Core Syllabus
IK	Indigenous Knowledge
LO	Learning Outcome
LPG	Learning Programme Guidelines
NCES	National Centre for Education Statistics
NCS	National Curriculum Statement
OBE	Outcomes-Based Education
ORF	Official Recontextualising Field
PRF	Pedagogic Recontextualising Field

RNCS	Revised National Curriculum Statement
TIMSS	Third International Mathematics and Science Study
UCT	University of Cape Town
WMS	Western Modern Science

Chapter 1: Introduction

"*If recontextualization totally severs any relation [between the parent knowledge structure and the recontextualized school subject], then how are specialised knowledges ever reproduced?*" (Muller, 2007, p.80).

1.1 Introduction

This study broadly represents an exploration of the relationship between biology as an academic discipline and biology as a school subject. Its theoretical basis is derived from Basil Bernstein's (1996, 1999) conceptualisation of the structure of knowledges, how knowledge in the field of production is recontextualised in a school curriculum, and the implications of this for social justice.

What is required of a curriculum if it is to help to narrow the gap between privileged and previously disadvantaged learners? Maton and Muller (2007) argue that the knowledge recontextualised in the curriculum must resemble its parent knowledge structure to a reasonable degree, if the role of schooling as a relay of specialised knowledges is not to be undermined. As Muller puts it in the same volume, "there has to be some form of specialisation of consciousness continuum in play; this could be called a founding assumption of modern education" (Muller, 2007, p.80). This is held to be most important in school subjects derived from what Bernstein (1996) termed "hierarchical knowledge structures", in particular the natural sciences. The argument is that if this continuum is disrupted too markedly, students, especially those from disadvantaged backgrounds, will not successfully be inducted into the realms of the formal knowledge structure (Muller, 2007; Taylor, 2001).

The pursuit of social equity by transforming the education system has been a priority in post-apartheid South Africa, and this has included extensive and ongoing revision of the curriculum (Christie, 2008). This year (2009) sees the implementation of a third version of the Grades 10-12 life sciences curriculum since the advent of democracy in 1994. In this study I present the results of a comparative analysis of the objectives and content specifications of the three successive versions, in an attempt to assess whether the revisions represent an improvement in the way biological knowledge has been recontextualised in the South African curriculum.

The resemblance between "academic" knowledge and "school" knowledge diminishes as knowledge is transformed to fit the goals of the curriculum. These goals are largely determined by the context in which the curriculum is constructed, as well as by the agents of curriculum construction and the various stakeholders in the process (Fataar, 2006; Jansen, 1999; Roberts, 1988). A changing socio-political context will typically result in curriculum revision, as has been evidenced in post-apartheid South Africa. But superimposed on the reality of the changing South African context is the fact that, on a worldwide scale, school science undergoes revision possibly more than any other subject (Donnelly, 2006). Several authors have highlighted how this tends to reflect a pendulum swing between two opposite emphases ï from ñscience-centredò to ñstudent-centredò (Jenkins, 2000), a dichotomy of approaches which has also been expressed as a "science of life" versus a "science of living" (Rosenthal & Bybee, 1987), ñscience for future scientistsò versus ñscience for allò (Fensham, 2000), and more recently, traditional or "pipeline" versus "humanistic" (Aikenhead, 2006).

Aikenhead (2006) holds that a humanistic approach to science education best serves the cause of promoting equity and social justice, and suggests that the persistence of the traditional approach simply reflects issues of political power. Yet the arguments of Bernstein and Muller (above) would appear to support a more traditional approach. Further research into the consequences for learners of different approaches to science education is needed to test these apparently opposite viewpoints, and is beyond the scope of this study. Nevertheless, they both served to supply conceptual tools for the analysis of the life sciences curricula in question, and provided a basis for assessing whether progress has been made towards the goal of a curriculum which promotes rather than undermines the cause of social justice in South Africa.

In this introductory chapter I provide a rationale for the research both from a personal perspective and by locating it in the present South African educational context. I outline the key questions of the study and methodologies employed. Finally, I provide a chapter-by-chapter overview of the thesis.

1.2 Rationale for the study

This study is intended to add to the body of research which has been conducted on the current South African National Curriculum Statements, such as those for physical sciences (Green & Naidoo, 2006) and history (Bertram, 2008).

My choice of life sciences as a subject for study was based on my own early and ongoing fascination with the natural world, tertiary studies in this field, and subsequent training and practising as a high school biology teacher. But I believe that the study of biology, as a science, has educational value beyond merely satisfying curiosity. In the words of Donnelly (2006):

> To have a knowledge of science and its particular mode of understanding the world as a significant and distinctive form of human intellectual activity is part of what it is to be educated. Such knowledge is a precondition for, and deployed within, intellectual autonomy and criticality (p.625).

Dempster and Hugo (2006) also argued that in particular the study of the theory of evolution, biologyõs highest ordering principle, can help to develop advanced cognitive skills in learners, and hence promote the cause of social transformation in South Africa ï a key guiding principle behind recent curriculum revision in this country.

Le Grange (2008) used the ñscience of life/science of livingò dichotomy as a lens for comparing the first two biology/life sciences curricula in post-apartheid South Africa. The present study aims to contribute to, strengthen and extend Le Grange's findings by including the third and latest version of the curriculum in the comparison, examining both the objectives and the content specifications of each, and employing techniques which generate quantitative as well as qualitative data.

1.3 A brief history of curriculum revision in South Africa post-1994

The process of curriculum reform in South Africa since the transition to democracy in 1994 has already been well documented (see for example Chisholm, 2000; Christie, 2008; Fataar, 2006; Hoadley, 2005; Jansen, 1999; Reddy, 2006; Taylor, Muller & Vinjevold, 2003). Here I provide a brief summary, focussing on the revision of the life sciences curriculum, and the social justice imperative which informed each stage of the process.

1.3.1 The Interim Core Syllabus

Prior to 1994 education had been a key site of struggle for the opponents of apartheid, and the cumbersome education system inherited by the democratic government was in a state of disintegration. Under pressure to bring about transformation, the new Ministry of Education embarked on a national process of curriculum revision aimed at ñpurgingò syllabi of material which could be deemed racially offensive, outdated, factually incorrect, or insensitive, and at consolidating the syllabi of the 19 education departments (Jansen, 1999).

The result was the Interim Core Syllabus (ICS)[1], a curriculum which, according to Jansen (1999), simply reflected the haste and political expediency of the process rather than change of any real educational significance. In most cases the improvements, if any, were minor, and the "new" syllabi tended to mirror those of the apartheid-era House of Assembly [white] education department. Jansen made the gloomy assessment that

> [t]he process has generated a public understanding that minimalist revisions to school subjects are both acceptable and workable. It will be extremely difficult in the future to change such expectations beyond the reshuffling of syllabus topics towards a national curriculum which *challenges the fundamental philosophical and ideological roots of apartheid education* [my emphasis] (p. 64).

Jansen does, however, mention one challenge to the philosophical *status quo*, which emanated from the committee debating the science curricula. The argument was that the so-called "Creator Clause" which appeared in the objectives to all science curricula should be removed, as it was felt that it reflected the conservative ideology of Christian National Education which had underpinned apartheid education, and might interfere with the teaching of evolution. The objective in question stated "that the child become aware of the majesty of creation through his acquaintance with the wonder and order of Creation ... in this way develop a sense of awe and reverence of the Creator" (quoted in Jansen, 1999, p. 62). The clause was removed, but this was clearly a symbolic gesture only; in biology, at least, the "revised" curriculum remained otherwise almost identical to that of apartheid-era white schools, and no mention was made of evolution.

1.3.2 Curriculum 2005 and its review

Between 1995 and 1997 a radical transformation of the curriculum in the GET phase (Grades R-9) was embarked upon, based on an entirely new approach known as outcomes-based education (OBE) (Fataar, 2006). This was defined as a system of education organised around "what is essential for all students to be able to do successfully at the end of their learning experiences" (Spady, 1994, as cited in Chisholm, 2000, p.8). Intended outcomes, then, were to be the starting point, with the curriculum to be planned ñbackwardsò from there. OBE was also associated with a number of other paradigmatic shifts, notably a learner-centred activity-based approach to education, with continuous assessment, and conformed to the constructivist view of learning which had gained popularity in other parts of the world since the 1980s (Muller, 2000, and see Chapter 2 of this study). The resulting curriculum, known as Curriculum 2005 (C2005), embodied a radical constructivist approach to curriculum design (Taylor, 2001) and was characterised by a strong emphasis on learner-centredness and groupwork, with minimal prescription of knowledge content, and a surfeit of terminology to explain the new approach.

C2005 was phased into schools from 1998, but major problems at the levels of both its philosophy and its implementation prompted its review as early as 2000 (Chisholm, 2000). Among the findings of the Review Committee was that the curriculum was weak on conceptual coherence and progression due to the understipulation of content, sequencing and pacing requirements. The ironical consequence of the implementation of a curriculum intended to overturn the legacy of apartheid education was argued by many to be the reinforcement and even the exacerbation of inequalities (e.g. Allais, 2007; Muller, 2000; Taylor, 2001).

1.3.3 The RNCS, the NCS, and supplementary documents

Following the review of C2005 and subsequent consultations with stakeholders, a new document, the Revised National Curriculum Statement (RNCS) for Grades R-9 (DoE, 2002) became policy in 2002 (Chisholm, 2005). Meanwhile the ICS at the FET level (Grades 10-12) was replaced by the National Curriculum Statement (NCS) which became policy in 2003 and was implemented in Grade 10 in 2006.

The chief principles on which these curricula were based remained the promotion of social transformation via outcomes-based education (DoE, 2002, p.1; DoE, 2003, pp.1-4). The introduction to each curriculum began with quotations from the Preamble to the country’s new Constitution, which focus on democracy and social justice, while the principles on which the NCS is based are listed as including “social transformation” and “human rights, inclusivity, environmental and social justice” (DoE, 2003, p.1).

Subjects were organised around "Learning Outcomes" (LOs) and their related "Assessment Standards" (ASs), with content knowledge regarded as the vehicle to achieve these. While the LOs and their attendant ASs were explained in some detail, the actual content specifications were minimal, expressed in point form in very broad terms. In order to flesh out the detail, documents known as Learning Programme Guidelines (or LPGs) were produced and given in booklet form to educators who attended training workshops for the new curriculum. They included grade by grade elaborations of the content specifications in the form of a table, one column for each Learning Outcome, with broad suggestions for pacing. Updated versions of the LPGs were posted on the Department of Education's website from time to time.

Although they provided far more detail than did the curriculum document itself, the LPGs for life sciences were still problematic in that the guidelines under

LOs 1 and 3 were identical for each grade. Subsequently, other documents known as Assessment Syllabi (also termed Elaborated Syllabi[2]) were constructed by the subject advisors. These were issued as a national document for Grade 12, and as provincial documents for Grades 10 and 11. Some provinces developed and issued their own documents (e.g. the Western Cape), while others shared documents (e.g. Gauteng and KwaZulu-Natal).

The stated purpose of the ES was ñto provide clarity on the information provided in the Learning Programme Guideline document...to outline the scope and depth of what is to be learnt and assessedò(DoE, 2006, p.2). These documents were even more detailed than the LPGs, and included more specific guidelines for pacing of the material. Their layout differed markedly from that of both the NCS and the LPGs, however, in that it consisted of content headings with an elaboration of what should be covered under each topic only; the Learning Outcomes no longer featured at all.

1.3.4 The revision of the NCS for Life Sciences

Even before the NCS for life sciences was implemented, it had been met with criticism. Muller (2004b), for example, lamented that it remained problematic in its underspecification of the content material and the organising principles on which the content is based, as well as a lack of progression across grades, which he predicted would result in both knowledge and conceptual gaps. He concluded with the conjecture that ñthe cost [of these weaknesses in the NCS] é will be high, and the cost will be a breach of social justice for already disadvantaged learnersò(Muller, 2004b, p.10).

Dempster and Hugo (2006), arguing from the premise that the concept of evolution is the highest organising principle in biology, critiqued the way that the topic was introduced in both the RNCS for Natural Sciences and the NCS for Life Sciences. The authors maintained that, while the new curricula represented an improvement on the ICS, the way that evolution was presented in these curricula was seriously flawed, and cautioned that the curricula thus ñendanger[ed] the social justice imperative which frames the entire National Curriculum Statementò (p.106).

The publication of Dempster and Hugoõs paper acted as a catalyst for the commissioning of the revision of the content framework of the Life Sciences NCS (Doidge, Dempster, Crowe & Naidoo, 2008). The official reason cited for its revision was the underspecification of the content (DoE, 2007), though in their summary of the revision process Doidge et al. (2008) also mentioned "the excessive emphasis on human biology, and the marginalizing of plants and much of the animal kingdom" (p.17), as well as the fact that evolution was introduced only in Grade12. The revision was first published on the Department of Education website on 25 September 2007 and has been implemented for the first time in 2009, at Grade10 level.

1.4 A personal journey

My study began in 2005 as an attempt to relate hierarchy theory to the science of biology and its school version. This followed my introduction to the sociology of Basil Bernstein, in particular his theory of hierarchical knowledge structures and the recontextualisation of knowledge in schools (see Chapter 2). As a former biology teacher I had been challenged by the following: ñOne of the tragedies of education is to witness a teacher attempting to teach without the guidance of the higher concepts of her subject and craftò (Hugo, n.d., p.10), and set out to explore the structure of biology and what some of those higher concepts might be, first by studying some of the writings of the leading twentieth century biologist and theoretician Ernst Mayr, and then by examining the organisation of content in some tertiary foundational biology textbooks. This was the beginning of Chapter 3 of this study.

In considering the recontextualisation of academic to school biology in the South African context, my interest was provoked by two papers which criticised the blurring of boundaries between "everyday" and "school" knowledge (Taylor, 2001) and the lack of conceptual progression (Muller, 2004b) in the then current South African school curricula. I analysed the content specifications of both the RNCS for natural sciences (DoE, 2002) and the NCS for life sciences (DoE, 2003) in relation to these two aspects, and presented my results as a poster at the Kenton Education conference at Mpekweni in October 2005 (Appendix 1).

I followed this with an attempt to answer the broader question "How are decisions made regarding a school biology curriculum?" by means of a literature search into the changing objectives of a school science education (Chapter 4). In 2006 I attended an Umalusi workshop at which the curricula of three other African countries were compared with those in South Africa (*Evaluating syllabuses and examinations*, 2007). From my literature search I had devised five categories of objectives of a school science curriculum, which I then used to analyse the objectives of the four African curricula (unpublished data), and later the curricula in question in this study (Chapter 6). Subsequent to this Aikenhead's (2006) book *Science education for everyday life* became available; his categorisation of the various approaches to school science as conforming to either a traditional or a humanistic position provided additional, more powerful categories for my analysis.

In 2007 Christie and Martin's *Language, knowledge and pedagogy* was published, in which Maton and Muller deftly summarised Bernstein's "sociology for the transmission of knowledges", and included the tantalising challenge that "Relations between knowledge structures and their corresponding curriculum structures is, in short, a key area for future exploration" (p.28). I attempted this in a specific case, by comparing my own synthesis of Mayr's key higher ordering concepts of biodiversity and evolution with the way these topics were presented in the NCS for life sciences. By this stage the revised version of the NCS, the new NCS, had been publicised, so I included this new version, as well as the ICS, in my comparison, and presented my findings at Kenton at P[h]umula in October 2007 (Appendix 2).

2008 marked the first year that the Grade 12 component of the NCS for life sciences, which covered evolution, was taught and examined in South African schools. The incorporation of evolution in the curriculum had already provoked an outcry from the conservative religious component of South African society. Possibly in response to this Professor George Branch, Emeritus Professor of Zoology at the University of Cape Town, delivered a public lecture entitled "Teaching evolution: the myths and the magic", in which he set out his personal position as a Christian on studying and teaching evolution (see Branch, 2009). I was privileged to attend the lecture which took place in September 2008 at UCT, and to interview him afterwards. This provided additional material for Chapter 3.

This year (2009) sees the implementation of the third of the three post-apartheid versions of the life sciences curriculum, the new NCS, at Grade 10 level[3]. While my study was initially intended to focus only on the NCS, it has instead been forced to evolve along with its constantly-changing subject matter. In this section I have attempted to explain the stages, events and influences which constituted its evolution. They are drawn together under the major research question and three key sub-questions which are outlined below.

1.5 Key questions addressed by this study

My major research question may be formally expressed as follows: *How is biological knowledge transformed in a school curriculum?* It is addressed via the following three sub-questions:

1.5.1 What are some of the core integrating concepts within the academic discipline of biology, and how can they be conceptualised as a hierarchy?

1.5.2 What are the goals of a school biology curriculum?

1.5.3 To what extent has there been a change in the recontextualisation of biology as an hierarchical knowledge structure in the three life sciences curricula implemented in South Africa since 1994, and what are the implications of this for social justice?

1.6 Notes on methodology

There are three main components to my study, related to the three sub-questions I ask.

Firstly, to derive a set of core concepts and conceptual organisation in the parent discipline of biology, I studied a selection of the writings of biologist and biological philosopher Ernst Mayr. I followed this with an examination of the contents pages of two university textbooks, and interviews with two professors of biology. The rationale for my choice of authors and texts is provided in Chapter 3. This part of the study was largely inductive.

The question "What are the goals of a school biology curriculum?" was also handled inductively by means of a literature search for relevant studies in the field of science education and curriculum. I synthesised my findings to a set of five broad objectives, which I could then use to analyse the objectives of the South African curricula.

Finally, the question of the extent to which the three successive South African biology/life sciences curricula have shown a change in their recontextualisation of biological knowledge was handled by means of a deductive analysis of the curriculum policy documents themselves. The methods of analysis and empirical precedents to this part of the study are discussed in detail in Chapters 5 and 6.

1.7 Overview of the thesis

Chapter 2 presents the conceptual framework for the study. Here I discuss Bernstein's theories of the structure of knowledges, the pedagogic device, and knowledge recontextualisation, and draw connections between these concepts and the pursuit of social justice. I present Aikenhead's (2006) views on traditional versus humanistic approaches to school science. Finally, I outline Schmidt, Wang and McKnight's (2005) concept of curricular coherence, which suggests criteria for applying Bernstein's theories to a curriculum.

In Chapter 3 I consider the knowledge structure of the parent subject of biology using three sets of sources. By examining some the writings of Ernst Mayr and the organisation of content in two widely prescribed introductory biology university textbooks, and conducting interviews with two biology professors, I generate a tentative set of core concepts in biology, and a possible hierarchical arrangement for these.

In Chapter 4 I review some of the literature on the changing goals of a science/biology education worldwide, and ways of categorising these. I also highlight some recent studies related to South Africa's school biology curriculum.

Chapter 5 begins with some general comments about curriculum policy research, and considers some empirical precedents to the methodology of this study. In Chapter 6 I present an overview of the curriculum documents analysed, and the specific methods used and results obtained.

Chapter 7 serves to discuss and draw together my findings, and also considers the limitations and implications of the study.

NOTES

[1] also known as NATED 550

[2] which term I will use in this study, to avoid confusion with the Assessment Standards

[3] which, apparently, is about to be rewritten yet again (Edith Dempster pers. comm. 24 November 2009).

Chapter 2: Knowledge and the curriculum: conceptual underpinnings of the study

2.1 Introduction

This study broadly takes the form of an exploration of the changes that occur when the academic discipline of biology is transformed to its school equivalent in the curriculum, and considers specifically how this has been done in the three most recent versions of the South African school life sciences curricula. Theoretical concepts which informed my analysis were drawn initially from the writings of Basil Bernstein, in particular his conceptualisation of hierarchical knowledge structures, their recontextualisation in the curriculum, and the implications of this for social justice.

While Bernstein's concepts provided a framework, their generic nature limited their usefulness for my specific analyses. Aikenhead's (2006) distinction between traditional and humanistic science and Schmidt, Wang and McKnight's (2005) concept of curricular coherence served as tools for a finer scale of investigation, and will thus also be outlined here.

2.2 Bernstein's theory of knowledge structures and the recontextualisation of knowledge

2.2.1 Hierarchical and horizontal knowledge structures

In educational sociology the distinction is frequently made between school (or official, specialist, or formal) knowledge and everyday (or local, common-sense, or informal) knowledge. Bernstein (1996) traces the origins of this dichotomy to Emile Durkheim's (1915 [1976]) famous distinction between the sacred (or religious) and the profane (or everyday). The domain of the sacred is characterised by "arbitrary conceptual relations", and gives rise to knowledge which is generalisable, non-sensory and collective, while the domain of the profane is characterised by non-arbitrary 'sensual representations' and gives rise to knowledge which is particular, sensory and individual (Muller, 2001, p.132). The sacred domain can readily be identified with written forms of specialised knowledges, which are typically produced in official institutions of the state and the economy, in societies with complex divisions of labour. In essence, this equates to the knowledge which society considers worth transmitting in formal educational settings, such as schools and universities.

Bernstein (1996, 1999) aimed to differentiate between these types of knowledge even further via the descriptors 'horizontal discourse' and 'vertical discourse'. Horizontal discourse equates to everyday or 'common-sense' ('profane') knowledge, which is typically transmitted orally and is localised, context-specific and context-dependent. As an example, Bernstein suggested a conversation between smallholders in which strategies for improving production are exchanged. What is most significant about this form of discourse, according to Bernstein, is that it is segmentally organised or differentiated. In other words, the 'knowledges' that are acquired during horizontal discourse 'are related not by integration of their meanings by some co-ordinating principle, but through the functional relations of segments or contexts to the everyday life' (Bernstein, 1999, p.160). Horizontal discourse thus consists of 'culturally specialised segments', embedded in a specific context, and of particular relevance to the acquirer's everyday life.

Vertical discourse, by contrast, consists of 'specialised symbolic structures of explicit knowledge' (Bernstein, 1999, p.161), and is not organised segmentally or context-bound, but is concerned with context-independent meaning within an integrated knowledge system. Vertical discourse usually has a written form, and equates to the 'specialised' or 'school' knowledge[1] discussed above.

Within vertical discourse Bernstein distinguished between ñhorizontalò and ñhierarchicalò knowledge structures. Horizontal knowledge structures, exemplified by the social sciences and humanities, ñtake the form of a series of specialised languages with specialised modes of interrogation and specialised criteria for the production and circulation of textsò (Bernstein, 1999, p.159). Hierarchical knowledge structures, on the other hand, are ñcoherent, explicit and systematically principledò as well as being "hierarchically organisedò (ibid), and are exemplified by the natural sciences, including biology (1996; 1999). Figure 1 serves to clarify Bernsteinõs categorisation of knowledge.

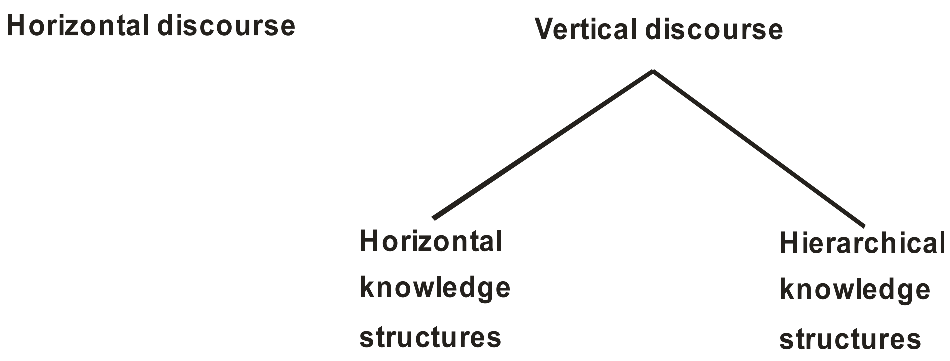


Figure 1 Bernsteinõs categorisation of knowledge

Bernstein elaborated on this further by writing that hierarchical knowledge structures

> [attempt] to create very general propositions and theories, which integrate knowledge at lower levels, and in this way [show] underlying uniformities across an expanding range of apparently different phenomena. Hierarchical knowledge structures appearé to be motivated towards greater and greater integrating propositions, operating at more and more abstract levelsé Development is seen as the development of theory, which is more general, more integrating, than previous theory (Bernstein, 1999, pp.162-163).

Hierarchical knowledge structures are thus shaped by “an internal logic… giving [them] a unity in terms of which new knowledge claims may be tested” (Christie, 2007, p.8). Bernstein represented hierarchical knowledge structures by means of a triangle [2], its pinnacle representing the general theories or propositions, and its base the phenomena which are integrated by these propositions (Figure 2; Bernstein, 1996). He added that there may be many such triangles, or hierarchies, in an hierarchical knowledge structure, and that “the motivation is towards triangles with the broadest base and the most powerful apex" (Bernstein, 1999, p.171). In other words, the general propositions or theories which are the most powerful are those under which the greatest amount of knowledge can be subsumed.

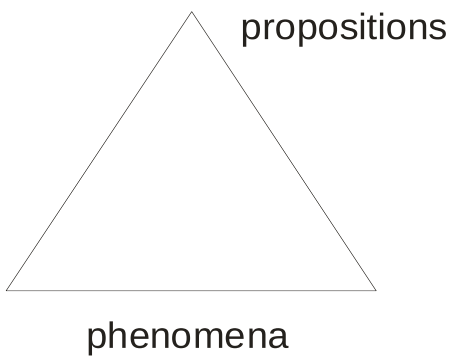


Figure 2 Bernstein’s depiction of an hierarchical knowledge structure (redrawn from Bernstein, 1996)

Other authors have elaborated on this concept, particularly in relation to the sciences. Muller (2007) introduced the term "verticality" (or “subsumption”) to describe how theory develops within hierarchical knowledge structures: "it develops through integration, towards ever more integrative or general propositions, the trajectory of development of which lends hierarchical knowledge structures a unitary convergent shape" (p.70). Muller pointed out that in 1973 Merton had encapsulated a similar concept with his use of the word “codification” by which he meant “the consolidation of empirical knowledge into succinct and interdependent theoretical formulations”, and noted that “the various sciences and specialities within them differ in the extent to which they are codifiedò (p.507, as quoted in Muller, 2007, p.69). In order to be inducted into strongly codified disciplines, students are required to grasp high-level propositions; into weakly codified disciplines, simply to learn ñmasses of particularsò (Muller, 2007, p.69).

In his discussion of the intellectual domains of science, Donnelly (2006) wrote of its ñanalytical, reductive, and universalizing tendency é to analyse the world into relatively simple, idealized, and delocalized elements, and then reintegrate these elements so as to understand more complex phenomenaò (p.627). While acknowledging that this may be characteristic of other forms of intellectual inquiry as well, Donnelly held that science is unique in its tendency to ñsubmerge specificities entirelyò (p.627) within universal truths.

Writing about science as an hierarchical knowledge structure, Martin (2007) described scientific taxonomies, for example classification in biology, as being ñrelatively comprehensive, deep and preciseò in comparison with those in other fields, or in everyday discourse, which he described as being ñrelatively piecemeal, shallow and fuzzyò (quotations from p.38). Here his focus is on hierarchy within the subject matter of biology, however, rather than the structure of the discipline itself.

O'Halloran (2007) considered the forms of science and mathematics, suggesting that both may in fact be a hybrid of hierarchical and horizontal knowledge structures, complementary to each other, while Schmidt et al. (2005) regarded science as being hierarchically structured, but less strictly so than mathematics.

While there appears therefore to be agreement in the literature that science conforms in the main part to Bernsteinôs conceptualisation of an hierarchical knowledge structure, none of these authors propose what the integrating high-level propositions or universal truths of biology might actually be. This then formed the basis for the first question of my study, which is *What are some of* *the core integrating concepts within the academic discipline of biology, and how can they be conceptualised as a hierarchy*? This is addressed in the next chapter.

2.2.2 The pedagogic device and the recontextualisation of knowledge

Towards the end of his life Bernstein asked questions about the relationship between knowledge structures and their equivalent educational forms, using the concept of the pedagogic device (Bernstein, 1996) to trace the way in which knowledge is transformed in educational settings. This theory has been usefully summarised by Maton and Muller (2007) and Bertram (2009) (see Table 1).

Table 1 A simplified representation of Bernstein's conceptualisation of the pedagogic device (adapted from Maton & Muller, 2007, p.18 and Bertram, 2009, p.48)

Field of practice	*Production*	*Recontextualisation: official recontextualising field (ORF) and pedagogic recontextualising field (PRF)*	*Reproduction*
Form of regulation	Distributive rules	Recontextualising rules	Evaluative rules
Kinds of symbolic structure	Knowledge structures (hierarchical and horizontal)	Curriculum	Pedagogy and evaluation
Typical agents	Academics	**ORF:** curriculum writers **PRF:** teacher trainers, textbook writers	Teachers, learners

Typical sites	Research papers, conferences, laboratories	**ORF:** curriculum policy **PRF:** textbooks, learning aids	Classrooms, examinations, assessment tasks

According to this concept, knowledge is generated in the field of production by specialists in the various disciplines, typically researchers and academics at universities. Within this intellectual arena, distributive rules govern the distribution of different forms of knowledge. These give rise to recontextualising rules which regulate the formation of pedagogic discourse within the recontextualising field. The recontextualising rules in turn give rise to evaluative rules, which constitute pedagogic transmission and acquisition in the field of reproduction, the schools.

Recontextualisation, then, involves the movement of knowledge from the primary context of the intellectual arena where knowledge is produced (sites of research such as universities), to the secondary context of the educational arena, where knowledge is reproduced (schools, colleges, etc.) (Bernstein, 1990). Bernstein distinguished between an "*official recontextualising field* (ORF), created and dominated by the state and its selected agents and ministries" - which includes the agents of curriculum construction - and a "*pedagogic recontextualising field* (PRF)" (Bernstein, 1996, p.48). In Bernstein's definition, the PRF "consists of pedagogues in schools and colleges, and departments of education, specialised journals, private research foundations" (Bernstein, 1996, p.48), while Bertram (2009) interpreted this to mean those who "take the official curriculum and recontextualise it as they train teachers, write textbooks or conduct research" (p. 52).

Due to the fact that knowledge undergoes a series of recontextualisations between production and reproduction, a school subject will not be an entirely true reflection of its parent knowledge structure. Bernstein stated that "pedagogic discourse is constructed by a recontextualising principle which selectively appropriates, relocates, refocuses and relates other discourses to constitute its own order. In this sense, pedagogic discourse can never be identified with any of the discourses it has recontextualised (Bernstein, 1996, p. 47).

This may seem an extreme view, but it does provoke the question of the extent to which a school subject reflects the knowledge structure from which it has been recontextualised (Maton & Muller, 2007), and provides the rationale behind the present study, which explores what happens to biology when it is recontextualised in the high school biology curriculum. This question has been addressed by Deng (2001) in relation to physical science, and Bertram (2008) in relation to history.

Bernstein also highlighted the fact that the process of recontextualisation is always influenced by ideological bias. "Every time a discourse moves," Bernstein wrote, "there is space for ideology to play" (Bernstein, 1996, p.24; see also Neves & Morais, 2001). In this way, he argued, the discourse acquires an invisible *perspective*[3], and questions such as "Whose perspective is it?", and "How is it generated and legitimated?" need to be asked. As the present study is concerned with the movement of biological knowledge from the field of production to the curriculum, the ideologies and priorities of the architects of the South African curricula would be pertinent here, but can be touched on only briefly in this study. The related influence of the socio-political *context*, both local and international, will, however, be considered.

2.3 The relevance of these concepts to the pursuit of social justice

At the heart of Bernstein's sociology was a concern for equity and social justice, and in particular the role of education in the reproduction of patterns of social injustices. Muller wrote that Bernstein's work was driven by "a sense of social justice and outrage at the continuing deformation of life chances by the pedagogic device" (Muller, 2004a, p.1). Thus his theories on knowledge structures and the recontextualisation of knowledge also embody a theory of social change, which will be outlined here. In tracing Bernstein’s argument it is first necessary to make reference to his theory of knowledge classification.

2.3.1 Knowledge classification and boundaries

Bernstein used the term “classification” to describe power relations between different discourses (Bernstein, 1996). According to him, strong classification means that there are clear boundaries between vertical and horizontal discourse and the knowledge mediated by each (i.e. formal versus everyday). In addition, a strongly classified knowledge system involves “a progression from concrete, local knowledge, to the mastery of simple operations, to more abstract general principles, which will be only available later in the transmission” (ibid, pp.25-6). Bernstein held that strongly classified knowledge is more highly valued by society (Hasan, 2004) and thus empowers those learners who are successfully inducted into its realm. He used the terms “recognition” and “realisation” to describe learners’ ability firstly to discern what is and is not relevant to a subject (recognition), and secondly to convey this accurately (realisation) (Bernstein, 1996). This suggests that the criteria for what does and does not belong within a subject must be made clear, or strongly classified, as weak classification will disempower learners.

Yet, as has been shown by Muller (2001), there are in fact two schools of thought regarding knowledge classification and boundaries: the first, espoused by Durkheim, Kant, and Simmel, amongst others (including Muller), affirms the necessity and value of boundaries - “Boundaries, or forms, are the precondition for meaningfulness. Without them, the immensity of the world would swamp life and render it a marsh of seamlessness and uncertainty” (Muller, 2001, p.129, after Simmel). By contrast, the second – the postmodernist view - holds that an *absence* of boundaries is the ideal (Jardine, 1999 and other references in Muller, 2001). A brief discussion of the postmodernist theory of constructivism is relevant here, as this theory, which has strongly influenced curriculum change in South Africa since the advent of democracy, results in the breakdown of the boundaries between formal and everyday knowledge, for reasons which will be explained below.

2.3.2 Constructivism and conceptual change theory

The theory of constructivism (a theory of learning), is based on the thinking that people construct their own meaning from what they experience. Thus for teaching to be effective, educators must first ascertain the learners' prior ideas about phenomena, which may then need to be developed, modified, or rejected (Bennett, 2003). Muller summarised the constructivist view as asserting that, seeing as all knowledge is unfoundable, all forms of knowledge and domains of meaning are equal – in other words, the boundaries between school and everyday knowledge are collapsed. Such forms of knowledge are then treated the same, and continuous with one another, as both have an arbitrary basis (Dowling, 1993; Muller, 2001). Using Bernstein's terminology, then, the constructivist approach represents weak classification of knowledge.

Constructivism has strongly influenced research into school science since the 1980s (see references in Bennett, 2003). In essence, the rise in constructivism has represented a pendulum swing from a narrowly positivist notion of science, that "science is a strictly logical procedure for pursuing truth by objectively observing the facts of nature" (Longbottom & Butler, 1998, p.481), to the extreme postmodernist view that "all knowledge claims are equally arbitrary" (ibid, p. 482).

Conceptual change theory, which has implications for science teaching, could be said to represent a middle road between a narrow positivist and extreme constructivist approach. In its earliest form, conceptual change theory attempted to explain the pedagogical and cognitive steps required to bring about change in children's intuitive, naïve understandings about science (Posner, Strike, Hewson, & Gertzog, 1982, in Davis, n.d.). As empirical studies revealed the resilience of learners' preconceptions about science, the theory was modified to take into account affective, social and contextual factors as well (Strike & Posner, 1992, in Davis, n.d.). In this sense conceptual change theory is constructivist, but it is directed towards a goal ï that of acceptable scientific thinking.

2.3.3 Applying Bernstein's sociology

Bernsteinôs concepts have served as valuable tools for studies in education worldwide (e.g. Moore, Arnot, Beck & Daniels 2006; Muller, Davies & Morais 2004; Muller & Gamble, in press; Neves & Morais 2001) and in South Africa (e.g. Bertram, 2008, 2009; Green & Naidoo, 2006; Hoadley, 2005; see also Fataar, 2006), particularly those concerning optimal pedagogies for the poor. Empirical findings have indicated that clearer, more explicit boundaries in the stipulations of the intended curriculum appear to be more beneficial to disadvantaged students (Muller & Gamble, in press). In other words, unless there is strong classification between formal and everyday knowledge in the curriculum, and the conceptual frameworks of school knowledge are coherently structured, their knowledge content clearly specified, and their requirements for sequencing met, learners from disadvantaged backgrounds are less likely to be able to access higher forms of knowledge.

This has been exemplified in post-apartheid South Africa, where constructivism has strongly informed the formulation of the new curricula (see Chapter 1 of this study). Curriculum 2005 (DoE, 1997) represented a paradigm shift from the positivist philosophy of pre-democratic days, known as ñfundamental pedagogicsò (Le Grange, 2008), to a radical constructivist approach by which it was seen as ñimperative to collapse the boundaries across subjects and between everyday and school knowledge in a bid to democratise and transform the education system, which was seen as too elite and too academicò (Bertram, 2008, p.132). The review of C2005 (Chisholm, 2000), however, revealed serious disparity between the purported aims of the curriculum and the actual effects on the learners, namely that differences of privilege were being entrenched, rather than reduced, by a curriculum which emphasised and elevated the learners' own life contexts and experiences, at the expense of clearly-stipulated content and concepts (Taylor, 2001).

2.4 The "everyday/school knowledge" dilemma, and Aikenhead's distinction between traditional and humanistic science

This is not to say that everyday knowledge has no place in the school context. Everyday knowledge, or to use Dowling's term, "public domain knowledge", in fact plays a crucial role in pedagogy as "it is the domain through which apprentices must enter the activity" (Dowling, 1993, p.136), or the means whereby learners "recognize themselves in the curriculum" (Taylor et al., 2003, p. 79). What matters is the type of everyday knowledge selected for inclusion, and the way it is used (Walkerdine, 1982, 1988, as cited in Taylor & Vinjevold, 1999). Hoadley (2005) showed how teachers in middle class schools managed successfully to recruit everyday knowledge to introduce new concepts, all the while keeping the everyday knowledge subordinate to the formal concepts. By contrast, in the working class schools of her study there was very weak classification between school and everyday knowledge, such that the latter predominated over conceptual knowledge. She speculated that this would seriously weaken the potential of the working-class schools to specialise the students' voice with respect to the reproduction of formal knowledge.

The term "everyday knowledge" is problematic in the case of a subject like science anyway; this is hinted at by Hasan (2004) in her comment that "it suggests that the line between, for example, scientific and everyday concepts is easy to draw; and I am not very certain that this is a viable proposition" (p.41). Many scientific concepts (such as temperature, nutrition, human physiology) could be argued to have both scientific and everyday relevance. Over the years a range of different terms have been proposed to delineate the formal/everyday knowledge dichotomy in science education (see Chapter 4);

the ones I selected for my analysis are the terms ñtraditionalò and ñhumanisticò as defined by Aikenhead (2006).

According to Aikenhead (2006), a traditional approach to science education is one which prioritises the teaching of canonical science content, with the view towards preparing capable students for further studies and careers in the fields of science or engineering. Content in the traditional curriculum is mostly abstract and decontextualised from everyday life, and students are expected to think and reason like scientists. Within this approach, ñscienceò refers to established, Western science only. This would equate to the formal school knowledge referred to above.

A humanistic approach to science education, while incorporating canonical science, is instead centred on the concept of *relevance* to studentsô everyday lives. Relevance may take the form of satisfying curiosity, everyday practical applications, or preparation for citizenship in a world increasingly shaped by science and technology. Moral reasoning and values are integral to humanistic science, and, as it is premised on the notion of *science as a human endeavour*, it includes learning about the history of science and scientists, and incorporates indigenous as well as Western science. In my analysis I will use the term ñhumanisticò in place of ñeverydayò knowledge, as the former clearly has broader connotations, more applicable to science education.

2.5 The concept of curriculum coherence

Finally, in applying Bernsteinian concepts to the curricula under scrutiny, I found the study by Schmidt, Wang and McKnight (2005) helpful. Their study was concerned with the quality of content standards in the United States[4], in particular those for mathematics and science, and while not referring to Bernstein, they utilised the concept of science as an hierarchical knowledge structure to guide their research.

In a previous paper (Schmidt et al., 1997, in ibid), the authors had decried what they termed the ñmile-wide inch-deep curriculumò- one in which the coverage of vast amounts of material takes priority above *depth* and *continuity*. They ascribed this all-inclusive characteristic to a process of curriculum construction in which political compromise, rather than *curricular coherence*, emerges as the organising principle.

In simple terms, according to the authors, curricular coherence can be taken to mean "sensible connections and co-ordination between the topics that students study in each subject within a grade and as they advance through the grades" (Newman et al., 2001, as cited in Schmidt et al., 2005). This is necessary to facilitate a proper *understanding* of the subject-matter. Taking understanding to mean ñto sense the simpler structure that underlies a range of instancesò(Bruner, 1995, as cited in Schmidt et al., 2005, p.528), Schmidt et al. (2005) then define a curriculum as coherent if it is ñarticulated over time as a sequence of topics and performances *consistent with the logical and, if appropriate, hierarchical nature of the disciplinary content from which the subject-matter derives*ò(p. 528, my emphasis). Thus a ñcoherentòcurriculum is one which makes visible to students ñan emerging and progressive senseò (p.528) of the inherent logical structure of its parent discipline.

The authors indicate that the implication of this, which can serve as a criterion for assessing the coherence of a curriculum, is that the subject matter should *progress* from particulars to the deeper structures which connect those particulars, or from descriptive to more theoretical and explanatory aspects, and that this progression should occur both within and across grades. New topics should not be introduced before the prerequisite knowledge has been covered, nor should material simply be repeated from grade to grade: *progression must supplant repetition*, and by so doing, ñrepresent a continuing penetration of the discipline moving to a deeper structureò(p.529). In Chapter

5 I describe how these concepts helped to provide a methodology for the analysis of the curricula.

2.6 Summary

This chapter has served to introduce the various theoretical concepts which helped to provide a language of description for my study. I began by outlining Bernstein's notion of types of knowledge structures, in particular hierarchical knowledge structures, of which biology is an example. Knowledge in an hierarchical knowledge structure builds upwards from the concrete and particular to ever more integrating and general propositions. When an hierarchical knowledge structure is transformed into a school subject, the knowledge is recontextualised during a series of processes, the first being the construction of the school curriculum. This is a selective process involving human agents with particular agendas, and the resulting curriculum will thus differ from its parent discipline. It has been argued the curriculum must nevertheless reflect the structure of the parent discipline to a reasonable degree, if the cause of social justice is to be upheld.

While formal knowledge needs to be strongly classified for students to be able to recognise what does and does not belong within a subject, the boundaries between formal and everyday knowledge are not always obvious in a subject like biology. More helpful terminology is provided by Aikenhead (2006) in his distinction between traditional and humanistic approaches to school science.

Lastly, Schmidt et al.'s (2005) concept of curricular coherence – the need for the material in a curriculum derived from an hierarchical knowledge structure to reflect the logical structure of the corresponding discipline - suggested criteria for measuring the coherence of the curricula in question.

NOTES

[1] While mainly concerned with the school context, Bernstein also extended this to relate to other contexts, for example doctor-patient, or lawyer-client. (Bernstein & Solomon, 1999).

[2] Muller (2001) described it as a pyramid, perhaps a richer metaphor in its suggestion of a greater volume of knowledge subsumed by the theory forming the apex.

[3] While Bernstein maintained that the concept of an ñinvisible perspectiveò is more applicable to horizontal knowledge structures, such as sociology, it may also apply in hierarchical knowledge structures when there is a choice between competing theories (such as the nature/nurture debate in biology), as the choice often has a social basis (Bernstein, 1999).

[4] Content standards could be said to equate to South Africaôs national curriculum, except that they act as recommendations rather than policy.

Chapter 3: Core concepts in biology

*"Science attempts to subsume the vast diversity of the phenomena and processes of nature under a much smaller number of explanatory principles" (*Mayr, 1982, p. 23).

3.1 Introduction

For the purposes of this study I am proceeding from the assumption that biology conforms to the notion of an hierarchical knowledge structure, *sensu* Bernstein; in other words, that knowledge in the discipline builds upwards towards a few abstract, integrating propositions or theories. In this chapter I consider the question *What are some of the core integrating concepts within the academic discipline of biology, and how can they be conceptualised as a hierarchy?*

In introducing his magnum opus *The structure of evolutionary theory* (2002), biologist Steven Jay Gould emphasised that the content of a scientific theory should be able to be expressed "as a *minimal list* of the *few defining attributes* of the theory's *central logic*" (p.10, Gould's emphases) – in other words, its "essence". My search for core concepts in biology is in a sense a search for the "essence" of the discipline of biology as a whole, a "minimal list of the few defining attributes of [biology's] central logic". This is obviously an ambitious project, given the limits of the dissertation. My intention was simply to develop, through a synthesis of my findings from a variety of sources, one possible set of concepts which could serve as a generative device to facilitate the analysis of the curricula under scrutiny.

Material for this part of the study was sourced from the writings of a theoretician in the field of production of biological knowledge, two tertiary level biology textbooks, and interviews with two biology professors. The rationales for my choices are given below. Before presenting my findings, however, I provide a brief sketch of the development of biology as an academic discipline.

3.2 The history of biology in the field of production: a brief sketch

Science can be defined as ña way of obtaining reliable information about the natural worldò (Moore, 1993, p.95), and ñlife sciencesò or biology is simply the science of life, or living organisms. The term ñbiologyò was coined only at the beginning of the nineteenth century, however, when the discipline started to emerge as a unified science (Magner, 1994).

Before the Scientific Revolution of the seventeenth century, the mysteries of the natural world were mostly ascribed to supernatural forces, though Greek philosophers such as Plato, Aristotle, Epicurus and others tried to find natural explanations through observation and rational thought. Along with the discovery of the universal laws of physics and mathematics during the Scientific Revolution, a philosophy known as ñphysicalismò developed. According to this the natural world was viewed mechanistically, and living organisms (with the exclusion of humans, who were believed to possess souls) were regarded as no more than machines, subject to the physical laws of the universe, and therefore no different from the inanimate world (Mayr, 1997).

Reacting strongly to this mechanistic view of the world, ñvitalistsò attempted to explain why the living world was unique, proposing a controlling ñvital forceò or ñlife forceò of some sort. A vitalist view prevailed till the early part of the twentieth century, and then collapsed, partly through an inability to prove the existence of a ñlife forceò, but also due to the rise of genetics and Darwinian thinking which together were able to provide solutions to the problems which had been explained by invoking this ñlife forceò (Mayr, 1997).

Biology initially existed in the form of numerous sub-disciplines, such as medicine (anatomy and physiology), botany (mainly the study of medicinal herbs) and natural history (generally linked to natural theology) (Mayr, 1982). The 18th century saw taxonomy flourish, as exploratory voyages led to an awareness of the enormous diversity of life and the concomitant description of thousands of new species. The 19th century, according to Mayr (1982), was “one of the most exciting periods in the history of biology” (p. 127) due to the rapid advances in many fields, such as embryology, cytology, physiology, organic chemistry and invertebrate zoology, and the increasing professionalisation of the discipline. But it was the major innovations in biological thinking in the 19th and 20th centuries, most notably the development of the theory of evolution, which led to the establishment of biology as a unified science.

Darwin's theory of evolution as expounded in his seminal work *On the origin of species by natural selection* (1859 [2004]) provided an explanation for the diversity of life, as well as a mechanism whereby this diversity could have arisen. It challenged the dominant religious thinking of the day by proposing that all beings, including humans, had evolved from a common ancestor (thus “dethroning man”) (Mayr, 1982, p. 508), and that the adaptation of organisms to their environment could be explained by natural selection (thus “dethroning God”) (ibid, p.510). Darwin's theory was strengthened by 20th century developments in the fields of genetics and biochemistry, in particular the discovery and description of DNA, which showed the chemical nature of both inheritance and variation and revealed that all living creatures are governed by the same genetic processes.

Modern theorists and philosophers of biology, such as Theodosius Dobzhansky, George Gaylord Simpson, Ernst Mayr, E.O. (Edward Osbourne) Wilson, Stephen Jay Gould and Michael T. Ghiselin, typically regard Darwin's theory of evolution by natural selection as the central unifying concept of the discipline. For the sake of feasibility I elected to consider some of the writings of just one of these, namely Ernst Mayr.

3.3 Core concepts and conceptual organisation of biology: a study of some of the works of Ernst Mayr

3.3.1 Rationale and biographical notes

Three main factors guided my selection of Mayr as the source within the field of production of biological knowledge from which to derive a sense of possible core concepts and conceptual organisation of the subject. Chief among these is that he is widely regarded as one of the worldôs leading evolutionary biologists, historians and philosophers of biology. According to Chung (2003), ñErnst Mayrôs contributions to evolutionary biology rightfully place him on any short list of the greatest evolutionary biologist of the twentieth centuryò (p.277). Similar descriptors - ñthe worldôs greatest living evolutionary biologistò (Stephen Jay Gould, quoted in Mayr 1997), ñone of the grand masters of twentieth-century biologyò (Edward O. Wilson, ibid), and ñnot only the greatest evolutionary biologist of the 20^{th} century, but even its greatest biologist overallò (Meyer, 2005) ï are not hard to find. Secondly, the clarity of his writing makes it not only authoritative, but also highly accessible. Thirdly, his views on biology helped to inform both the study (Dempster & Hugo, 2006) which acted as a catalyst for the rewriting of the NCS for life sciences, as well as the overview document which provided the thinking behind the construction of the new life sciences curriculum, and thus have a particular relevance to the present study.

Extensive biographical notes on Mayrôs life and contributions to biology are provided in obituaries by Meyer (2005) and Ruse (2005). In addition, his contributions to science according to (his own) categories of synthesiser, disseminator, compiler or cataloguer, analyst and innovator are evaluated by Provine (2005)[1]. Here I provide a brief summary of his life and influence.

Mayr was born in Germany in 1904 and moved to the United States in his twenties, working initially as a systematist at the American Museum of Natural History in New York. Here his exposure to variation in nature spawned an interest in evolutionary biology and, together with geneticist Theodosius Dobzhansky and paleontologist George Gaylord Simpson, he helped to develop what became known as "the evolutionary synthesis" or "neo-Darwinism". Essentially this served to integrate Darwin's theory of evolution by natural selection with the newer science of population genetics. With Dobzhansky Mayr developed the "biological species concept" which is still widely accepted as the most heuristic conceptualisation of this fundamental unit of biology (see for example Campbell & Reece, 2005, p.473, and Starr & Taggart, 2001, p. 298). His extensive research on bird taxonomy and biogeography led to his theories on geographic mechanisms of speciation, in particular the importance of allopatry and the "founder effect".

Mayr was pivotally involved in the "professionalisation" of the discipline of evolutionary biology in the middle of last century, establishing the Society for the Study of Evolution and serving as the first editor of its journal, *Evolution*. He was appointed Alexander Agassiz Professor of Zoology at Harvard University and curator of birds at the Museum of Comparative Zoology in 1953, where he made important contributions on the theory of systematics.

In the latter half of his life Mayr's writings focused on the history and philosophy of biology. His emphases were the autonomy of the subject as a science, the importance of an holistic, rather than a reductionistic approach to the life sciences, and the centrality of evolution. Mayr was a prolific writer, producing 25 books and almost 700 scientific papers. He died in 2005 at the age of 100.

Mayr certainly had, and still has his detractors (e.g. Mallett, 2008; Provine, 2005), and as an evolutionary biologist and more specifically a zoologist, his work shows a bias towards those fields. Nevertheless, I believe that as a biologist whose thinking was grounded in a lifetime's research in the subject, he serves as an acceptable source for my purposes.

3.3.2 Source material and methods

This part of the study was based on qualitative and inductive methods. I selected the following five of Mayr's works as source material, as they mostly deal with the whole field of biology, and by their largely philosophical nature could be expected to provide answers to the question of what concepts are core to the subject:

1) *The growth of biological thought: diversity, evolution and inheritance* (1982)
2) *Towards a new philosophy of biology: observations of an evolutionist* (1988)
3) *One long argument: Charles Darwin and the genesis of modern evolutionary thought* (1991)
4) *This is biology: the science of the living world* (1997)
5) *The Autonomy of Biology* (Walter Arndt Lecture, 2005)

The first three books deal chiefly with evolutionary biology. *The growth of biological thought* (1982), at 974 pages, is the longest of these works, and serves as an overview of the history of systematics, evolutionary biology, and genetics. It has been regarded as Mayr's "most important work" on the history and philosophy of biology (Meyer, 2005). In *Towards a new philosophy of biology: observations of an evolutionist* (1988) Mayr aimed to show that a balanced philosophy of science requires an incorporation of those aspects of biology which make it unique and autonomous from other sciences, and thus elaborated on these and other "problems" in the philosophy of biology. In *One long argument: Charles Darwin and the genesis of modern evolutionary thought* (1991) Mayr concentrated on the mechanisms of evolution and on the historical development of the major concepts and theories of evolutionary biology.

The latter two works deal with biology more broadly. In *This is biology* (1997) Mayr stated that his intention was to ñshed some lightò on the life sciences as a whole, and what the different disciplines within the subject have in common, to provide ña conceptual framework from which working biologists can attain [a] broader perspective on their specific research agendaò (p.xiv). He also aimed ñto help readers gain a better understanding of our place in the living world, and of our responsibility to the rest of natureö, and thus intended the book to be relevant to ñbiologists, physical scientists, philosophers, historians and others with a professional interest in the life sciencesö, as well as to ñevery educated personò (p.xv).

Finally, in his lecture ñThe Autonomy of Biologyò (delivered at the age of 100!) Mayr outlined the origins of the science of biology, and again summarised those characteristics of biology which make it an autonomous science, different from but on a par with other sciences.

In my study of the above works, I noted those biological concepts which were repeated frequently in all or most them and could thus be regarded as core to biology according to Mayr, or those which he specifically referred to as being ñcoreö, ñdominantö, ñindispensableö, ñimportantò or ñfundamentalò to the subject. I also looked for what he regarded as biologyøs organising principles.

3.3.3 Findings

Core concepts in biology

There is much repetition and reinforcement of Mayrøs conceptualisation of biology over the five works. A common theme in his writings is the autonomy of biology - that it is a unique science, on a par with what are often considered the "hard sciences" of physics and chemistry, though with fundamental differences. Clearly the most obvious difference is that biology deals with the living world, while physics and chemistry deal with the inanimate world. But another difference that Mayr stressed is that while much of the knowledge of physics and chemistry can be reduced to *laws*, biology is characterised more by *concepts*.

Laws in the physical sciences can be defined precisely; they are universal, enable deterministic predictions, and do not have exceptions. Biological concepts, by contrast, are abstract ideas which attempt to provide explanatory principles for phenomena in the living world. They are often restricted in time and space, they are more flexible than laws, and they are subject to change. Indeed, Mayr asserts that progress in biological science is largely a matter of the development of new concepts, the repeated refinement of the definitions by which these concepts are articulated, and the occasional elimination of erroneous concepts (Mayr, 1982).

Mayr does not provide a list of "core concepts in biology" as such. Based on my reading of the five reference works I studied, I compiled a list of nine related and often overlapping sets of concepts in biology, which, due to his frequent discussion of them, I believe is a fairly accurate representation of those Mayr regarded as most important. I summarise them very briefly below, in no particular order. Other important concepts included under each heading are italicised.

1. Life

Mayr took pains to assert that attempts at defining "life" are futile as "there is no special substance, object or force that can be identified with life", and that only the "process of living" can be defined (Mayr, 1982, p.53)[2]. In *This is Biology* (1997, pp.21-23) he does, however, list the following characteristics which distinguish living organisms from inanimate matter, which I paraphrase below:

- *Evolved programmes,* i.e. the genetic and somatic programmes which control the development, behaviour and other activities of living organisms, and which have evolved over millions of years
- *Chemical properties*, i.e. the possession of macromolecules, such as nucleic acids, peptides, enzymes and hormones, which are essential for the development and functioning of living organisms
- *Regulatory mechanisms,* i.e. the many mechanisms, such as multiple feedback mechanisms, which control and regulate living systems
- *Organisation,* i.e. the fact that living organisms are complex, ordered systems with the capacity for regulation
- *Teleonomic systems,* i.e. that living organisms have been adapted by natural selection, and are programmed for goal-directed activities throughout their development and adult life [3]
- *Limited size*, but composed of basic units ï cells and their components - which are very small and thus allow for developmental and evolutionary flexibility
- *Life cycles,* i.e. a definite sequence of developmental stages in sexually reproducing organisms, varying in complexity from species to species
- *Open systems,* i.e. energy must continuously be obtained from the environment and the waste products of metabolism eliminated. By being open systems, they are not subject to the law of entropy.

These properties in turn give living organisms the following unique capacities: to evolve, to self-replicate, to grow and differentiate according to a genetic programme, to metabolise, to self-regulate, to respond to stimuli, and to undergo change at the level of both the genotype and the phenotype. Many of these concepts are incorporated within the concepts listed below.

2. Evolution

To Mayr, "evolution took an honored and central place" in the life sciences (Ruse, 2005, p.627); or, to quote his own words, "If you don't accept evolution then most of the facts of biology just don't make sense" (*Ernst Mayr: What Evolution Is*, 2001). Evolution is evidenced by studying change in species over space *(*biogeography*)* and over time (via paleontology, the study of fossils*)*.

Mayr (1997) proposed that Darwin's theory of evolution was in fact a combination of five theories, namely:

1) The theory of *evolution as such*: organisms evolve steadily over time (*adaptation*, or vertical evolution)

2) The theory of *common descent*: different kinds of organisms are descended from a common ancestor (this is reflected in the Linnaean taxonomy)

3) The theory of *speciation*: species multiply over time (diversification, or horizontal evolution)

4) The theory of *gradualism*: evolution takes place through the gradual change of populations

5) The theory of *natural selection*: the mechanism whereby evolution takes place (includes concepts such as *competition* and *survival of the fittest*)

3. Complexity, hierarchy and emergence

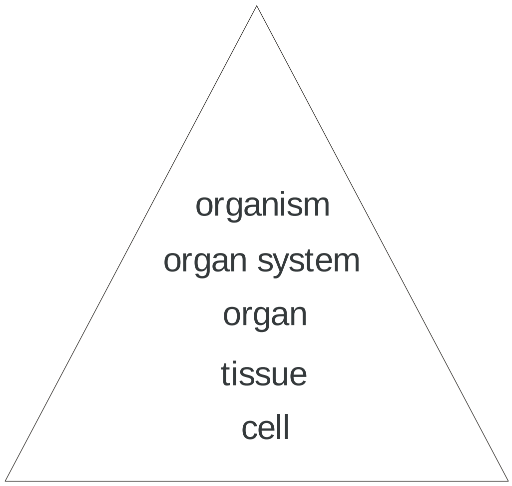
Most aspects of biology are characteristically complex, but this complexity is highly organised, and the organisation is often hierarchical. The classical example of this is the sequence *cell, tissue, organ, organ system, individual* making up the structure of multicellular organisms (Figure 3a). In this arrangement, which Mayr termed a *constitutive hierarchy*, the members of a lower hierarchical level are physically combined into new units at the next hierarchical level, with new unitary functions and emergent properties. In explaining emergence Mayr writes that “When two entities are combined at a higher level of integration, not all the properties of the new entity are necessarily a logical or predictable consequence of the properties of the components” (Mayr, 1988, p.34). In other words, it is not only the properties of the components of a system which determine the properties of the whole, but the arrangement and *interactions* of these components, which give rise to the emergent properties of living systems.

Biology recognizes hierarchy above the level of the individual as well, through *populations, communities, ecosystems, biomes,* and the *biosphere*, categories utilised as organising devices in the sub-discipline of ecology (Figure 3b). This sequence is typically included as an extension of the previous one, though it in fact differs on a number of counts. Here the members of lower levels are not physically combined to form higher levels, and emergent features tend to be more abstract. For example, a population of unicellular organisms will have different emergent properties from those of a group of cells combined to form a tissue (Valentine & May, 1996). In addition, above the level of the community, non-living components are included – the concepts of ecosystems, biomes and the biosphere all incorporate physical aspects such as soil and climate.

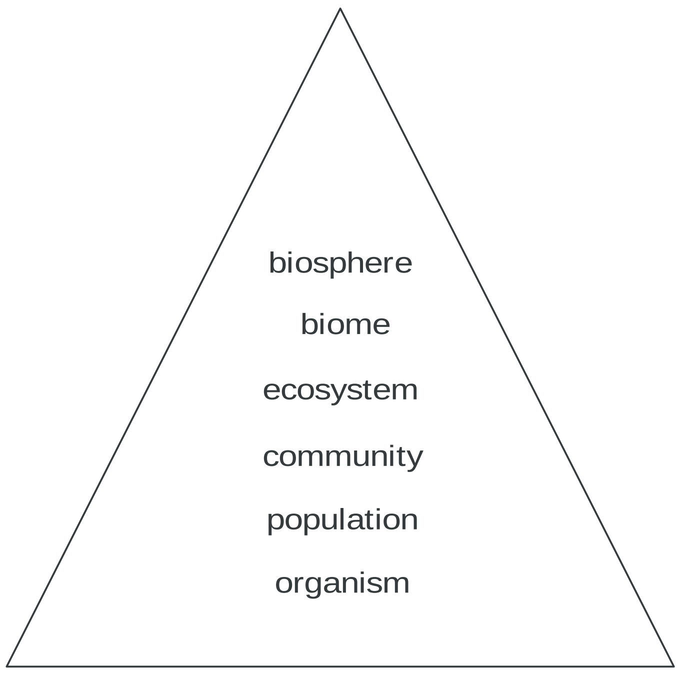
Within ecology, *energy flow* can be studied hierarchically through the demarcation of *trophic levels*. Green plants produce food via the process of *photosynthesis*; they are eaten by *herbivores (primary consumers)* which in turn are eaten by *carnivores (secondary and tertiary consumers)*. Finally all organic matter is broken down into its constituent parts by *decomposers*. Trophic levels can be represented by means of an *energy pyramid*, which portrays the diminishing flow of usable energy through an ecosystem (Starr & Taggart, 2001) (Figure 3c).

Another type of hierarchy is evident in classification systems, such as the Linnaean taxonomy of *species, genus, family, order, class, phylum,* and *kingdom* (Figure 3d). Mayr referred to this form of hierarchy as *aggregative*. Here the members of a lower level are grouped for convenience to form the next level; they do not interact with each other to form the higher levels, and thus higher levels have no emergent properties. There may be also be discontinuities in this form of hierarchy. However, according to Mayr, Darwin showed that hierarchical classifications such as these are not simply artificial constructs but in fact reflect common ancestry (Mayr, 1982, p. 210). Darwinõs theory of common descent is ñstrictly hierarchicalò (Mayr, 1988, p.479), and paleontology, which can be seen as the elucidation of common descent, also follows an hierarchical approach (see Valentine & May, 1996).

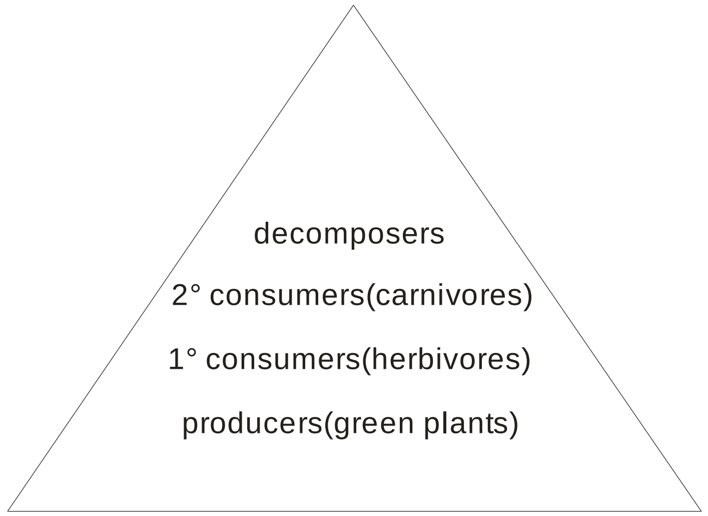
a)



b)


biosphere
biome
ecosystem
community
population
organism

c)


decomposers
2° consumers(carnivores)
1° consumers(herbivores)
producers(green plants)

d)

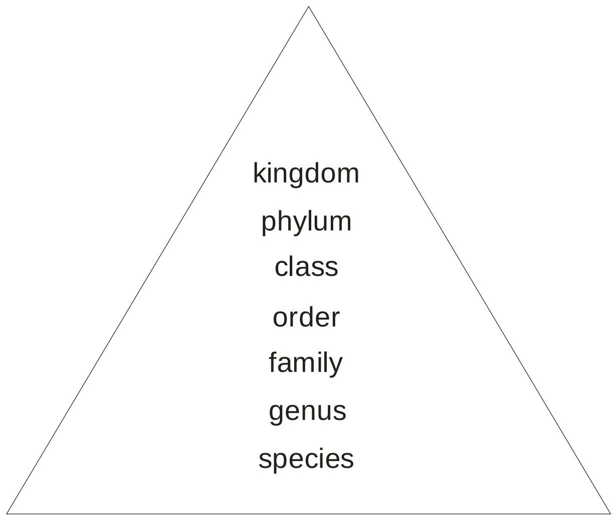


Figure 3 Four hierarchies within the subject matter of biology:
a) Levels of organisation within the body of a multicellular organism;
b) Levels of study within ecology; c) Trophic organisation in an ecosystem;
d) The Linnaean taxonomic hierarchy

4. Inheritance

Inheritance refers to the fact that the characteristics of parents are transmitted to their offspring via a highly evolved *genetic programme*, coded in DNA, which forms the *genotype* of the individual. The genotype directs the individualõs ontogeny, physiology and behaviour, and is physically manifested as its *phenotype*, or set of physical characteristics. ñThe possession of a genetic programme is the most fundamental difference between living organisms and inanimate matterò (Mayr, 1982, p. 630), and thus is a major unifying feature of biology.

5. Uniqueness, variability and biodiversity

While inheritance suggests constancy, the living world is characterised by variability. Units at every hierarchical level in biology ï from cells, through individual organisms, right through to ecosystems ï are unique. *Mutations*, which typically occur when the genetic programme replicates, provide the primary source of *genetic variation*. Further variation is introduced during sexual reproduction, thus the offspring of parents in sexually reproducing species are genetically unique. The uniqueness of individuals, and of the environmental pressures to which they are subjected during natural selection, results in an almost unlimited biodiversity, which Mayr regarded as the ñmost characteristic property of lifeò (Mayr, 1982, p.133).

6. Population and species concepts

The fact of variation among individuals is crucial to Mayrøs concept of the population, which he defined as a geographically circumscribed group of similar but unique individuals, where variation in characteristics is more important than averages.

In terms of species, Mayrøs view was that they are not simply a mental construct but the ñbasic kinds of living beings that make up the diversity of natureò (Mayr, 1982, p.296), and the basic unit of study in evolution, systematics, ecology and ethology. Together with Dobzhansky, Mayr devised the *biological species concept* which states that ña species is a reproductive community of populations, reproductively isolated from others, that occupies a specific niche in natureò (Mayr, 1982, p.273). This replaced earlier species concepts (e.g. the morphological species concept) by taking into account ecological, genetic, geographic and other factors as well, and emphasising the variation that can occur among members of a species (Chung, 2003). While this concept is limited in being more relevant to animals and less to plants and asexually reproducing organisms, and has been challenged in recent years (e.g. Mallett, 2008), it is still the most widely used definition of a species (Meyer, 2005).

7. Indeterminacy/unpredictability

Mayr frequently emphasised that predictions in biology are probabilistic rather than deterministic, due to the complexity of living systems, emergence at higher hierarchical levels, the significance of random events such as mutations, the uniqueness of individuals, and the role of chance in the effect of varying environmental conditions on different genotypes.

8. Interactions

Interactions occur at all levels of biological systems ï among genes, between genes and tissues, between cells and other components of the organism, between individual organisms, and between the individual and the environment. Mayr believed that ñthis interaction of parts gives nature as a wholeé its most pronounced characteristicsò (Mayr, 2005 p.7).

9. Proximate and ultimate causation

Mayr viewed biology as a series of problems about nature to be solved, and asserted that no problem in biology is fully solved until both its proximate and ultimate causes are determined (Mayr, 1982, p. 131). Proximate causation is concerned with answers as to *how* things happen in biology. In fields such as physiology, embryology and physiological genetics, proximate causes are those which explain how particular structures and processes operate within a biological entity, how they develop, and how they are inherited. In the field of ethology, proximate causes may be the environmental stimuli which trigger certain behaviours. Another way of understanding proximate causation is that it reflects the translation of the genetic programme of the organism into its phenotype. The main technique of study to answer proximate questions is experimentation, and results are typically quantitative.

The search for ultimate causation involves the asking of *“why”* questions, in other words it is the realm of evolutionary biology, dealing with evolution and inheritance. Here the interest lies in the historical acquisition of the genotype - the selection pressures which have changed the genetic programme of an individual over historical time. The main technique of study is via natural history ï the observation, description and comparison of organisms in their natural environment - following which ñhistorical narrativesò are constructed to try to explain the origins of observed phenomena (Mayr, 1997, p.64). Such study will therefore yield qualitative results.

Conceptual organisation of biology

Mayr initially regarded the distinction between proximate and ultimate causations as the best conceptual ordering device in the life sciences. Later he expanded on this when he suggested that the life sciences can be organised along the lines of ñthree big questionsò: *“What?”*, *“How?”* and *“Why?”* (Mayr, 1997, p.113ff).

ñWhat?ò questions are answered by means of description. Description of some sort is by necessity the first phase of all biological disciplines because it serves to ñ[establish] a solid factual basisé [through] recording the observations and findings on which theories are basedò (Mayr, 1997, p.113). Thus ñwhatò questions represent the fundamental beginnings of all studies in biology, but in particular the study of biodiversity, which is the chief focus of natural history, taxonomy, systematics and biogeography [4].

ñHow?ò questions are the realm of functional biology, in other words, the search for proximate causations. ñHowò questions are asked in sub-disciplines such as physiology, embryology, molecular biology, biochemistry, functional morphology, developmental biology, physiological genetics and some aspects of ecology and ethology, where the methods of research may include observation, experimentation and laboratory work.

"Why?" questions deal with ultimate causations, the evolutionary explanations for phenomena in the life sciences, which includes the origin and history of genetic programmes, and the selective advantage of characteristics. Evolutionary biology, transmission genetics, comparative morphology, and certain aspects of ecology and ethology are concerned with "why" questions.

3.3.4 Limitations of the method

The study of Mayr's writings aimed to derive one possible set of answers from the field of production of biological knowledge to the question posed at the start of the chapter. The validity of the findings depends partly on the validity of the choice of Mayr as a source, and this could be challenged on a number of grounds. Mayr was primarily a systematist and evolutionary biologist, and three of the books I studied (Mayr, 1982; 1988; 1991) had these topics as their main focus. This would fit into Mayr's domain of "ultimate causations"; very little of the domain of "proximate causations" (functional/ physiological and developmental biology) was covered in the works I studied. As Mayr himself asserted, a full understanding of biological phenomena must take both domains into account, and thus one would have to refer to other sources which deal more with functional biology to have a more complete coverage of the subject. In addition, some of Mayr's theories, especially those related to species definitions and speciation have recently been challenged (e.g. Mallett, 2008).

In terms of its usefulness as a reference for a school biology curriculum, the list is also limited, perhaps, in the abstract and complex nature of some of his terms, such as *proximate and ultimate causation, indeterminancy*, and *population* and *species* concepts. These represent the culmination of decades of thought by some of the world's most brilliant scientists and philosophers, and may simply be too intellectually challenging for most school students, many of whom may not yet have the ability to understand abstract ideas even by the senior grades (see Bennett, 2003, p.59).

In order to move from the field of production to the official recontextualising field of the school curriculum, then, a connecting device (or "logical spanner") was required. To this end I followed a precedent set by Deng (2001) who, in a study on the distinction between key ideas in teaching high school science (in this case physics) and those in the corresponding discipline of science, defined key ideas in physics as being those "concepts or principles that a physics major would concentrate on learning in courses offered by the department of physics" (p.264). These he determined from a study of two science textbooks prescribed for students majoring in physics, asserting, after Kuhn (1970, as cited in Deng, 2001), that current textbooks represent the "authoritative source" for the fundamental concepts and principles which scientists need to know.

I studied two biology textbooks which are widely prescribed in both national[5] and international tertiary institutions, namely *Biology: The Unity and Diversity of Life* (9th edition) (Starr & Taggart, 2001) and *Biology* (7th edition) (Campbell & Reece, 2005). Firstly I summarised Campbell and Reece's "eleven themes that unify biology" (p.27), following which I examined the organisation of content material in the list of contents in both books, as well as their use of key concepts in introducing each chapter.

3.4 Core concepts and conceptual organisation of biology according to two commonly prescribed general biology textbooks

3.4.1 Unifying themes in biology

In their first chapter Campbell and Reece (2005) list eleven themes that ñpervade all of biologyò(p.26-27), which are summarised below. They propose that these can help students ñdevelop a coherent view of lifeé ways of thinking about life that will still apply decades from now, when much of the specific information é in any textbook will be obsoleteò. As such they correlate to core integrating concepts of biology, which are the subject of this chapter.

Eleven themes that unify biology (Campbell & Reece, 2005, p.27)

1. The cell
2. Heritable information
3. Emergent properties of biological systems
4. Regulation
5. Interaction with the environment (living and non-living)
6. Energy and life
7. Unity and diversity
8. Evolution
9. Structure and function
10. Scientific enquiry
11. Science, technology and society

3.4.2 Organisation of content material

The contents of Starr & Taggart are divided into an introduction and seven sections, while the contents of Campbell & Reece are divided into an introduction and eight sections. The names of each section, and the chronology, are remarkably similar, as shown in Table 2 below.

Table 2 Comparison of organisation of topics in *Biology: The Unity and Diversity of Life*, 9th Edition (Starr & Taggart, 2001) with that in *Biology*, 7th edition (Campbell & Reece, 2005)

CAMPBELL AND REECE	*STARR AND TAGGART*
Introduction: Exploring life	Introduction: concepts and methods in biology
1. The chemistry of life	1. Principles of cellular life
2. The cell	
3. Genetics	2. Principles of inheritance
4. Mechanisms of evolution	3. Principles of evolution
5. The evolutionary history of biological diversity	4. Evolution and biodiversity
6. Plant form and function	5. Plant structure and function
7. Animal form and function	6. Animal structure and function
8. Ecology	7. Ecology and behavior

It is noteworthy that both books arrange the topics in exactly the same hierarchical order, beginning with chemistry, and continuing through cells, to whole organisms and finally to ecosystems. This is acknowledged by Starr and Taggart in their statement that ñThis conceptual organization parallels the levels of biological organizationò (p.xxii). Campbell and Reece add that

> é we realize that there is no one ñcorrectò sequence of topics for a general biology course. Though a biology textbookõs table of contents

must be linear, *biology itself is more like a web of related concepts without a fixed starting point or a prescribed path.* (Campbell & Reece, 2005, p.ix, my emphasis)

and make the suggestion that courses could just as easily start with “molecules and cells, with evolution and the diversity of organisms, or with the big-picture ideas of ecology” (p.ix).

The role of key concepts

In their preface Campbell and Reece (2005) discuss in some detail their belief in the importance of a “careful unfolding of conceptual content”, using examples to “reinforce rather than obscure the conceptual framework” (p.ix). Both textbooks make use of “key concepts” at the start of each chapter, their purpose being to act as a “framework… that will help students keep the details in place” (Campbell & Reece, 2005, p.iv) , or, put differently, as “the chapter’s advance organizer” (Starr & Taggart, 2001, p.xxiii).

In Campbell and Reece the concepts take on the form of brief sentences. These serve to elaborate on a word concept, for example “Biological systems are much more than the sum of their parts” (p.2) (the concept of emergence); describe a structure, for example “Cellular membranes are fluid mosaics of lipids and proteins” (p.124); summarise a process, for example “The main stages of food processing are ingestion, digestion, absorption and elimination” (p.844), or other variations.

In the case of Starr and Taggart the concepts take on the form of brief explanatory paragraphs, for example:

> Cells engage in metabolism, or chemical work. That is, they use energy to stockpile, build, rearrange and break apart substances. Cells also use energy for mechanical work, as when they move cell

structures such as flagella. They also channel energy into electrochemical work, as when they move charged substances into or out of the cytoplasm or an organelle compartment (Starr &Taggart, 2001, p.95).

In this example a variety of techniques are used, such as the simple definition of a biological term ("metabolism, or chemical work"); listing processes, such as "they use energy to stockpile, build, rearrange and break apart substances"; and giving examples of types of work (mechanical and electrochemical). This technique of organising each chapter is hierarchical in that each concept triggers a set of relevant information.

3.5 Core concepts in biology according to two biology professors

A third source of answers to the question posed in this chapter was two practising professors of biology, each with more than three decades of teaching and research experience: Professor George Branch (Subject A), Emeritus Professor of Zoology at the University of Cape Town, and Professor Lawrence Harder (Subject B), Department of Biological Sciences, University of Calgary, Canada. I asked each subject the question, "If I had to ask you to list about ten core concepts or integrating principles of biology, what would your list comprise?" In the case of Prof. Branch, the question was posed during an interview, while in the case of Prof. Harder, the question was given in an email, but with the enjoinder that it should be answered more or less spontaneously. Their responses are listed below.

<u>Subject A:</u>

1 evolution
2. trophic organisation (linked with energy flow)
3. cell concept
4. genetics/inheritance
5. physiology (including regulation and homeostasis)

6. comparative morphology
7. biogeography (incorporating diversity)
8. embryology
9. interaction (competition, predation, co-operation)

<u>Subject B:</u>

1. evolution (especially by natural selection)
2. the cell as the essential unit of life (ignoring viruses)
3. DNA as the code of life (including mutation as the source of genetic variation)
4. photosynthesis as the source of energy for life
5. metabolism as the engine for life
6. homeostasis keeping life in balance
7. sex and replication and the maintenance of diversity
8. competition/mutualism and life in limited environments
9. predation and the organisation of energy and matter flows
10. extinction as the fate of all species

3.6 Summary of findings: core concepts in biology and how they can be conceptualised as a hierarchy

My study as a whole is an examination of the movement of biological knowledge from the field of production of knowledge to the official recontextualising field of the school curriculum. This chapter represents an attempt to find answers to the question *What are some of the core integrating concepts within biology, and how can they be conceptualised as a hierarchy?* Answers were sought from three sources: the writings of a world-renowned theoretician of biology, two university textbooks, and two practising biologists. The lists derived from each source are not directly comparable, in that the two biologists were expected to give almost immediate and hence unprepared answers, while the written sources would have been prepared and peer-reviewed over an extended period of time. Despite this fact, there was considerable overlap, with all sources in agreement that the following seven concepts - *the cell, inheritance, evolution, interactions*, *regulation, energy flow* and *diversity* - at least, are integral to the discipline of biology, while the concepts of *hierarchical organisation* and *emergence* were also highlighted by Mayr and the textbooks.

Conceptual organising devices were proposed by Mayr and suggested by the sequence of topics covered in the textbooks. The textbooks followed an hierarchical approach, from the smallest to the largest levels of biological significance (biochemistry to ecology). Mayr held that biology is structured according to ñwhatò, ñhowò and ñwhyò questions, which equate broadly to issues of biodiversity, structure in relation to functioning, and evolution, respectively. If one were to utilize this device to organise biological knowledge as a hierarchy, ñwhatò questions would form the base of the knowledge triangle as the descriptive knowledge thus generated is concrete and particular, providing a solid factual basis for the development of theories. ñHowò questions, the realm of functional biology, would occupy the centre of the triangle; these go beyond descriptions of organisms and structures to the explication of processes in living systems. ñWhyò questions, which search for ultimate causation or historical and evolutionary causes of phenomena, would occupy the apex of the knowledge triangle, as they serve to unite all the knowledge of the subject under the most general and abstract principle, that of evolution. In Figure 4 I have arranged the seven core concepts listed above according to Mayrôs three questions.

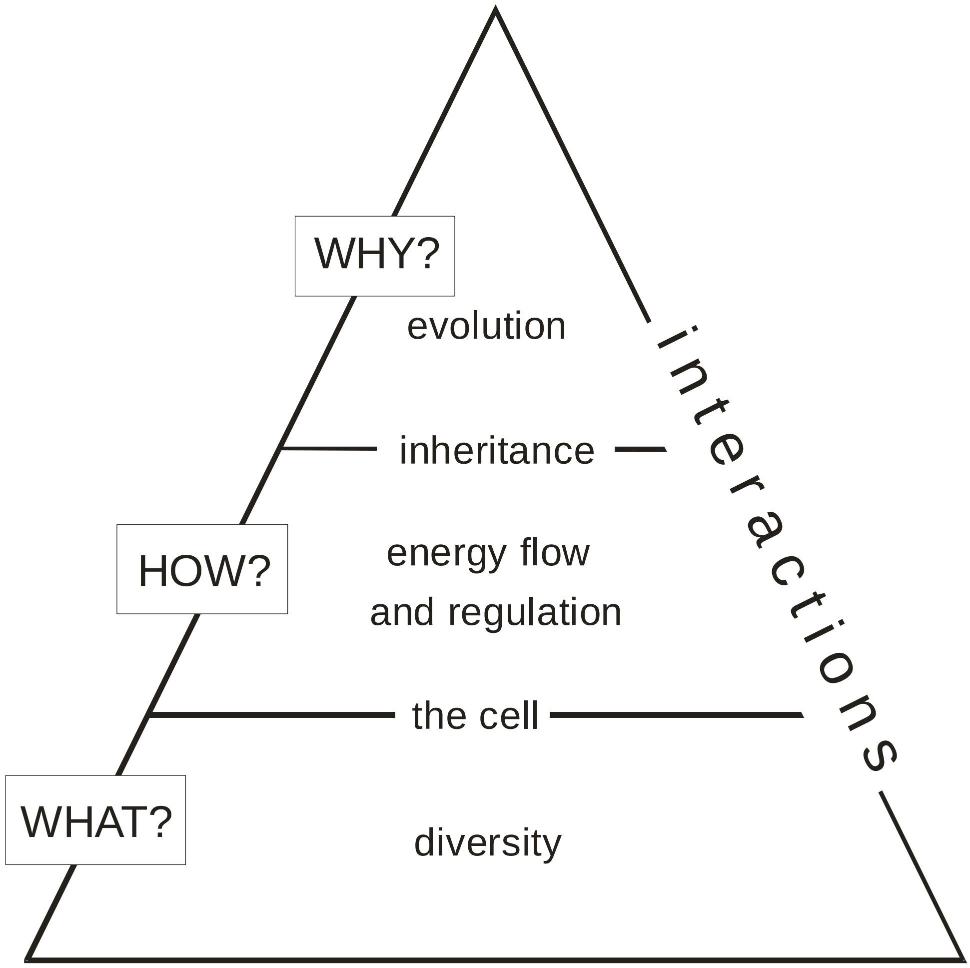


Figure 4 Schematic representation of a possible hierarchical arrangement of seven core concepts in biology

In this scheme Mayr's categories of “what”, “how” and “why” are used to divide the knowledge triangle horizontally. The lower levels represent more concrete knowledge, which becomes more abstract in higher levels.

Diversity forms the lowest, broadest level as it encompasses all living organisms, both past and present, the description of which forms the foundation of all other studies in biology. *The cell*, as the basic unit of life, is included next, straddling categories “what” and “how”, as the topic can be studied in relation to the diversity of cells, as well as their structure and functioning. *Regulation*, which characterises metabolism and serves as a unifying concept within physiology, is placed within the “how” category.

Metabolism requires energy; this is transferred from the sun through plants, herbivores, carnivores and omnivores, and finally decomposers; the study of *energy flow* through an ecosystem is also included in the ñhowò category.

Inheritance straddles the ñhowò and ñwhyò levels ï functional genetics (e.g. protein synthesis) is essentially physiological, while transmission (classical Mendelian) genetics relates to issues of evolutionary significance. *Evolution* forms the apex of the knowledge triangle; in drawing together all sub-disciplines of biology and demonstrating the historical development of life, it unites all aspects of the subject. Finally, because *interactions* occur at all levels of biology, as well as between living organisms and the non-living environment, this concept is placed along the side of the triangle.

3.7 Conclusion

This chapter has been concerned with the elucidation of a set of concepts which could be regarded as core to the academic discipline of biology, as well as a means of organising them, in order to facilitate the latter part of the study which aims to consider how closely the contents of the recent South African life sciences curricula reflect their parent subject.

Before turning to the curricula themselves, however, I take, in the following chapter, a broad historical overview of some of the factors that have influenced the recontextualisation of biology into the school curriculum worldwide.

NOTES

[1] This evaluation is not entirely complimentary to Mayr, but is in turn assessed and critiqued by Futuyma (2006).

[2] This follows a discussion on the rise and fall of the nineteenth-century philosophy of "vitalism", which proposed the existence of a ñvital forceò or ñlife forceò which controlled the workings of living beings.

[3] As opposed to *teleological,* i.e. purposeful or deterministic, which Mayr asserts, and Donnelly (2006) reaffirms, is not a characteristic of the natural world.

[4] *Taxonomy* refers simply to the basic descriptions and classification of organisms, while *systematics,* which incorporates taxonomy, is the study of the evolutionary relationships among organisms. *Biogeography* is the study and description of the geographic patterns of distribution of plants and animals

[5] In South Africa in 2007, Starr and Taggart was prescribed at first year level at the Universities of KwaZulu-Natal and the Free State, and Campbell and Reece at the Universities of Cape Town and the Witwatersrand.

CHAPTER 4: The official recontextualising field: the goals of a school biology curriculum

"It might plausibly be argued that natural science is the most revised of established curricular areas, at least in respect of proposals for reform" (Donnelly, 2006, p.623).

4.1 Introduction

My study is concerned with how formal biological knowledge is transformed when it is recontextualised in the school curriculum. The previous chapter considered the conceptual structure of biology as an academic discipline; in this chapter I turn to biology as a school subject[1]. There is a vast and ever-expanding body of writing on science in the school curriculum; this chapter represents a brief survey of some of this literature, in which I focus on the objectives for the subject and how these have changed over time.

I begin by noting the reasons for the frequent revision of science curricula, and then derive a simple categorisation of its objectives. I mention how the nature and prominence of these objectives have shifted over the years, typically between more "pure" and more "applied" science, and show how Aikenhead's (2006) distinction between a "traditional" and "humanistic" approach to school science effectively captures this dichotomy. I conclude with a brief discussion of the extent to which recent literature about the goals for biology as a subject in the South African school curriculum has reflected international trends.

4.2 Science curriculum revision

The history of science education in the developed world has been discussed by various authors, including Goodson (1983), Rosenthal and Bybee (1987), Goodson and Dowbiggin (1993), Atkin and Black (2003), and Le Grange (2008). The question of what science ï or *whose* science - children ought to be taught in school forms a frequent refrain (e.g. Aikenhead, 2006; MacDonald, 2003; Zembylas, 2005). The answer is informed by what are perceived to be the goals of a science education, but such goals are by no means cast in stone, and have been debated almost continuously since the inception of science as a school subject in the late nineteenth century (Aikenhead, 2006; Bybee, 1977). In considering the question ñWhat counts as science education?ò, Roberts (1988) concluded that ñthe answer is a defensible decision, rather than a theoretically determined solutionò (p.30), because the goals for a school science education are determined by numerous factors, including the historical, political, economic and sociological context, the agents responsible for drawing up the curriculum, and any stakeholders or interest groups - none of which is static.

The consequence, as observed by Donnelly (2006), is that science as a school subject is arguably the ñmost revised of established curricular areasò (p.623). Reasons given for the frequent revision of the subject are multiple. Ideally, curricula would be revised to keep pace with advances in scientific knowledge (Hurd, 2000), though in reality this is often substantially delayed (Rosenthal & Bybee, 1987). Revision more typically occurs in response to concerns on the part of the state, higher education institutions, teachers or the public about studentsô poor performance in the subject, either in national examinations or in international comparative tests such as TIMSS (Adler, 2006; Valverde, 2005). It may be provoked by dissatisfaction regarding the present curriculumôs ability to prepare students adequately for tertiary studies and future careers (BouJaoude, 2002), or for citizenship in an increasingly scientifically- and technologically-orientated society (Hurd, 2000; Ogunniyi, 1986). Curricular revision may also reflect concerns about declining numbers of students opting for science courses at a secondary or tertiary level, and the intention may chiefly be to increase student interest in and hence selection of the subject (Bennett, 2003; Hall, Reiss, Rowell, & Scott, 2003). Sometimes the curriculum is seen to be problematic from a sociological perspective, in disadvantaging girls or minority groups (Eisenhart et al., 1996, in Zembylas, 2005; Ministry of Education, New Zealand, 1997; Sjøberg & Imsen, 1988).

Curricula are also typically revised when the socio-political landscape changes (e.g. Barberá, Zanón & Pérez-Plá, 1999; Neves & Morais, 2001). Historically, the socio-political context in which science curriculum revision takes place has been highly significant, from increasing urbanisation at the turn of last century (Atkin & Black, 2003), to reaction to the launch of Sputnik in 1957 (Dede & Hardin, 1973; Saadeh, 1973), to economic recession in the 1970s (Bybee, 1977). New contexts typically result in a reassessment of the goals and purpose for which children should study science. Within each particular context, the aims of the curriculum itself are largely determined by the agents of its construction, who may be professional scientists, university researchers or educators, school teachers, or textbook writers.

The process is further influenced by stakeholders (Roberts, 1988), for example government, parent bodies, and special interest groupings such as religious organisations. A fascinating exploration of this was provided by Barberá et al. (1999), who examined the forces that shaped biology curriculum construction in Spain during the twentieth century, and were able to show how the political, social and religious beliefs of the prevailing powerful social groups influenced the inclusion or exclusion of socially controversial biological issues in the curriculum.

4.3 General objectives of a school science curriculum

There have been many attempts over the years to summarize and categorize the goals (or ñemphasesò ï see Roberts, 1982) of a school science or specifically biology education (e.g. BouJaoude, 2002; Bybee, 1977; DeBoer, 2000; Fensham, 1997 in Fensham, 2000; Ogden & Jackson, 1978; Roberts, 1982, 1988; Rosenthal & Bybee, 1987). Goals typically fall into one of the following five broad categories: *knowledge*, *skills*, *applications, attitudes and values*, and *science as a human enterprise*. Table 3 lists the kinds of topics which could be included in each category.

Table 3 The main objectives of a Western school science education

Category	*Elaboration*
Knowledge	scientific facts, concepts, generalisations, principles, hypotheses, theories and laws, answering the question ñWhat do scientists know?ò (Bybee, 1977, p.86); preparation for future studies and careers in the sciences. [2]
Skills	includes those skills, abilities, methods, techniques and processes specifically concerned with the study of science, answering the question, ñWhat do scientists do?ò (Bybee, 1977, p.86), for example skills associated with doing scientific investigations, such as observation, hypothesis formation, data collection and processing, laboratory procedures, and the communication of scientific findings; ñdeveloping the capacity to do researchò (Ogden & Jackson, 1978, p.293); as well as generic skills such as critical thinking and problem solving, communication and co-operation. [3]
Applications	understanding and solving problems regarding the scientific or technological aspects of daily life; science as a means for solving problems in society and the environment, as well as the limits of science in solving problems, and the potential for the applications of science and technology to harm the individual and the environment.
Attitudes and	incorporates what are considered to be ñscientificò attitudes and values such as objectivity, respect for evidence, critical thinking, openness, honesty and

values	so forth, but also the fostering of positive attitudes towards the subject, aesthetic appeal, satisfying curiosity, promoting appreciation and respect for nature; ethics. [4]
Science as a human enterprise	the nature of science; how science functions as an intellectual enterprise; science as a means of generating knowledge about the world; the nature of evidence and the relationship between evidence and theory; the tentative, changing and self-correcting nature of science; the history of science and scientific discoveries; science as a product of human endeavour, a part of our intellectual heritage (DeBoer, 2000); the dichotomy between "Western modern science" and "indigenous knowledge"; different worldviews; social, political and religious influences on science; multiculturalism; different interpretations of phenomena by different cultural and religious groups, including the creation-evolution debate; biases.

4.4 Shifts in priorities

The relative prominence of these goals has varied over time. Some authors have noted how this can be represented in broad terms as a pendulum swing between the extremes of "pure" and "applied" science, calling to mind Durkheim's notions of "sacred" and "profane", or Bernstein's "formal" and "everyday" knowledge (see discussion in Chapter 2). In other words, is the chief purpose of a science curriculum to teach canonical scientific knowledge[5], or is it to explore how science relates to humans as individuals and in society? Must the curriculum focus on preparing a select group of students for future studies and careers in the sciences (a "science for future scientists" approach), or preparing all students for future life (a "science for future citizens" approach) (Bennett, 2003)?

Rosenthal and Bybee (1987), writing about the early (pre-World War II) history of biology as a school subject in the United States of America, referred to the two alternative approaches as "a science of life" (emphasising knowledge) and "a science of living" (emphasising personal and social needs). They showed that the two goals have existed from the earliest days of biology's history, sometimes in opposition but other times in parallel, quoting authors such as Finley (1926) who wrote that óthe aim in biology teachingé changed from ñbiology for the sake of biologyò to ñbiology in relation to human welfareòô, and Linville (1910) who wrote that ñBesides teaching people how to think, we need to teach them how to liveò (as quoted in Rosenthal & Bybee, 1987, p. 135). Similarly Goodson (1983), tracing the historical background of biology as a school subject in the United Kingdom, wrote that until it was able to exhibit the ñdual characteristicsò of both ñintrinsic valueé as a disciplinary trainingò and ñutilitarian potentialò (p.43), the capacity of the subject to gain a place in the school curriculum was limited. In the section that follows I highlight a few key movements within the more recent history of science curriculum reform, in order to illustrate trends in how the various objectives have been prioritised.

The Soviet launch of Sputnik I in 1957 (see Dede & Hardin, 1973; Saadeh, 1973), for example, precipitated science curriculum reform in the USA in the 1960s that was geared towards an elite minority of students who would continue their studies and careers in science (a *science for future scientists* approach). Professional scientists had the monopoly on the development of curricula, which became characterised by their highly academic nature and emphasis on laboratory procedures. The new curricula were strongly criticised, however, as being too tightly prescribed and too difficult, and for overemphasising the subject such that the needs of pupils and society were ignored (Dede & Hardin, 1973).

In contrast to this approach, the *science for all* movement arose in the 1980s. This called for science to occupy a central role in the curriculum for all the years of schooling, and have a content which was relevant and accessible to all students, most of whom would not go on to study science at a tertiary level (Fensham, 2000). The concept of ñscience for allò has remained popular, with Bennett (2003) suggesting that

> the 'science for all' of the 2000s should be one which places less emphasis on the facts and theories of science, and more on how scientific knowledge is applied and how decisions are reached about what could and should be done with the knowledge (p. 20).

In addition, as awareness of the impact of science and technology on the environment increased, *environmental education* was promoted in the USA. This emphasised the development of cognitive and evaluative skills for understanding environmental issues, changing attitudes and taking responsible action (Bennett, 2003). Environmental education became incorporated within social studies, but led to the development of science courses known as *science-technology-society (STS)*. These were based on a consideration of controversial socioscientific issues, with a key aim being to teach methods of informed decision-making for solving problems in society (Bybee, 1977). Such courses were found to increase students' interest in science, but seemed ineffective in terms of changing their attitudes or enabling them to apply their scientific knowledge to issues in society (Solomon, 1988). The STS approach is nevertheless still in favour in many parts of the world (e.g. Kolstø, 2001; Mbajiorgu & Ali, 2003; Ministry of Education, New Zealand, 1997).

It is the promotion of *scientific literacy*, however, which currently appears to be the most frequently expressed goal of school science in literature from the developed world (cf. BouJaoude, 2002; Burden & Hall, 2005; Leonard, 2004; Ministry of Education, New Zealand, 1997; Roth, 2007). The term was coined in the late 1950s by Hurd, who has provided a useful history and philosophy of the concept (Hurd, 1998). Despite acknowledgement that no one single definition for scientific literacy exists (BouJaoude, 2002; Brown, Reveles & Kelly, 2005; Hurd, 2000; Laugksch, 2000; Norris & Phillips, 2003), there is general agreement that it embodies a sense of citizenship - that children require a degree of scientific literacy in order to act as informed and socially responsible citizens in a modern, democratic and changing society in which science and technology play an increasingly significant part.

One of the most ambitious national projects for the promotion of scientific literacy has been the American Association for the Advancement of Science's Project 2061, which was based on the principle of "help[ing] all Americans to become literate in science, mathematics and technology" (*Project 2061*, 2006). At its outset, 100 professional scientists were asked to list the most important knowledge in their fields (Fensham, 2000) which was then translated into "benchmarks for science literacy", statements of the scientific knowledge and skills students should have acquired by the end of each grade, to be utilised as guidelines for curriculum construction. Several authors have criticised Project 2061, however, as increasing the range of content students are expected to know (Fensham, 2000) and conveying an old-fashioned, positivist notion of science, which ignores the self-identities and cultural diversity of students (see references in Aikenhead, 2006).

During the past two decades, as many Western schools have become increasingly multicultural, there has been a growing sense that school science is experienced by underprivileged and minority groups as alienating. In 2005 Zembylas wrote that "the challenge in helping all children achieve scientific literacy becomes greater when 'all' children include not only the expected ones (i.e. those who are privileged), but also those whose backgrounds reflect a variety of differences" (p.709). This has resulted in a new emphasis on *science education for social justice* – science teaching and learning which validates the various cultural and historical backgrounds of all learners, in order to build their self-identity, and empower them to take action towards building a more just society (Aikenhead, 2006; Zembylas, 2005).

This is related to an ongoing discussion in the literature about what is termed the *nature of science* – its history, sociology, philosophy and epistemology (see for example Cobern, 1996; Hodson, 1988, 1993; Longbottom & Butler, 1998; Matthews, 1998; Reiss & Tunnicliffe, 2001; Rudolph, 2003). The discussion is typically conducted within a constructivist framework (Matthews, 1998) (see Chapter 2 of this study), and tends to emphasise the tentative, contested nature of Western scientific knowledge (Donnelly, 2006), and the need for curricula and schools to be sensitive to differing beliefs and cultural values among students (Reiss & Tunnicliffe, 2001). A large component of the debate has been between so-called universalists and multiculturalists around the relative status of Western Modern Science (WMS) and alternative forms of science, in particular indigenous knowledge (IK), and their place in school curricula (e.g. Brown-Acquaye, 2001 and others in *Science Education*, volume 85; El-Hani & Mortimer, 2007; Horsthemke, 2004; Rudolph, 2003; Siegel, 2002; Stanley & Brickhouse, 1994). Universalists hold that science is universal, and that WMS, as the paradigm of science, is superior to traditional forms of knowledge. This view is criticised by multiculturalists as being problematic from a philosophical as well as a political and moral standpoint, in that it serves to exclude those who hold to alternative ways of knowing (Irzik, 2001). Multiculturalists claim that there are as many forms of science as there are cultures, arguing that the relative merits of various forms of science should be debated in schools, and that IK be incorporated in science curricula. This has been attempted in New Zealand, for example, where Maori beliefs about the natural world have been included in the science curriculum (Ministry of Education, New Zealand, 1997) [6].

This short history of the changing goals of school science suggests that while the alternative aims of ñpureò and ñappliedò science have been present since the subjectõs beginnings, in recent years the goals appear to have become more complex as curriculum agents have increasingly attempted to infuse sociological issues into the curriculum. For this reason, I found that Aikenheadõs (2006) distinction between a ñtraditionalò and ñhumanisticò approach to science education currently provides the most useful terminology for analysing science curricula.

4.5 Aikenhead's "traditional" vs "humanistic" science dichotomy

Aikenheadõs distinction between ñtraditionalò and ñhumanisticò approaches to school science was outlined in Chapter 2. It can be recalled that according to Aikenhead, the traditional approach focuses on canonical science content and ways of thinking, in order to ñfunnelò capable students down ñthe pipelineò towards science and engineering degrees. In a traditional science curriculum, then, the objectives of *knowledge* and *skills* (i.e. those specifically associated with science) would be prioritised, and the others (*applications, attitudes and values* ï except for those considered specifically ñscientificò ï and *science as a human enterprise*) excluded or downplayed. This is the *science for future scientists* approach; Aikenhead regarded Project 2061, mentioned above, as an example of this traditional, ñpipelineò ideology.

Problems associated with the traditional approach have been acknowledged. It has been recognised that only a very small percentage of students studying science continue their studies after school or pursue scientific careers, and in the case of science-related everyday situations, canonical science is generally not directly applicable. A traditional approach to science could thus result in students viewing the subject as irrelevant and even alienating, particularly in the case of those whose background and culture differ from that of the dominant Western scientific worldview (references in Aikenhead, 2006).

By contrast, the term ñhumanisticò is used to describe an approach to science education which is far more concerned with *relevance* to the lives of students as individuals and in society, with nurturing a critical, ñoutsiderõsò view of science and technology, and with considering other forms of science (especially indigenous knowledge). The objectives of *applications, attitudes and values* and *science as a human enterprise* would be regarded as more important, or at least of equal importance as those of knowledge and skills. Both STS curricula and those aimed at promoting social justice are regarded by Aikenhead as advancing a humanistic perspective.

Aikenhead (2006) makes reference to various studies which have described some positive consequences of a humanistic rather than a traditional approach. For example, a curriculum which is perceived by students to be relevant to their everyday lives is likely to be more favourably received, and consequently would result in increased student recruitment and in students and teachers alike being more motivated to learn and teach the subject. A humanistic approach has also been shown to have the potential to promote student self-identity, achievement and even empowerment, particularly in those students whose cultures differ from that of Western science, and in this sense can help to promote social equity.

Aikenhead's views are not universally supported, however. Donnelly (2006), in particular, sounds a warning that a humanistic approach to natural science is typically an *ad hoc* approach which could, in fact, represent a crude instrumentalism, whereby science education serves the agendas of those in control of the curriculum rather than the needs of the learner "as a growing human being" (p.636). It is not my intention here to debate the merits of these positions; it is simply to show how the terms "traditional" and "humanistic" effectively capture a dichotomy of approaches to school science.

4.6 Goals of biology education in South Africa: some recent studies

Le Grange (2008) has synthesised the literature on the history of biology education in South Africa, using Rosenthal and Bybee's (1987) distinction between a "science of life" and a "science of living" as a lens through which to view changes in the curriculum. He noted that all curricula prior to 1994, as well as the Interim Core Syllabus of 1996, followed a content-laden, highly academic, "science of life" approach, and yet excluded any mention of the topic of evolution. This he ascribed largely to the positivist apartheid educational philosophy known as "fundamental pedagogics", in which science was regarded as value-neutral, and curricula included very little application to the students' personal lives or to issues in society - presumably to avoid opportunities for questioning the socio-political *status quo*. Evolution was excluded because it contradicted the conservative religious views of Christian National Education, which was based on "fundamental pedagogics".

Le Grange (2008) also mentions that before the implementation of the NCS (see Chapter 1 of this study), three papers were published criticising the way biology was presented in the South Africa school curriculum. Watson (1990), Schreuder (1991) and Doidge (1996) all argued that the syllabus was irrelevant to the needs of the majority of South African students, who would not pursue a science-related career after school, and ignored pressing social and environmental problems that faced the country. Writing before the final demise of apartheid, Watson (1990) suggested that an ideal biology syllabus would include topics relevant to the issues of population size, sustained yield, water resources, pollution control, human health, and diversity of ecosystems/ conservation, while Schreuder (1991) believed that following the principles of environmental education could be effective in rendering the curriculum more relevant. Doidge (1996), writing at the dawn of South Africa's new democracy, proposed that a curriculum constructed according to the "science, technology, society" approach would be the most useful for "providing well-informed citizens with appropriate skills who can take their place in a democratic and new South Africa" (p.48). Thus issues which were being debated internationally were regarded as being relevant in South Africa as well.

Le Grange (2008) then considered the NCS policy document for life sciences, quoting sections to show that topics of relevance to the students' personal lives and to needs in society had been incorporated, and that the curriculum had thus swung in the direction of a "science of living" approach. He expressed his view that the "science of life" and "science of living" approach should be integrated in the curriculum, and his belief that

> the NCS for Life Sciences provides an enabling framework for integrating both these approaches so that the subject is more relevant to learners' lives but at the same time not biased towards social aspects to the extent that the foundation (the discipline structure) of biology, which is important for future studies, becomes eroded (Le Grange, 2008, p. 103).

Nevertheless, by the end of the paper the impression is given that he favours a "science of living" approach, with an emphasis on environmental issues. He concluded his work by stating that the study by Dempster and Hugo (2006), with its assertion that evolution should be the unifying theme of a school biology curriculum, promotes a "science of life" approach, which he suggested may be a less appropriate unifying theme for a contemporary South African biology curriculum than that of "sustainability" (p.103).

4.7 Conclusion

In the above review I have attempted to portray the recent history of school science in the developed world using the shifting goals of school science as a theme, in order to provide the international context for the South African biology/ life sciences curricula under analysis. I began by delimiting five broad categories of objectives, and then showed which of these objectives have been prioritised in some recent prominent curriculum reform movements. Although the trend appears to be towards curricula which are governed by a more complex set of objectives than a simple dichotomy would imply, I believe that Aikenhead's (2006) sense of "traditional" and "humanistic" approaches effectively captures this complexity. I concluded with a consideration of Le Grange's (2008) history of biology education in South Africa, to show that the debates in school biology education internationally have influenced thinking in this country as well.

NOTES

[1] As biology (as a school subject) is typically subsumed under the word ñscienceò in the literature, I will use the words ñbiologyò and ñscienceò interchangeably in this chapter.

[2] Exactly *what* content ought to be included and what omitted is seldom specified in the literature, though the current view is that, for greatest interest and retention, it is preferable to cover fewer topics in greater depth (the principle of ñ*less content, more learning*ò, Fensham, 2000, p.148; Hall et al., 2003; or see Schmidt et al., 2005, for criticism of the ñmile-wide inch-deep curriculumò).

[3]The *skills* category incorporates both practical, hands-on skills, those involved in field and laboratory work for example, as well as those with a more cognitive dimension such as critical thinking and problem solving. Skills are often taught during so-called ñpractical workò; Bennett (2003) has provided a useful summary of the literature concerning the history, purposes and debates around practical work. This has shifted from the ñprocess approachò (e.g. Gagne, 1966) and ñdiscovery learningò (e.g. Atkin & Karplus, 1962, in Atkin & Black, 2003) in the 1960s and 70s, to a current emphasis on ñinquiryò (in the USA) and ñinvestigationsò (in the UK) (see Chin & Chia, 2006; Duschl, 2000; Leonard, 2004; Smith & Trexler, 2006; Zion et al., 2004).

[4]*Attitudes and values*, while often not included as a distinct category of objectives, are nevertheless seldom omitted from discussions of the purpose of a science education, and are arguably integral to science itself - Mayr (1997) wrote that ñin both basic and applied science, any discussion of the objectives of scientific research always entails questions of valuesò (p. 40). Donnelly (2006) noted that a key feature of recent science curriculum reforms has been the inclusion of science-related ethical questions, often of a sociological and political nature.

[5] which can be defined as “the generally accepted facts, ideas, concepts, and theories shared within the scientific community” (NCES, 2006, p. 7).

[6] Interestingly, it appears to be mainly Western authors who challenge the predominance of WMS in non-Western cultures. A recent comparison of biology syllabi in 15 African countries found IK in only two – Ethiopia and South Africa (Edith Dempster, pers. comm., 24 November 2009). Brown-Acquaye (2001), writing from a Ghanaian perspective, stated that

> The dilemma of African governments (and ... governments in most developing countries) is whether to employ tested, proved-to-be-effective WMS for the task of eradicating poverty, disease, hunger, etc., or to rely on indigenous knowledge and technology whose results are left to chance (p.69).

This is an enormous area of debate, well beyond the scope of this study, though one worth pursuing in the South African context where indigenous knowledge has been incorporated in many post-1994 curricula (see Horsthemke, 2004, and Berger, 2006, for relevant discussion).

Chapter 5: Analysing the curricula: empirical precedents and methodology

[With regards to policy,] "systematic knowledge generated by research is an important and necessary component in the decision-making process" (Rist, 2000, p.1003).

5.1 Introduction

Having considered biology both in its parent form (Chapter 3) and in the school curriculum (the official recontextualising field; Chapter 4), I now narrow my focus to a comparative analysis of the most recent South African biology/life sciences curriculum documents, in order to address the third question of my study: *To what extent has there been a change in the recontextualisation of biology as an hierarchical knowledge structure in the three life sciences curricula implemented in South Africa since 1994, and what are the implications of this for social justice?*

In its simplest sense, the methodology of the bulk of this part of the study is that of document analysis (Fraenkel, 1993): in order to compare the curricula, I divided the documents into statements, which were then assigned to categories of objectives or content most commonly included in school biology curricula. However, because the documents under analysis are curriculum policy documents, I begin by making some general comments about curriculum policy research, before considering some empirical precedents to the actual methodology I adopted.

5.2 Curriculum policy research

Rist (2000) emphasised the fact that policy research and analysis tends to be characterised far more by the huge diversity of methodologies employed, than by its actual impact on policy making. Perhaps this is due to the fact that research into (curriculum) policy faces at least three sets of dichotomies: the purpose of the analysis (*for* or *of* policy), the approach (inductive or deductive) and the methods used and types of results obtained (quantitative or qualitative).

5.2.1 Purpose

Policy research is typically viewed as serving either an "engineering" or an "enlightenment" function (Rist, 2000). The former approach assumes that "sufficient data can be brought to bear to determine the direction and intensity of the intended policy initiative, much as one can develop the specifications for the building of a bridge" (ibid, p.1003). Rist is of the opinion that this is the less useful approach, because policy making is a *process* rather than an event, a diffuse process at that, often cyclical and iterative, and subject to numerous constraints. Policy research for "enlightenment", on the other hand, the view that Rist favours,

> suggests that policy researchers work with policy makers and their staffs over time to *create a contextual understanding about an issue*, build linkages that will exist over time, and strive constantly to educate about new developments and research findings in the area (ibid p.1003, my emphasis).

Green and Naidoo (2006) draw a similar distinction, between research ĩforò and research ĩofò curriculum policy. Research ĩforò policy, which correlates with the "engineering" view of policy research described above, is ĩaimed at successful implementationò, while research ĩofò policy ĩseeks a more conscious, skeptical and *theoretically informed approach*" and is aimed at the ñenhancement of understanding about it, including *the influences that shaped it and its likely ramifications*ò (Green & Naidoo, 2006, p.71, my emphases).

My study conforms to the latter approaches (research ñofò policy, or for ñenlightenmentò) not only because it is retrospective, analysing curricula which have already become policy and been implemented, but also because it attempts to understand the curricula in terms of influences from within both the local and the international context, and has been conducted within the theoretical framework outlined previously (Chapter 2).

5.2.2 Inductive or deductive?

An inductive approach would allow issues and themes to emerge from the data, while a deductive approach would rely on predetermined categories for analysing the data. Both can be valuable in curriculum policy analysis. Morgan (2007) suggested a pragmatic approach to research methodology in the social sciences, which connects theory and data by abductive reasoning - moving between induction and deduction.

So far in this study I have followed an inductive approach in attempting to derive, from various sources, biologyôs core concepts (Chapter 3) as well as the goals of a school science curriculum (Chapter 4). In my actual analysis I proceed deductively, turning these findings into categories according to which the curricula can be analysed.

5.2.3 Qualitative or quantitative?

Bertram (2008) discussed how the terms qualitative and quantitative are used in the social sciences to describe either a research paradigm, or the methods of data collection. Here I employ the latter usage, and extend it to include the types of data obtained. I follow the approach of Green and Naidoo (2006) which they describe as ña mixed mode quantitative-qualitative methodologyò, in that qualitative decisions had to be made when assigning statements to categories, but that this method gave rise to quantitative results which facilitated comparison among the curricula.

5.3 Some empirical precedents to the methods used in this study

5.3.1 Analyses of objectives and content

Bernstein's concern with issues in contemporary education pertaining to social class differences and how these are perpetuated has resulted in his sociology informing educational research in many countries, including Australia, Chile, Finland, Portugal, the UK, the USA and South Africa (Maton & Muller, 2007). In particular, the work of Morais and Neves, who have conducted extensive research into school science education reform in Portugal using Bernsteinøs model of pedagogic discourse as their conceptual framework, has had a significant influence on recent research into South African curricula (see for example Bertram, 2008; Green & Naidoo, 2006).

Morais and Neves analysed the degree and direction of the recontextualising which had taken place at the various levels of the pedagogic device by comparing texts from different periods of science education reform in Portugal, and relating this to the socio-political context in which the reform had taken place (e.g. Neves & Morais, 2001). They analysed the content of the science syllabi according to categories they had established, based on Bernsteinian concepts, with their unit of analysis being the ñsentenceò, taken to mean ña part of the text of the syllabus with one or more sentences, which on the whole have a given semantic meaningò (Neves & Morais, 2001, p.535). In their study they distinguished between the contents and relations to be transmitted (the ñwhatò) and the form of how these contents and relations are transmitted in the teaching-learning context (the ñhowò).

My study focuses only on the ñcontentsò component of the ñwhatò, and not the ñhowò (recommended pedagogy), nor on any assessment criteria. There are two reasons for these omissions. The first is a conceptual one, in that the focus of the study relates to the *recontextualisation* of knowledge and not its *reproduction*, which occurs during transmission (pedagogy) and evaluation (assessment) (Maton & Muller, 2007). The second is a practical one, in that the policy document for the Interim Core Syllabus provided notes on the format of the Standard 10 (Grade 12) final examination papers only, and not on any other forms of assessment in this or the other grades; in addition, the changes to the NCS related to the content framework only; the Assessment Standards remain the same in the new NCS. In terms of pedagogy, very little explicit mention is made of this, especially in the first and third of the three curricula. I also consider, however, what could be termed the ñwhyò - the stated objectives of each curriculum.

Following the method of Neves and Morais (2001), Green and Naidoo (2006) investigated changes in the types of knowledge valued in the Interim Syllabus (1995) and the NCS (2004) for physical sciences at Grade 10 level. They describe their theoretical approach as ñeclecticò in that they used a variety of theoretical resources to inform different aspects of their analysis, not only those derived from Bernstein. Similarly, Bertram (2008) compared the ICS for History (Higher Grade) (1996) with the NCS for History Grades 10-12 (2003) using Bernstein's concepts of classification and framing to analyse the bulk of the document, and Blooms' Revised taxonomy to analyse the Learning Outcomes and Assessment Standards.

As my study is not focussed specifically on the Bernsteinian concepts of classification and framing *per se*, but more on the structure of biology itself and how it is transformed in school curricula, a number of local and international studies on biology/science curricula also informed my research. These included the Spanish study by Barberá et al. (1999), discussed in Chapter 4, and that of BouJaoude (2002) who investigated the balance of scientific literacy themes in the Lebanese science curriculum, to assess whether the curriculum has the potential to prepare scientifically literate citizens. He synthesised various definitions of scientific literacy to produce a framework of aspects of scientific literacy, which he then used to analyse components of the Lebanese curriculum. I used a similar method when analysing the objectives of the three curricula.

For the analysis of the content, studies by Valverde (2005) and Schmidt et al. (2005) suggested ways of presenting the data. Valverde (2005) used school-leaving examinations in mathematics and biology from six Middle Eastern and North African countries as an indicator of the goals of the intended curriculum of each country, comparing these with those of the French baccalaureat examinations. He used "test tasks" as the unit of analysis, coding these according to the categories of the TIMSS curriculum framework, and distinguishing between content and performance expectations. In addition, a table of content topics present in at least 70% of the tests for each country was constructed to reveal a "composite curriculum core", or that content considered most important to be examined. Content topics were also tabulated in the study by Schmidt et al. (2005), though their paper mostly informed my consideration of conceptual progression (see below).

In South Africa, Dempster and Hugo (2006) assessed the effectiveness of the way in which the RNCS for natural sciences (DoE, 2002) and the NCS for Life Sciences (DoE, 2003) introduced evolution. They used Mayr's (1997) summary of the theory of evolution to provide a framework for analysing the curricula qualitatively. In my study Mayr's writings were also utilised, in that they served as an initial source of biology's core concepts.

Finally, reference has already been made to Le Grange's (2008) study in which he used the science of life/science of living dichotomy to view changes in the high school biology curriculum in post-apartheid South Africa (i.e. the ICS and the NCS). His method was entirely qualitative and was based on selected extracts from the NCS which showed that the emphasis had swung to a ñscience of livingò approach. This represents an anecdotal approach, which was criticised by Bryman (1988, in Green & Naidoo, 2006) on the basis that the generality or representativity of the quotes cannot be established, and thus any bias of the researcher cannot be controlled for. Le Grangeøs (2008) study nevertheless supplied important background material for my research.

5.3.2 Conceptual progression

As I discussed in Chapter 2, Schmidt et al.øs (2005) concept of curricular coherence incorporates criteria for assessing conceptual progression within a curriculum. These are that the material should progress from particulars to the deeper structures which connect those particulars, or from descriptive to more explanatory aspects; that new topics should not be introduced before the prerequisite knowledge has been covered, and that material should not simply be repeated from grade to grade. The authors used tables of content topics covered in the curricula of the top achieving TIMSS countries, as well in the US national standards, to show where topics entered and left the curricula and thus to assess conceptual progression. For my purposes I felt that concept maps rather than tables would provide a clearer visual indication of conceptual progression, in particular the linkage between topics in the South African curricula.

Concept mapping has been widely used in various aspects of education, especially science education (see references in Starr & Krajcik, 1990) as an effective tool for illustrating relationships between concepts. Starr and Krajcik (1990) showed how concept maps could serve as a useful heuristic for science teachers to assist them to develop curricula which are ñhierarchically arranged, integrated, and conceptually drivenò (ibid, p.988). In Project 2061øs *Atlas of Science Literacy* (*Project 2061*, 2006), themes within suggested science curricula are represented as concept maps, arranged hierarchically by grade; these served as the model for the conceptual progression maps constructed by Dempster (in prep.) in her comparative analysis of the school biology curricula of four African countries, including South Africa's NCS for life sciences. In the two studies which served as precursors to this one, I used concept mapping to evaluate conceptual progression in the RNCS for Natural Sciences and the NCS for Life Sciences (Appendix 1), and to show the presence or absence of core topics within the themes of biodiversity and evolution, and whether or not they were linked, in the ICS, the NCS and the new NCS (Appendix 2).

5.4 Conclusion

In this chapter I have outlined the methodological approach I adopted towards the analysis of the South African curricula by referring to various other studies in curriculum policy research, particularly in the sciences, which suggested ways of analysing the data and presenting the results. In the following chapter I present the specific methods I used, and the results I obtained.

Chapter 6: A comparative analysis of post-apartheid South African Life Sciences curricula

6.1 Introduction

This chapter presents the results of a comparative analysis of the objectives, content frameworks and conceptual progression in the three life sciences curricula implemented in South Africa since 1994, namely the Interim Core Syllabus (ICS), the National Curriculum Statement (NCS), and the new NCS. The purpose of the analysis was to try to assess whether the successive versions represent a change in the recontextualisation of biology as an hierarchical knowledge structure, according to the arguments developed thus far in the study, and to determine the balance of canonical and humanistic material in each.

6.2 Documents analysed

In the case of the ICS I used the KwaZulu-Natal Department of Education and Culture's Interim Core Syllabus and Provincialised Guide for Biology (n.d.), as this was the document available to me. For the analysis of the content framework of the NCS (DoE, 2003), I included its elaborated version (the ES) because of the extreme underspecification of the content in the original document. At the time of analysis, the ES for Grades 11 and 12 were in draft form only, but a comparison with the final versions showed that very few changes had been made to the draft versions. The curriculum I call the new NCS was publicised on the Department of Education's (Gauteng) website as "A New Content Framework for the Subject Life Sciences" in 2007. Further details about the documents are provided in Table 4 below.

Table 4 Curriculum documents analysed in this study.

Full title and source of document analysed	*Name used in this study*	*Status of document*	*First year implemented in grade 10*	*Last year examined in grade 12*	*Analyses performed in this study*
Interim Core Syllabus and Provincialised Guide for Biology Grades 10 - 12 Higher Grade and Standard Grade, Implementation Date: 1996 (KwaZulu-Natal Department of Education and Culture, n.d.)	the Interim Core Syllabus (ICS)	Policy	1996	2007	Objectives, content specifications and conceptual progression
National Curriculum Statement Grades 10-12 (General) - Life Sciences (DoE, 2003)	the National Curriculum Statement (NCS)	Policy	2006	2010 (intended)	Objectives, content specifications and conceptual progression
Assessment Syllabus Life Sciences ï Grade 10 (DoE, 2006); Grade 11, Draft (National DoE, 2007); Grade 12 (National DoE, n.d.)	the Elaborated Syllabus (ES)	Guidelines	n/a	n/a	Content specifications only

Full title and source of document analysed	*Name used in this study*	*Status of document*	*First year implemented in grade 10*	*Last year examined in grade 12*	*Analyses performed in this study*
Circular 67/2007: A New Content Framework for the Subject Life Sciences as Listed in the National Curriculum Statements Grades 10 ï 12 (General) (DoE, 25 September 2007)	the new National Curriculum Statement (new NCS)	Policy	2009	?	Objectives, content specifications and conceptual progression

I first provide an overview of the different formats and approaches of the four documents, focussing on the status and priority given to the knowledge content, as well as any guidelines concerning sequencing and pacing.

6.3 Format and approach of the curriculum documents

Appendix 3 consists of a sample page from each document to exemplify their different formats, which are described below.

6.3.1 The Interim Core Syllabus (ICS)

The ICS, a 55-page document, comprises a brief introduction incorporating the objectives of the syllabus, notes on the approach to the syllabus, and some details about the final Standard 10 examination, with the bulk of the document taken up by the syllabus itself. Content is presented separately for Higher and Standard Grades within each standard (8-10), and is organised as numbered points with several orders of headings and subheadings. No guidelines for pacing are included; in terms of sequencing the comment is made, “examining bodies are at liberty to alter the order in which these topics are presented” (p.2).

6.3.2 The National Curriculum Statement (NCS)

As the NCS was based on a completely new set of principles which needed to be defined and elaborated upon, this document takes the form of a rather wordy booklet of four chapters plus a glossary. Chapter 1, which is generic for all subjects, introduces the principles of the NCS and defines key new concepts such as “outcomes-based education” and “learning outcomes”. Chapter 2 introduces the subject Life Sciences as conceptualised by the curriculum, and describes the Learning Outcomes. Chapter 3 links the Learning Outcomes to their respective Assessment Standards, and details the “content and contexts for the attainment of the Assessment Standards” (p.32), which includes the content specifications themselves. The fourth chapter deals with assessment. Of the 65 pages comprising the document, fewer than seven (10.8%) cover the actual content specifications.

In the NCS the subject is structured according to three Learning Outcomes, each of which is assessed by means of three Assessment Standards. The Learning Outcomes are worded as follows:

> Learning Outcome 1: Scientific enquiry and problem-solving skills
> *The learner is able to confidently explore and investigate phenomena relevant to life Sciences by using enquiry, problem solving, critical thinking and other skills*
>
> Learning Outcome 2: Construction and application of Life Sciences knowledge
> *The learner is able to access, interpret, construct and use Life Sciences concepts to explain phenomena relevant to Life Sciences*
>
> Learning Outcome 3: Life Sciences, technology, environment and society
> *The learner is able to demonstrate an understanding of the nature of science, the influence of ethics and biases in the life sciences, and the interrelationship of science, technology, indigenous knowledge, the environment and society* (p.12).

The actual knowledge to be taught is organised into four knowledge areas, namely

- tissues, cells and molecular studies
- structure and control of processes in basic life systems
- environmental studies
- diversity, change and continuity

According to this approach the Learning Outcomes are intended to take priority, followed by the Assessment Standards, with the actual knowledge to be taught coming third in line, as the following quotations from the document reveal: "A [school] subject...is broadly defined by Learning Outcomes and not only by its body of content" (p.6); "Content must serve the Learning Outcomes and not be an end in itself" (p.32); ñThe Assessment Standards are vehicles of knowledge, skills and values through which Learning Outcomes can be achieved" (p.14), and ñThe knowledge areas areé vehicles to attain the Assessment Standardsé [t]he Assessment Standards and not the knowledge areas determine the depth or levelò(p.32).

In keeping with the new approach, there is no division into higher and standard grades. The organisation of the content is firstly by knowledge area, then by Learning Outcome, and then by grade (10-12). The material is listed grade by grade under LO 2 only, however; in the case of LOs 1 and 3 there is no distinction between grades for the listed topics. No guidelines for pacing or specific teaching sequences are recommended, though the comment is made that "knowledge, which is foundational to others, should be dealt with first" (p.32).

6.3.3 The Assessment/Elaborated Syllabi (ES)

The Elaborated Syllabi were produced separately for each grade, but have a generic introductory section. This comprises a brief introduction and six tables: three which provide an outline of the level at which the Assessment Standards of each Learning Outcome should be achieved at the three grades, and three which clarify the Assessment Standards in each Learning Outcome. The introduction begins with the following words:

> This assessment syllabus was designed to é outline the scope and depth of what is to be learnt and assessed. The approach used is an integration of the various learning outcomes into a logical sequence

> within each topic or sub-topic of each knowledge areaé When using the contents of this assessment syllabus to formulate learning activities, an attempt should be made to further integrate LO 1 and LO 3 into the learning experiences designed for the learner (p.2).

What this means in practice is that the organisation of content specifications according to Learning Outcomes has been done away with, and replaced with an elaborated, and formalised, list of topics to be taught within each knowledge area. The level of detail has increased dramatically, most specifically in Grade 12, where the external examination makes it essential that teachers and learners know what will be assessed in the examination.

Suggested time frames are given for each topic; in terms of sequencing the comment is made in the introduction that ñYou should feel free to rearrange the various items in a story-line that suits the learners you are working withò (p.2).

6.3.4 The new NCS

As the new NCS represents a revision of only the content framework of the NCS, and is intended to be read in conjunction with the National Policy previously issued, this document also consists merely of an introductory section followed by the content framework. The introduction includes a list of outcomes which learners should have attained by the end of Grade 12, an overview of the holistic nature of life sciences, a brief description of the knowledge content to be covered in each grade, an elaboration of the learning outcomes, and a list of ñsuggested references for reading about South African natural historyò.

The first two knowledge areas have been renamed ñlife at the molecular, cellular and tissue levelòand ñlife processes in plants and animalsò, while the last two remain unchanged. Specific recommendations on the sequencing of the knowledge areas are made, related to seasonality (in the case of environmental studies at Grade 10 level) and conceptual progression.

The Learning Outcomes have been retained but are worded slightly differently: LO 1 reads ñInvestigating phenomena in the Life Sciencesò, LO 2 ñConstructing Life Sciences knowledgeò, and LO 3 ñApplying Life Sciences in societyò. The intended relationship between the three is described as follows: "LO 2 forms the content framework that is investigated in LO 1 and applied/linked to society in a variety of ways in LO 3" (p.7). No suggestion is made that the LOs take precedence over content, as in the NCS.

The actual content specifications are given firstly according to grade and then to knowledge area (called ñstrandò here), and are presented in table form, one column per Learning Outcome, with LOs 1 and 3 being specifically linked to the related topic in LO 2. In the introduction to each of the knowledge areas in each grade, a brief paragraph provides a summary of the major biological concepts underlying the content, and indicates connections among the topics, both within and between grades. In addition, subheadings indicate the focus of each knowledge area in each grade.

6.4 Comparative analysis of objectives

The stated objectives of each curriculum could be expected to provide the rationale behind the inclusion and organisation of content material, and give insights into how the subject was viewed by the agents of curriculum construction. My aim in comparing the objectives of the different curricula was to reveal how these objectives have changed and to what extent the changes reflect the different rationales behind each curriculum. In addition, the comparison can provide a means of determining the alignment between objectives and content, and can also serve as a test of the usefulness of the categories I devised in Chapter 4 for analysing the objectives of other science curricula.

The introductory sections of the ICS, the NCS and the new NCS all include, in various formats, a set of objectives[1]. This is the most explicit in the ICS, taking the form of a list of seven numbered points under the heading "Objectives of the syllabus" (p. 2). No specific, numbered list appears in the first NCS; instead the whole of Chapter 2 ("Life Sciences") could be said to deal with objectives. I analysed the first two paragraphs of this chapter under the subheading "Purpose" (p.9), as these most closely align to the conceptualisation of objectives in the other curricula. I numbered each sentence for ease of comparison. The seventh sentence, which states ñA study of concepts and processes ... uses contributions from the past to inform the present, and therefore promotes construction of new knowledgeò (p.9) was omitted from the analysis, as it was decided that this does not state a new objective. In the new NCS, the list of ten points following the words "At the end of Grade 12, learners should have" (p. 4) was selected for analysis.

I assigned each numbered point to one or more of the five categories of objectives devised in Chapter 4 of this study. To enhance the validity of the results, the analysis was also performed independently by four other biology educators, known to me, who have experience in teaching biology/life sciences at a senior secondary or junior tertiary level but who were unfamiliar with the curricula in question, so that any bias could be minimised. The wording of the task is provided in Appendix 4, where curriculum A refers to the ICS, curriculum B to the NCS, and curriculum C to the new NCS.

The results of the five individual analyses were synthesised as follows: an objective which was placed in a category by three or more of the five analysts was regarded as belonging to that category. If placed in a category by fewer than three analysts, it was omitted from that category. The total number and percentage of objectives scored in each category, for each curriculum, was then calculated.

The results of the analysis of objectives are given in Table 5 below. In 21 of the 24 objectives either four or five of the analysts were in agreement; in two cases three were in agreement, and in only one case (Attitudes and values in the NCS) were the results too different to be scored.

Table 5 Categorisation of objectives of three South African Life Sciences curricula (n = number of objective statements coded)

Curriculum document	*ICS (n=8)*[2]	*NCS (n=6)*	*new NCS (n=10)*
Knowledge (%)	2 (25)	1 (16.7)	1 (10)
Skills (%)	3 (37.5)	1 (16.7)	3 (30)
Applications (%)	1 (12.5)	2 (33.3)	3 (30)
Attitudes and values (%)	2 (25)	no agreement	1 (10)
Science as a human enterprise (%)	0	2 (33.3)	2 (20)

One immediately obvious result is that none of the objectives of the ICS scored in the category "science as a human enterprise", while a significant proportion of objectives of the other two curricula (33.3% and 20% respectively) were placed in this category. In addition, the percentage of objectives scored in the "applications" category was substantially lower in the ICS (12.5%) than in the other two curricula (33.3 and 30%), while the percentage related to biological knowledge was higher (25%, as opposed to 16.7% and 10%). In the skills-related objectives the ICS recorded its highest percentage (37.5%), the NCS just one objective (16.7%), and the new NCS three, or 30%. Of the three curricula, the new NCS appears to show the best overall balance of objectives, according to the categories used.

6.5 Comparative analyses of content frameworks

The knowledge content specifications of the ICS, the NCS, the ES and the new NCS were imported into the first column of four separate MSWord tables, which were in turn divided into Grades 10, 11 and 12. The second column of the tables was left blank for the actual coding. In the case of the ICS, only the Higher Grade text was analysed, as the Standard Grade specifications are essentially a subset of this. In the case of the NCS and the new NCS, where the material is divided into the three Learning Outcomes, the divisions were removed and all the text included. The text was divided into "statements", one statement per row. A statement is defined here as one or more sentences, phrases or words that clearly deal with just one topic. Headings were included in the tables, but not coded. Italicised phrases in the new NCS were omitted, as these typically dealt with pedagogical matters.

The following analyses were performed:

1. alignment of content with objectives
2. "canonical" versus "humanistic" biology content
3. themes within the canonical content
4. themes within the humanistic content

The first analysis (alignment of content with objectives) was performed by the author and three other biologists, different from those who helped to analyse the objectives, with experience in teaching general biology courses at a tertiary level. As this analysis was more complex than that for the objectives, the analysts met over two consecutive mornings to perform the analysis together, and decisions were made on the basis of consensus. All the other analyses were performed by the author alone.

6.5.1 Alignment of content with objectives

Analysis was according to the categories listed in Table 6 below. These represent a simplified version of the ñobjectivesò categories used in the previous analysis, modified by consensus during the course of the analysis to be more applicable to the material analysed.

Table 6 Elaboration of criteria or key words used to assign content statements to categories

Category	*Elaboration*
Knowledge	Canonical biology: facts, concepts, generalisations, principles, hypotheses, theories, laws, answering the question ñwhat do scientists know about the living world?ò Basic human biology was included here. Statements relating to the biological or ecological role of an entity.
Skills	ñHands-onò biology ï practical work, experiments, laboratory procedures, dissections, research (including using books, field guides, keys etc), investigations. Any kind of actual data collection by learners. Presenting information (by means of talks, posters or reports). Field trips and outings. The use of microscope slides, micrographs, diagrams, charts, models or actual material. Drawing and labelling.
Applications	Human hygiene, health, disease, genetic conditions, genetic counselling etc. Medical procedures. Biotechnology. Economic, agricultural and industrial applications. Food production. Environmental issues/problems. Conservation. Legislation. Ecotourism. Employment opportunities. Invaders, pests.
Attitudes and values	The ñaffective domainò. Debates, controversies, ethical issues, political issues. Impact on society. Advantages and disadvantages. Issues around HIV/AIDS. Incorporation of the word ñsustainableò.

Science as a human enterprise	The history of science - scientific discoveries and the people who made them. How science functions as an intellectual enterprise. The scientific method. Evidence. The tentative, changing, self correcting nature of science. Different interpretations of phenomena by different cultural and religious systems. Beliefs. Traditional medicines and practices.

The total numbers of statements in each curriculum, and for each category, were determined. However, in several cases, more than one code was applied to a statement. To determine percentages meaningfully, then, the total number of codes (or *codings*) actually assigned in each analysis, rather than the total number of statements, was taken as the maximum (100%). The results are shown in Table 7 below.

Table 7 Categorisation of content statements in four South African life sciences curriculum documents, given as a percentage of the total number of categorisations (codings) in each curriculum (n = number of statements; number of codings)

Curriculum document	*ICS (n=245; 276)*	*NCS (n=84; 144)*	*ES (n=530; 713)*	*new NCS (n=418; 512)*
Knowledge	85.1%	29.2%	43.9%	45.7%
Skills	10.9%	11.8%	16.3%	17.8%
Applications	3.6%	34.7%	22.3%	22.5%
Attitudes and values	0.4%	13.9%	10.4%	7.8%
Science as a human enterprise	0.0%	10.4%	7.2%	6.3%

Some similarities between the results for the objectives analysis (Table 5) and this analysis are evident. As before, the ICS has no statements which could be categorised in the ñscience as a human enterpriseò category, as well as a greater emphasis on ñknowledgeò and less on ñapplicationsò than do the other curricula, though there are no similar parallels for the other two categories. What is also interesting is how the results for the ES match those for the new NCS more closely than they do those for the original NCS, of which it is intended as an elaboration.

The differences between the number of statements in each curriculum are also notable: the brevity of the content specifications for the NCS is evident (just 84 statements, as opposed to the 245 statements of the ICS); this has increased to 418 in the new NCS, and more dramatically to 530 in the ES.

6.5.2 Canonical versus humanistic biology

While the previous analysis allowed an assessment of the alignment of objectives and content specifications, and also revealed interesting trends between the curricula, the delineation of the categories themselves proved problematic during the analysis, particularly the last three categories (applications, attitudes and values, and science as a human enterprise). The content statements were therefore analysed again, this time using just the two broad categories ñcanonical biologyò and ñhumanistic biologyò (after Aikenhead, 2006). In essence all the statements coded as ñknowledgeò in the first analysis were regarded as ñcanonical biologyó, and all those coded in the last three categories were regarded as ñhumanistic biologyó. The statements coded as ñskillsò were assigned to either canonical or humanistic biology, depending on whether they were skills associated more with the former, such as microscope work or drawing and labelling biology specimens, or the latter, such as research into environmental or health issues.

Table 8 Change in proportion of content statements related to canonical and humanistic biology in four South African life sciences curriculum documents

Curriculum document	*ICS*	*NCS*	*ES*	*new NCS*
No. of canonical biology codings (%)	265 (96%)	52 (36.1%)	395 (55.4%)	310 (60.5%)
No. of humanistic biology codings (%)	11 (4%)	92 (63.9%)	318 (44.6%)	202 (39.5%)

Here the changes in emphasis between the four documents are striking: from an overwhelming emphasis on canonical biology (96%) in the ICS, to a sharp swing in favour of humanistic biology (63.9%) in the NCS, to a swing back towards canonical biology (60.5%) in the new NCS. As with the previous analysis, the ES shows a closer alignment to the new NCS than to its "parent" document, the original NCS.

6.5.3. Themes within canonical biology

While the NCS, the ES and the new NCS have their content specifications divided into four knowledge areas, no such delimitation occurs in the ICS. In order to compare the coverage of different themes in canonical biology across all the documents, seven broad themes, based on the core concepts of biology derived from Mayr and the textbooks (Chapter 3) but modified to be more applicable to the curricula in question, were delimited. These were *Life at the molecular and cellular level*, *Inheritance*, *Evolution*, *Diversity*, *Plant (chiefly angiosperm) structure and functioning*, *Animal (chiefly mammalian and human) structure and functioning*, and *Ecology*. Within these themes, topics included in at least one of the four documents were listed. The inclusion or omission of each topic in any grade within each curriculum was then recorded. The results are given in Table 9.

Table 9 Canonical biology themes and topics included in four South African life sciences curriculum documents

THEMES and topics (included in at least one of the documents)	*ICS*	*NCS*	*ES*	*new NCS*
1. LIFE AT THE MOLECULAR AND CELLULAR LEVEL				
▪ the chemistry of life (biological compounds and nutrients)	•		•	•
▪ the microscope; cell structure and function	•	•	•	•
▪ diffusion and osmosis	•		•	•
▪ mitosis	•	•	•	•
▪ cellular respiration	•	•	•	•
▪ photosynthesis	•	•	•	•
2. INHERITANCE				
▪ meiosis	•	•	•	•
▪ DNA, RNA and protein synthesis	•	•	•	•
▪ genetics	•	•	•	•
3. EVOLUTION				
▪ basic principles of evolution (Lamarck; Darwin; sources of variation; adaptation; speciation; natural selection)	*	•	•	•
▪ biogeography			•	•
▪ the geological time scale			•	
▪ the fossil record		•	•	•
▪ extinctions		•	•	•
▪ human evolution		•	•	•

THEMES and topics (included in at least one of the documents)	*ICS*	*NCS*	*ES*	*new NCS*
4. DIVERSITY				
▪ concept of biodiversity		•	•	•
▪ classification as a system of organisation in biology			•	•
▪ viruses, bacteria, protists and fungi	•	•	•	•
▪ plant and animal diversity (examples and basic features of major groups)	•		•	•
5. PLANT (ANGIOSPERM) STRUCTURE AND FUNCTIONING				
▪ tissues and organs	•	•	•	•
▪ structural support	•	•	•	•
▪ movement of water through the plant, from uptake to transpiration	•	**	**	•
▪ translocation of manufactured food		**	**	•
▪ responses to the environment	•			•
▪ gaseous exchange			•	•
▪ reproduction	•		•	•
6. ANIMAL (MAMMALIAN - HUMAN) STRUCTURE AND FUNCTIONING				
▪ tissues	•	•	•	•
▪ structural support (skeleton, joints and muscles)	•	•	•	•
▪ transport (heart, blood and lymph)	•	•	•	•
▪ responses/ co-ordination (nervous and endocrine systems)	•	•	•	•
▪ nutrition	•	•	•	•
▪ gaseous exchange	•	•	•	•
▪ excretion	•	•	•	•
▪ reproduction	•	•	•	•
▪ immunity		•	•	•

THEMES and topics (included in at least one of the documents)	*ICS*	*NCS*	*ES*	*new NCS*
7. ECOLOGY				
▪ basic ecology (biosphere, biomes and ecosystems; biotic & abiotic factors; trophic relationships; energy flow; nutrient cycling)	●	●	●	●
▪ population studies (population parameters; estimate of population size; population regulation)	●	●	●	●
▪ community interactions (competition; predation; parasitism; mutualism; commensalism)	●	●	●	●
Total number of topics (out of a possible 38)	**27**	**27**	**35**	**37**

* The phrase "natural selection" appears in the section on "Genetic mechanisms" in two places: ñThe significance of mutations for natural selection" and ñthe genetic basis of natural selection" (both p.21), while the phrase "the introduction of genetic variation" is mentioned under "the significance of meiosis" (p.20). The term "evolution" does not appear though.

** These topics are presumably covered under the heading ñTransportò in the Grade 11 component of the NCS and the ES. No elaboration of this term is given in the NCS, and in the ES the directives are unclear. The terms ñtranspirationò and ñtranslocationò are not mentioned in either document.

The weighting of each theme in each curriculum was then determined, by calculating the number of statements related to each theme as a percentage of the total number of canonical biology codings. The results are shown in Table 10.

Table 10 Weighting of canonical biology themes in four South African life sciences curriculum documents (n = total number of canonical biology codings)

Theme	*ICS (n=265)*	*NCS (n=52)*	*ES (n=395)*	*new NCS (n=310)*
Life at the molecular and cellular level	13%	13.3%	15.5%	16.2%
Inheritance	7.6%	6.7%	14%	7.2%
Evolution	0%	20%	8.9%	9.6%
Diversity	29.8%	4.4%	6.6%	13.4%
Plant (angiosperm) structure and functioning	5.9%	6.7%	3.4%	10.3%
Animal (mammalian - human) structure and functioning	34.9%	20%	34.4%	33.3%
Ecology	8.8%	28.9%	17.2%	10%

This analysis revealed some interesting trends. The theme "Life at the molecular and cellular level" holds a consistent proportion (13-16.2%) in all the documents, and that of "Inheritance" is at a lower, though similarly consistent level (6,7-7,2%) in the three actual policy documents, rising to 14% in the ES. Apart from a brief mention of natural selection, the theme "Evolution" is not covered at all in the ICS, but occupies a full 20% of codings in the NCS, dropping to around 9% in the ES and new NCS. The ICS has a large percentage of statements (29,8%) relating to "Diversity", in that major plant and animal groups are surveyed in Standard 9 (Grade 11), but this theme receives very little coverage in the NCS and ES (just 4,4% and 6,6% respectively), and slightly more (13,4%) in the new NCS.

ñPlant structure and functioningò, which is largely restricted to that of angiosperms, receives a consistently low percentage in all curricula, dropping as low as 3,4% in the ES and rising to just 10,4% in the new NCS. By contrast, ñAnimal structure and functioningò, which deals almost exclusively with mammals, and chiefly humans, occupies the bulk of content (33,3%-34,9%) in all but the NCS where it nevertheless occupies a significant 20% of all canonical codings. The bulk of the content in the NCS is occupied by the ñEcologyò theme (28,9%), which drops to 17,2% in the ES, and is even lower at 8,8% and 10% in the ICS and new NCS, respectively.

6.5.4 Themes within humanistic biology

Within the content material deemed ñhumanisticò, different emphases were apparent. These were categorised, based on emphases noted in Aikenhead (2006) but adapted to be more applicable to the documents in question, as follows: *Human health, Human impact on the environment, Other applications of biology, Controversies and debates, History and nature of science,* and *Cultural knowledge*. Table 11 below elaborates on what could be included in each of these themes, while Table 12 presents the results of the analysis.

Table 11 Elaboration of criteria or key words used to assign humanistic content statements to categories

Theme (Aikenhead's term)	*Possible topics included*
Human health (personal-curiosity science)	Human diseases and disorders including genetic defects, their treatment, medical procedures, impact on and attitudes of society, biotechnology in medicine (e.g. production of antibiotics and insulin); basic aspects of health e.g. nutrition, hygiene, exercise; pregnancy, childbirth and contraception; first aid; drug and alcohol abuse; relevant legislation
Human impact on the environment (social responsibility)	Emphasis on environmental degradation e.g. pollution, overpopulation, loss of biodiversity, deforestation, and responses to this: conservation, ecotourism, sustainable development; relevant legislation
Other applications of biology (utility of science)	More positive/neutral focus e.g. agricultural, industrial, commercial, forensic applications; natural resources; economic importance of natural organisms or processes; relevant legislation
Controversies and debates (moral and ethical reasoning)	Moral and ethical aspects/different viewpoints, beliefs, values/ debates around/ legislation regarding (especially controversial) issues in scientific research/medical procedures e.g. cloning, blood transfusions, organ transplants, euthanasia, abortion, infertility treatment. Evolution/creation/intelligent design debate.
History and nature of science (knowledge about science and scientists)	History/development of: scientific discoveries, apparatus (e.g. the microscope), thought, theories, methods; contributions of famous scientists. Includes palaeontology.
Cultural knowledge	Specific inclusion of the qualifiers “indigenous”, “traditional”, “cultural” or “muti” in relation to knowledge, practices, treatments, diets; natural remedies etc.

Table 12 Weighting of humanistic biology themes in four South African life sciences curriculum documents (n = total number of humanistic biology codings)

Theme	*ICS (n=11)*	*NCS (n=92)*	*ES (n=318)*	*new NCS (n=202)*
Human health	40%	23.6%	39.5%	41%
Human impact on the environment	30%	33.3%	25.9%	23.7%
Other applications of biology	30%	15.3%	9.6%	14.1%
Controversies and debates	0	18.1%	8.8%	3%
History and nature of science	0	2.8%	8.3%	13.5%
Cultural knowledge	0	6.9%	7.9%	5.1%

In all but the NCS, the top three positions for categories of humanistic biology were occupied by ñHuman healthó, ñHuman impact on the environmentò and ñOther applications of biologyó, respectively. In the NCS ñHuman impact on the environmentò came first, ñHuman healthò second and ñControversies and debatesò third. ñHistory and nature of scienceò and ñCultural knowledgeò were covered the least in all but the new NCS, where the ñHistory and nature of scienceò occupied fourth highest place, and ñControversies and debatesò were included the least.

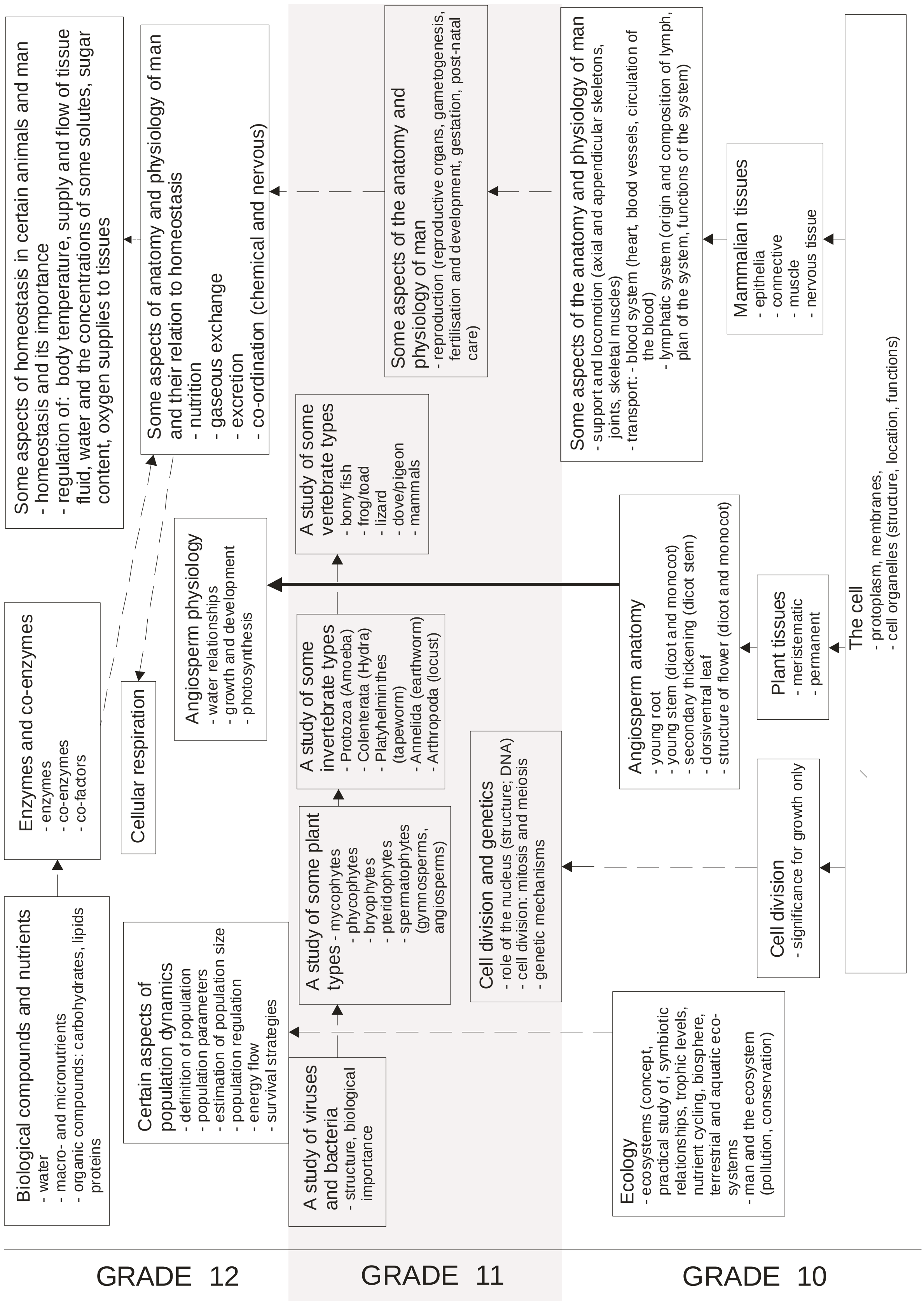
As a final point of interest, it was noted that while the ICS made no direct reference to the use of South African examples to illustrate the content, the original NCS tended to focus on negative applications such as disease and environmental degradation, while the new NCS made use of positive examples such as its rich biodiversity and fossil record, and the contributions of South African scientists to the production of knowledge.

6.6 Conceptual progression of the canonical content material

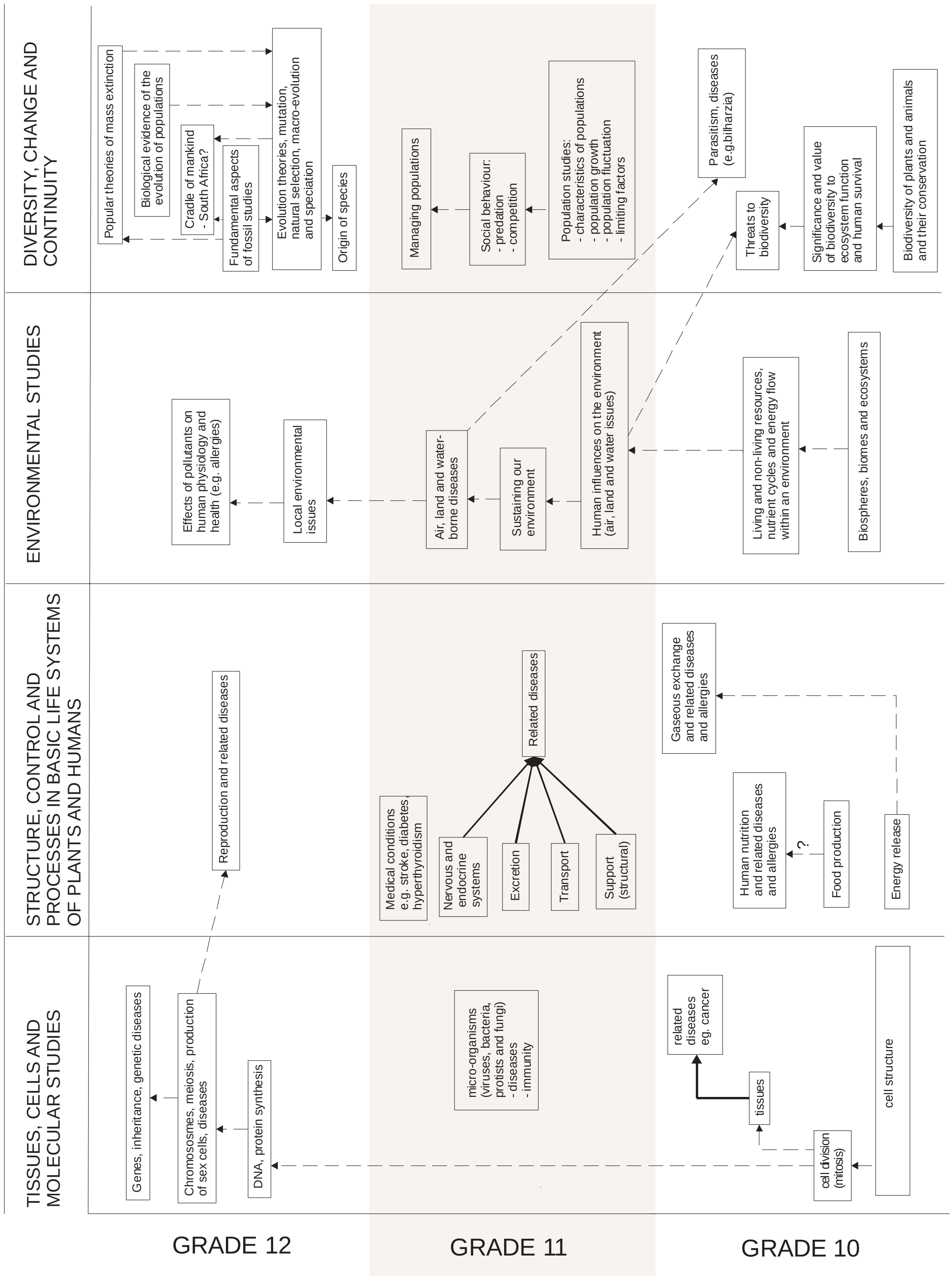
For the above content analyses, material from all three grades was combined for each curriculum, to show which topics are included during the three year course of study. In order to be able to make judgements about whether the canonical content material progresses from grade to grade, according to Schmidt et al.'s (2005) concept of curricula coherence, I mapped the content specifications of the ICS, the NCS and the new NCS grade by grade, using the (draft concept) maps of Project 2061's *Atlas of Science Literacy* (*Project 2061*, 2006) as a model. The ES was not mapped as it follows the same format as the NCS, though in a highly elaborated version.

In the case of the ICS, where there are no divisions into either Learning Outcomes or knowledge areas, all the content material was included in abbreviated form. In the case of the original and the new NCS, only the material from LO 2 was included, with the four knowledge areas forming columns on the maps. The subheadings indicating the focus of each knowledge area in each grade in the new NCS were included on the map as well. For each curriculum major topics were placed into individual "boxes" which were connected by broken lines if, according to my judgement, the topics are related. If the connection was actually stated in the curriculum, the boxes were joined with solid lines.

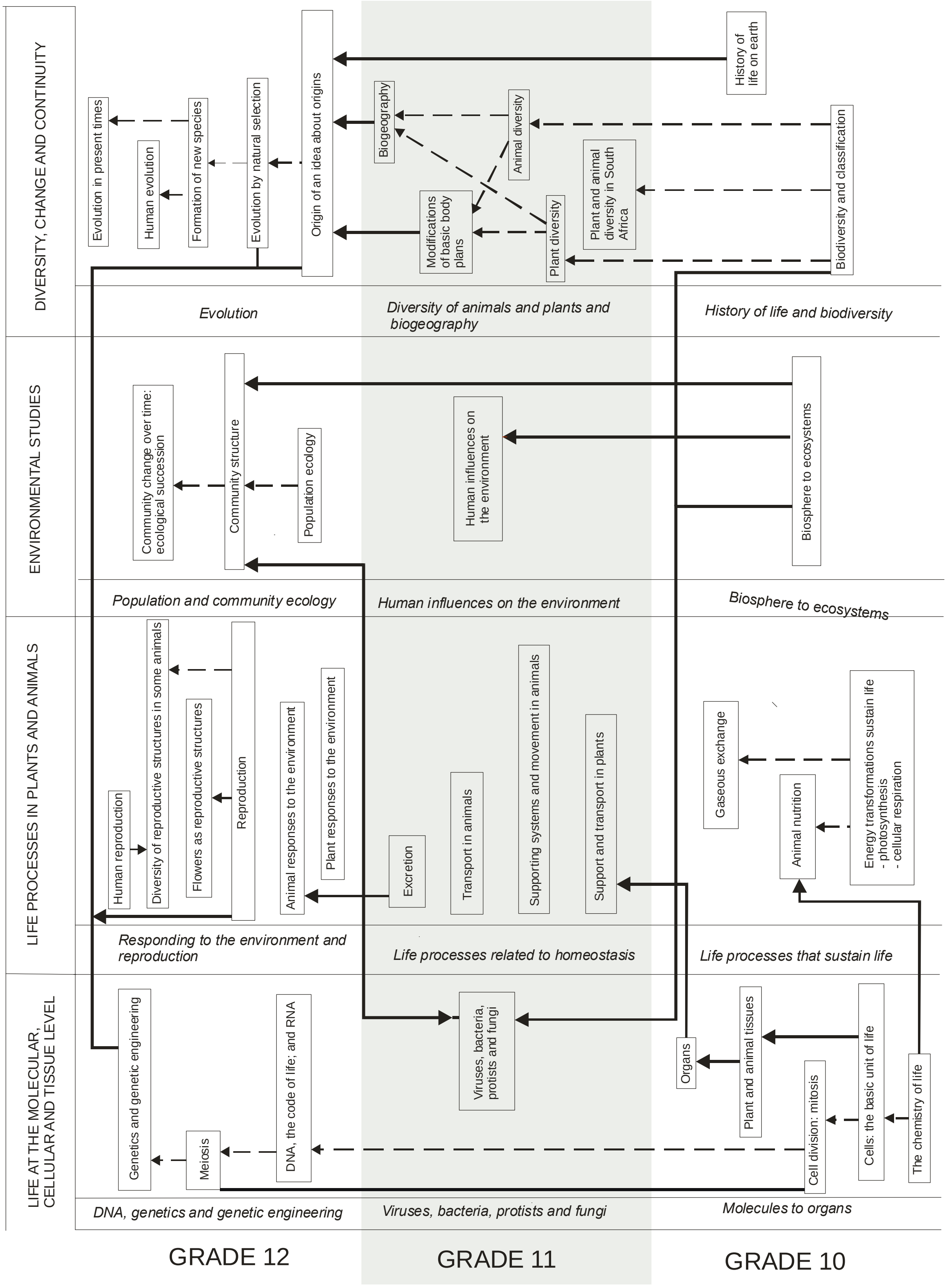
The progression maps for the three policy documents are shown in Figure 5 a) – c) below.



a) The Interim Core Syllabus



b) The National Curriculum Statement



c) The new National Curriculum Statement

Figure 5 Conceptual progression maps of content specifications in three South African Life Sciences curriculum documents: a) The Interim Core Syllabus; b) The National Curriculum Statement; c) The new National Curriculum Statement

While an initial reading of the ICS document suggests little or no sequencing, the map instead reveals a certain logicality in the structure of the syllabus. There is progression within grades, as seen in the constitutive hierarchy cells - tissues - organs - organ systems in Grade 10; the Linnaean hierarchy within the section on classification in Grade 11, and the sequence biological compounds and nutrients - enzymes and coenzymes, which acts as foundational material for the topic of nutrition in Grade12. There is progression between grades: a brief introduction to cell division in Grade 10 is followed by a more detailed handling of this topic in Grade 11, together with a study of genetics. Similarly, the studies of plant and animal tissues in grade 10 lays the foundation for the topics in physiology studied in Grades 11 and 12 (in humans) and Grade 12 (in angiosperms). In the case of angiosperm physiology, the connection is overtly drawn (shown on the map by a solid line) via the directive ñThroughout the study, structural features of tissues and organs must be related to the various physiological processesò (p. 26). The only topics that appear discretely are Ecology in Grade 10, Population Dynamics in Grade 12 (though these are typically included in the same chapter in the tertiary textbooks studied), and the section on Classification in Grade 11, which is complete within itself.

The latter two curricula apparently have more structure in that the material is divided into four knowledge areas. A closer inspection of the progression map of the NCS, however, actually reveals less structure than in the ICS. In particular, conceptual hierarchies are hard to find, apart from the constitutive hierarchy within the knowledge area ñTissues, cells and molecular studiesò, where cell structure comes first, followed by tissues in Grade 10; cell division is also included, which serves as a foundation for the section on DNA, chromosomes, meiosis and so on in Grade 12. Apart from the rather dubious sequence of “food production” to human nutrition under “Structure, control and processes...” in Grade 10, there are few other examples of hierarchies, or foundational material being introduced. This is particularly evident in the handling of evolution: no foundational material is included before Grade 12, nor is there any logical sequence to the list of topics specified for the teaching of evolution. I could find no examples in the NCS of connections between topics being overtly drawn, apart from “Related diseases” in the Grade 10 knowledge area “Tissues, cells and molecular studies” and the Grade 11 knowledge area “Structure, control and processes”[3].

Another feature of the NCS is a tendency towards repetition, particularly between the knowledge areas “Environmental studies” and “Diversity, change and continuity”. The reason for this probably is that in using the more contemporary sense of the term “biodiversity”, the emphasis is on conservation rather than diversity as such. Thus the Grade 10 coverage of the theme “Diversity, change and continuity” tends to overlap with topics covered in “Environmental studies”, particularly in Grades 11 and 12.

The new NCS has attempted to structure the content still further by using thematic headings for the material covered within each knowledge area in each grade. This clarifies the constitutive hierarchy “molecules to organs” within the knowledge area “Life at the molecular, cellular and tissue level” for example, as well as “biosphere to ecosystems” in “Environmental studies”, Grade 10. In terms of conceptual progression, this is best demonstrated in the theme “Diversity, change and continuity”. As in the NCS, evolution is covered in Grade 12, but in this case the foundations have been laid from Grade 10, and are drawn together in Grade12 as “lines of evidence” for the theory of evolution: the fossil record (Grade10), diversity (Grade 11), biogeography (Grade11), descent with modification (Grade 11), and genetics (Grade 12). Thus by the time evolution is introduced in Grade 12, much of the evidence for it has already been covered.

The repetition evident in the NCS between the themes of ñDiversity, change and continuityòand ñEnvironmental studiesòis avoided here in that the concept of ñbiodiversityòis related to the more traditional meaning of ñclassificationòin Grade 10, and is followed by a more detailed section on plant and animal diversity in Grade 11. This is similar to that in the ICS, except that in the new NCS the emphasis is on the basic body plans of selected taxonomic groups, and understanding these groups in terms of their evolutionary links with one another. The focus on human influences on the environment is restricted to Grade 11 of the ñEnvironmental studiesòtheme, which then reverts to more classical ecology in Grade 12 with its focus on population and community ecology.

Connections between topics, both within and between knowledge areas and grades, are frequently stated throughout the syllabus, typically via italicised notes, for example ñ*[This links to nutrition]*òin the section on ñThe chemistry of lifeòin Grade 10 (p.13).

6.7 Conclusions

This chapter has served to outline the different formats and approaches of the four documents, and to describe the methods used and results obtained in the comparative analyses. In the next chapter I discuss the significance of these results, and draw together my conclusions from the study as a whole.

NOTES

[1] The ES does not have its own set of objectives as it is simply an elaboration of the NCS.

[2] Only seven objectives are listed in the ICS (see Appendix 4, Curriculum A); however, objective number 6 was scored in two categories: both Attitudes and values, and Applications. For this reason, it was regarded as representing two objectives; hence n=8, not 7. This was the only instance in which this occurred in the analysis of the objectives (although it occurred frequently in the comparative analyses of the content frameworks).

[3] In the ES, connections were drawn between knowledge areas in the same grade, or between grades, but only in the sense of reviewing concepts or topics, for example, ñReview energy flow through an ecosystem (from environmental studies)ò (under Biodiversity, change and continuity in the Grade 10 syllabus, p. 20), and ñRevise parts and functions of the microscope (from Gr. 10)ò (Grade 11 syllabus, p.10).

Chapter 7: Discussion and Conclusion

7.1 Introduction

This study set out to explore the way biological knowledge is transformed when it moves from its disciplinary form to a high school biology curriculum, and to examine how this process unfolded in the successive versions of the biology/life sciences curricula implemented in post-apartheid South Africa - the Interim Core Syllabus (ICS), the National Curriculum Statement (NCS) with its elaborated form, the Assessment/Elaborated Syllabus (ES), and the recently implemented new NCS. As the construction of these documents was undertaken within the paradigm of the promotion of social justice in the newly democratic society, the study also aimed to speculate whether the revisions of the curriculum represent progress towards this goal.

In this final chapter I summarise and discuss the key findings of the study in relation to the three questions posed at the outset, which were:

1. What are some of the core integrating concepts within the academic discipline of biology, and how can they be conceptualised as a hierarchy?

2. What are the goals of a school biology curriculum?

3. To what extent has there been a change in the recontextualisation of biology as an hierarchical knowledge structure in the three life sciences curricula implemented in South Africa since 1994, and what are the implications of this for social justice?

The chapter also considers issues regarding the methodologies I adopted, the limitations of the study, and recommendations for further research in this area.

7.2 Core concepts in biology

In setting out to explore the relationship between the knowledge structure of biology and its corresponding curriculum structure, it was first necessary to acquire a sense of the structure of the discipline itself. The study proceeded from the assumption that biology is an hierarchical knowledge structure *sensu* Bernstein (1996, 1999), and therefore that all the knowledge of the discipline builds progressively upwards towards a few general, integrating propositions, or core concepts. The work of the study thus commenced with an attempt to elicit some of the core concepts in biology, and how they may be organised conceptually.

Biology is a vast domain: in 1998 Hurd wrote that “There are now over 400 named fields of biology requiring more than 20, 000 journals to report findings” (p.409). Like its subject matter, the discipline is highly diverse, complex and evolving, and has an historical dimension which must be taken into account if sense is fully to be made of it. For the sake of feasibility Ernst Mayr, a key theorist of biology, was taken to represent the field of production of biological knowledge, while two foundational biology textbooks and two practising biological researchers and educators served as connecting devices to the official recontextualising field of the school curriculum. Though obviously representing just one of many approaches, Mayr’s writings offered a wealth of insight into the history, philosophy, structure and subject matter of biology. For my purposes they supplied a set of concepts which correlated nicely with those suggested by the other sources, as well as a workable conceptual ordering device.

Seven concepts emerged as being core to the discipline, namely *the cell, inheritance, evolution, interactions*, *regulation, energy flow* and *diversity.* While each of these concepts could theoretically be shown to subsume large amounts of biological knowledge, I suggested a way in which the concepts themselves could be arranged in a hierarchy, using Mayr’s (1997) “three big questions in biologyò- ñwhat?òñhow?òand ñwhy?ò- as an ordering device (Figure 6). According to this model, *diversity* forms the foundation of biological knowledge (ñwhatò) and *evolution* its pinnacle (ñwhyò), with the other concepts forming the body of the knowledge triangle (ñhowò), apart from *interaction*s which operate at and between each level, and with the non-living environment.

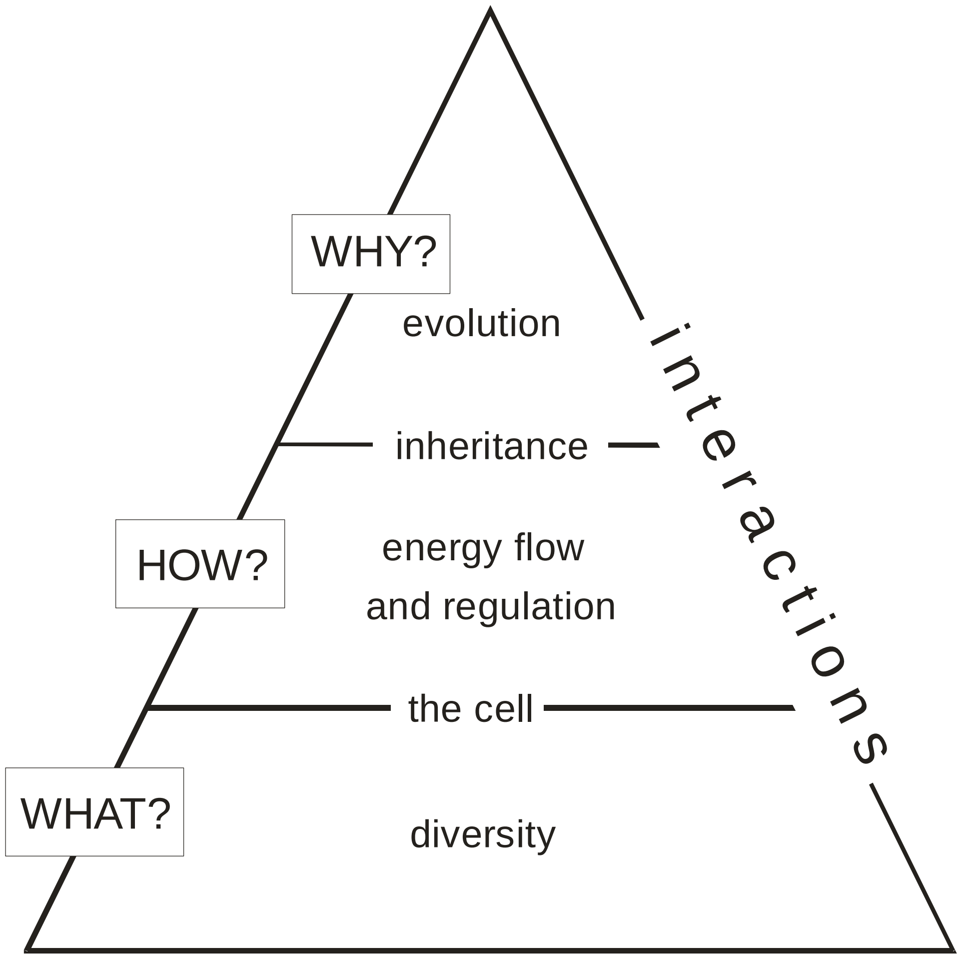


Figure 6 Schematic representation of a possible hierarchical arrangement of seven core concepts in biology (from Chapter 3)

But how useful - or necessary - for induction into the realms of academic biology is the concept of biology as an hierarchical knowledge structure: one which

> [attempts] to create very general propositions and theories, which integrate knowledge at lower levels, and in this way [shows] underlying uniformities across an expanding range of apparently different phenomena (Bernstein,1999, p.162-163)?

Certainly biology has, in the form of the theory of evolution, a "proposition" which integrates and unifies biological knowledge – or to put it more strongly, in Dobzhansky's famous words, "Nothing in biology makes sense except in the light of evolution" (Dobzhansky, 1973). To a lesser extent, the other six "core concepts" my research yielded could also be shown to subsume and integrate a large range of phenomena. However, although I suggested a possible hierarchical arrangement of these concepts, the criteria for their positioning within the hierarchy were not thoroughly explored or tested. Hierarchy suggests a degree of linearity, for example, and the hierarchy I depicted may well not survive close scrutiny according to this criterion.

This is perhaps not surprising, given the nature of biological knowledge. Campbell and Reece (2005) have already been quoted as saying that, "Though a biology textbook's table of contents must be linear, *biology itself is more like a web of related concepts without a fixed starting point or a prescribed path*" (p.ix, my emphasis). Schmidt et al. (2005) had something similar to say in relation to mathematics:

> "even in an area that is largely hierarchical … not all topics are hierarchical, and, hence, may only be locally sequential - in fact, in such cases *the structure may be more akin to a web (and not a hierarchy) in which the inter-connections become a critical part of the structure*" (p.528; my emphasis).

Perhaps it is enough at this point to affirm that the discipline of biology indeed has a deeper structure, which may well be integrated by a few core concepts, but also that an awareness of the *interconnections* between these concepts is just as essential for induction into the subject.[1] This will have implications for the structuring of a curriculum.

7.3 Goals of a school biology curriculum

A variety of factors shape the process of the recontextualisation of biological knowledge from the field of production to the official recontextualising field of a school curriculum. These include the sociopolitical context, the agents of and stakeholders in the construction of the curriculum, and the prevailing views on education in general and science education in particular. Perceptions of the most important goals of a school science education have been in a state of flux since the earliest days of the subjectõs inclusion in the school curriculum. I have categorised these goals as relating to *knowledge, skills, applications, attitudes and values*, and *science as a human enterprise*.

According to Aikenhead (2006), the traditional approach to a science education emphasizes the transmission of canonical *knowledge* and the development of scientific *skills*, with the aim of preparing students for future studies and careers in science or engineering. By contrast, a humanistic approach focuses more on *relevance*, in terms of the *applications* of science to the studentsô everyday lives and to society at large, the development of *attitudes and values* which support moral and ethical reasoning, and an understanding of *science as a human enterprise*, which includes the historical, social and cultural dimensions of science, as well as an appreciation of non-Western and indigenous sciences.

Science education reform movements have tended to emphasize either a more traditional or a more humanistic approach. The most significant question which emerged from this part of the study turned out to be not so much ñWhat are the goals of a school biology curriculumò, but rather, ñWhat is the balance of canonical and humanistic science in a curriculum, and what are the consequences for learners ï and indeed for society - of this balance?ò

7.4 The recontextualisation of biology in post-apartheid South African life sciences curricula

7.4.1 Comparative analyses of the curriculum documents

The above findings were used to construct a framework for the comparative analyses of the life sciences curricula implemented in post-apartheid South Africa. My aim was to determine whether the revisions of the curricula reflect a change in the recontextualisation of biology as an hierarchical knowledge structure, as a possible measure of their potential to assist with the promotion of social justice in this country.

The stated objectives and content specifications of the curricula were initially analysed according to the five goals of a school curriculum delimited above, following which the content material was re-analysed according the categories canonical and humanistic biology. The results provided quantitative support for Le Grange's (2008) observation that the highly traditional (or "science of life") approach of the ICS was replaced by a more humanistic ("science of living") approach in the NCS. In the former, the emphasis in both the objectives and the content specifications was on imparting knowledge and skills, with very little attention paid to applications and none to science as a human enterprise; when the categories canonical and humanistic biology were applied, the content was shown to fit almost exclusively (96%) within the realm of canonical biology. By contrast, the NCS had a strongly humanistic focus in both its objectives and knowledge content specifications, emphasising applications above knowledge, and with canonical content occupying just 36.1% of the total.

The results for the new NCS were the inverse of this, with the canonical component accounting for 60.5%. Here skills and applications were forefronted in the objectives, while knowledge ranked highest in the content specifications. The results for the content specifications of the ES were nearly identical to those of the new NCS.

The canonical and humanistic material was then further analysed separately, in order to obtain a more nuanced sense of the differences between the curricula. In categorising the canonical material, the “core concepts” of biology were reformulated as themes - *Life at the molecular and cellular level, Inheritance, Evolution, Diversity, Plant structure and functioning, Animal structure and functioning,* and *Ecology* – which incorporated those concepts but were more directly applicable to the curricula. All seven themes were represented in all the curricula, apart from Evolution which did not appear in the Interim Core Syllabus. The bulk of the material in the ICS dealt with Animal structure and functioning (34.9%) and Diversity (29.8%), while in the NCS Ecology was emphasised (28.9%). In both the ES and the new NCS, Animal structure and functioning again took precedence (34.4% and 33.3% respectively). Plant structure and functioning occupied less than 11% of the material in each document, down to as little as 3.4% in the ES.

The humanistic material was analysed according to six categories, loosely based on emphases noted in Aikenhead (2006), namely *Human health, Human impact on the environment, Other applications of biology, Controversies and debates, History and nature of science,* and *Cultural knowledge*. Again, the conservative approach of the ICS was evident in that the very small proportion (4%) of humanistic statements all related to relatively “safe”, apolitical topics such as human health, human impact on the environment, and other applications of biology, with no material related to controversies and debates in biology, the history and nature of science, or cultural knowledge. By contrast, in the NCS a significant proportion of material covered controversies and debates (18.1%), though very little dealt with the history and nature of science (2.8%). The converse was true for the new NCS (history and nature of science 13.5%; controversies 3%), while the results for the ES were mostly midway between those of the latter two curricula. The main emphasis in the humanistic content of all but the NCS was on human health (ICS 40%, ES 39.5% and new NCS 41%) ; in the NCS human impact on the environment was most favoured (33.3%). The proportion of material related to cultural knowledge was below 8% in each of the NCS, ES and new NCS.

In order to test whether the curricula could be judged as coherent, that is, consistent with the logical and hierarchical structure of the parent discipline (Schmidt et al., 2005), the canonical content material of the three policy documents was mapped, grade by grade. In general, the ICS appeared to show reasonable coherence, but in the case of the NCS, the map revealed that the curriculum was deficient in terms of conceptual progression, the linking of related concepts, and the incorporation of biological hierarchies. There was also repetition between the knowledge areas Environmental studies and Diversity, change and continuity. In addition, no specific guidelines for sequencing or pacing of the material were provided (though this was partially amended in the Elaborated Syllabi).

By contrast, the map of the new NCS content showed clear conceptual progression from lower to higher grades in all topics, particularly in the handling of the Evolution theme, and that the repetition evident in the NCS was absent. Links were frequently drawn between topics, both within and between grades. While no guidelines regarding pacing were given, logical recommendations concerning sequencing were made.

7.4.2 Interpreting the findings

If Darwin's theory of evolution by natural selection has the explanatory power to account for all the diversity of life, and thus serve as the chief "integrating proposition" of all biological knowledge, a school biology curriculum which fails even to mention the word "evolution", as did the ICS and its predecessors under Christian National Education[2], therefore has to be seen as being critically flawed and in need of revision.

This point has already been discussed at length by Lever (2002) and, following on from his paper, by Dempster (2005). Lever's chief argument was that the exclusion of Darwin's theory of evolution by natural selection from the South African biology curriculum (i.e. the ICS and its predecessors) served to reduce the syllabus content to a "tedious compendium of facts for children to regurgitate" (Lever, 2002, p. 41), and to keep both the youth and the general public ignorant of one of science's most powerful ordering frameworks. This echoes Dobzhansky's statement that

> [s]een in the light of evolution, biology is, perhaps, intellectually the most satisfying and inspiring science. Without that light it becomes a pile of sundry facts – some of them interesting or curious but making no meaningful picture as a whole (Dobzhansky, 1973, p.129).

It is also reminiscent of Muller's point (see Chapter 2) that in weakly codified disciplines students are simply required to learn "masses of particulars" (Muller, 2007, p.69). The implication is that, by omitting evolution, biology's highest, most integrating proposition, the ICS presented the subject as being weakly codified, and obscured its deeper structure.

Lever's (2002) paper formed the focal point of a meeting where a range of prominent South Africans presented their views on the topic of introducing evolution into the new biology curriculum (James & Wilson, 2002). In her review of the meeting's publication, Dempster (2005) railed against the fact that no natural scientists had contributed to the debate; as a result, she believed, the theory of evolution had been seriously misrepresented, and the need to include it in the biology curriculum questioned in an uninformed way. She also expressed her deep concern that the imperative to democratise knowledge in the construction of the biology curriculum could result in ñ[obscuring] the essential concepts of biology in the name of democracyò (p.113), with the ironical consequence that learners would be denied ñaccess into the very structures that can assist their empowermentò (p.115).

According to these arguments, then, the NCS should have represented an improvement on the ICS because it incorporated evolution as a topic for study. Yet despite the fact that evolution occupied as much as 20% of the canonical content, it was introduced in Grade 12 only, in the form of an apparently arbitrary ñlaundry listò (Schmidt et al., 2005) without any coherent, logical structure. This issue has been explored in greater detail by Dempster and Hugo (2006), who concluded their study with the suggestion that

> "it is time to consider implementing the final stage of a trajectory that began with a creationist outlook [the ICS] and progressed to the implicit introduction of all the necessary components to understand Darwinian evolution [the RNCS and NCS].[3] Taking the final step of directly and explicitly teaching the principles of Darwinian evolution at schools exposes South African children of all backgrounds to one of the key organising principles underlying the modern view of life and our world" (p.112; my insertions).

Could the new NCS be regarded as the ñfinal stage of [the] trajectoryò in terms of its handling of evolution? My study has shown that it certainly represents substantial progress on the original NCS, in that all the components of Darwinõs theory, according to Mayr (1997; see Chapter 3 of this study), are explicitly or implicitly included ï gradualism (Grade 10) is implied, while common descent (Grade 11), the fact of evolution, speciation, and natural selection (Grade 12) are all explicitly covered. In addition, it is not simply the inclusion of the topics, but the way in which this has been done which is significant. In a manner suggestive of the ñconsilience of inductionsò approach recommended by Costa (2003), lines of evidence - the fossil record (Grade10), diversity (Grade 11), biogeography (Grade11), descent with modification (Grade 11), and genetics (Grade 12) - are first presented to the learners, following which they are drawn together under the common explanatory principle of the theory of evolution by natural selection in Grade 12. On these grounds it could be concluded that the new NCS reflects the ñwhyò component of the discipline of biology, at least, far more successfully than did its predecessor.

But the analysis of the canonical content revealed that the original NCS was wanting in its coverage of the ñwhatò component of biology as well, in that only 4.4% of the canonical material covered diversity *per se*, rising to just 6.6% in its elaborated form, the ES. It has already also been pointed out (in Chapter 6) that in these two documents the emphasis in the diversity-related content was on conservation, rather than a description of the diversity of life forms. The ICS had had a strong emphasis on diversity (29.8% of the canonical material) due to the extensive coverage given to the characteristics of the major taxa in Std 9 (Grade 11). While Lever (2002) suggested that the scientific framework ordering this section would be hidden from all but the most gifted children, and that it merely promoted extensive rote-learning, learners under the ICS were nevertheless likely to have left school with a far better sense of the diversity of life ï one of the foundations for understanding evolution - than their counterparts under the NCS.

In the case of the new NCS, the coverage of diversity has risen to 13.4%, and the topic is handled more progressively in that the major taxa are overviewed in Grade 10, and reintroduced in more detail in Grade11. The approach is to link the concepts of biodiversity (via classification) and evolution, as is revealed by the following extracts from the Grade 11 section on animal diversity: ñConcept of phylum as illustrated by a body plané . A very brief comparative analysis of body plans of the different phyla is required. It should be explained in the context of evolution.ò (LO 2), and ñInterpret a phylogenetic tree representing the evolutionary history of animalsò (LO 1) (DoE, 2007, p.24). The goal is thus to help students to understand evolution by considering the phylogenetic relationships between groups of organisms – a so-called “tree-thinking” approach (see Smith & Cheruvelil, 2009). The history as well as various systems of classification are also included in LO 3 of Grade 10, aspects which did not feature in either the ICS or the NCS but which would potentially increase the depth of the students’ appreciation of the topic.

Mayr’s “how” component of biology, in other words the functioning of biological systems, appears in the curricula largely within the themes of Life at the molecular and cellular level (which received a consistent coverage of between about 13 and 16% in all the documents), and Plant and Animal structure and functioning. Some of the criticism aimed at the NCS related to its “excessive emphasis on human biology and the marginalizing of plants and much of the animal kingdom” (Doidge et al., 2008, p.17). Dempster (2005) had already made the point that “humans are but one species of possibly twenty million existing on the planet Earth… we can learn very little about broad biological processes by focusing so intently on humans” (p.114). This appears to be a matter for concern elsewhere as well: Reiss and Tunnicliffe (2001), for example, noted that “one of the unfortunate things about recent reforms to school biology curricula in England and Wales has been the increasing extent to which organisms other than humans are marginalized” (p.128).

My results revealed, however, that canonical material relating to the plant kingdom increased only slightly from the NCS to the new NCS (6.7% to 10.3%), while material relating to the theme of Animal structure and functioning actually increased substantially (from 20% in the NCS to 33.3% in the new NCS). A separate analysis of what percentage of this relates only to human biology (as opposed to that of other animals) would be required to confirm whether or not the new curriculum presents a less human-centred approach to biology than did the NCS[4].

According to Schmidt et al.'s (2005) criteria for judging the coherence of a curriculum, the conceptual progression maps provide evidence of flaws within the structuring of the content material of the NCS, and improvement in the case of the new NCS (see discussion above). It was also noted that in the new NCS an attempt was made to convey the unifying principles of the subject and draw connections among the topics, both within and between grades, in the introduction to each of the knowledge areas in each grade, something which is absent from both the ICS and the NCS.

Another point raised by Schmidt et al. (1997, in ibid, 2005) warrants revisiting, however – their notion of the "mile-wide inch-deep curriculum" (see also Adler, 2006). By this they meant that the inclusion of large amounts of content in a curriculum can result in the shallow and hence inadequate treatment of the material. This issue has received attention from others in relation to science education: Fensham (2000), for example, endorsed the principle of "less content, more learning" (p.148). And in a comparative study of eighth-grade science teaching, lessons in Japan – the country typically placed first in TIMSS science assessments - were found to be characterised by the development of only a few canonical science ideas, which were treated in greater depth than in other countries (NCES, 2006). Still more recently, Schwartz, Sadler, Sonnert and Tai (2009) found that students who had covered science topics in greater depth and for longer periods in high school performed better in introductory college science courses than did those who had covered a larger number of topics more briefly, particularly in the case of biology.

My analysis of the South African curricula revealed a trend in the documents produced after the highly underspecified NCS (i.e. the ES and the new NCS) towards greater breadth, in that the total number of different topics covered within the canonical biology themes increased from 27 in the ICS and the NCS, to as many as 35 in the ES and 37 in the new NCS. It would appear that there is a danger that the new NCS, in increasing its coverage, may find the depth of the teaching compromised, particularly as no guidelines for pacing have been included.

7.4.3 Implications

From the outset of the study I have mentioned that the implications of my findings for the promotion of social justice will be considered. It seems highly presumptuous to attempt to draw a correlation between a school biology curriculum and an issue as weighty as the latter, particularly in a country such as South Africa which is still a young democracy and remains beset with social disparities, not least in its education system. Nevertheless, as discussed in Chapter 2, various authors have suggested criteria on which to base such a judgment. These will briefly be revisited here.

In their summary of Bernsteinôs theorisation of knowledge, Maton and Muller (2007) proposed that there must surely be a limit to the amount of recontextualisation a knowledge structure can undergo, before the reproduction of specialised knowledges in schools is undermined. Individually, Muller (2007) argued that keeping sight of issues of hierarchy and progression in relation to the recontextualisation of knowledge structures in schools is essential for ñproviding to poor children access to the tools of powerful knowledgeò (Muller, 2007, p.83). It can also be recalled that Bernsteinôs argument (e.g. Bernstein, 1996) was that strongly classified knowledge ï that is, in which the boundaries between formal and everyday knowledge are made clear, and there is progression from concrete knowledge to more abstract general principles - is more highly valued in society, and thus is empowering to learners who are successfully inducted into its realms. Finally, Schmidt et al. (2005) argued that curriculum coherence is essential for successful induction into a subject, defining a curriculum as coherent if it is ñarticulated over time as a sequence of topics and performances consistent with the logical and, if appropriate, hierarchical nature of the disciplinary content from which the subject-matter derivesò (p. 528, my emphasis). My third question, *To what extent has there been a change in the recontextualisation of biology as an hierarchical knowledge structure in the three life sciences curricula, and what are the implications of this for social justice?*- was intended to consolidate the criteria suggested by these authors for judging the capacity of a curriculum to facilitate the induction of learners into the higher order concepts of the discipline, and thereby support the social justice imperative.

Overall, I believe my findings have provided evidence that there has been an improvement in the recontextualisation of biology as an hierarchical knowledge structure in the Biology/ Life Sciences curricula implemented in South Africa since 1994. I have shown that the current version (the new NCS) is the most faithful to the hierarchical structure of its parent discipline in that:

- its canonical content material most closely reflects the structure of academic biology in terms of its inclusion and handling of biology's core concepts, in particular its most integrating principle, the theory of evolution;
- there is clear conceptual progression towards these higher order concepts, with adequate knowledge foundations established in the lower grades and linkages carefully drawn between topics within and between grades, as opposed to the mere repetition of material;
- several hierarchies within biological knowledge have been included; and
- logical directives for sequencing have been given.

On these bases the tentative conclusion could be drawn that the new NCS has the greatest potential of the three to empower South African learners by inducting them into the realms of formal biological knowledge.

There was another dimension to the study, however, and that was the balance of canonical (formal) and humanistic (everyday) knowledge in each of the curricula, which could be taken to indicate the strength of the boundaries (or "classification", Bernstein, 1996) between these forms of knowledge. The argument already expressed is that a weakening of the boundary between "school" and "everyday" knowledge will have negative implications for learners, particularly those from disadvantaged backgrounds (Muller & Taylor, 2000; Taylor, 2001; and see discussion in Chapter 2). It has previously been shown empirically that differences in academic performance between privileged and disadvantaged learners tend to be exacerbated when boundaries between formal and everyday knowledge are collapsed (e.g. Hoadley, 2005). An alternative view, however, is that a more humanistic approach actually promotes the upliftment of learners (Aikenhead, 2006 and references therein). It has not been my intention in this study to debate which view is closer to reality. What the present study has shown, however, is that the new NCS occupies a middle ground between the almost exclusive emphasis on canonical biology in the ICS (strong classification), and the predominantly humanistic approach of NCS (weak classification)[5].

Perhaps it is relevant here to return to Donnelly's (2006) assertion that

> to have a knowledge of science and its particular mode of understanding the world as a significant and distinctive form of human intellectual activity is part of what it is to be educated. Such knowledge is a precondition for, and deployed within, intellectual autonomy and criticality (p.625; see Chapter 1 of this study).

Donnelly holds that science has unique ontological and epistemological intellectual qualities, and it is these qualities which render it educationally legitimate according to the liberal tradition – that which is concerned with promoting independent, critical, and creative ways of thinking. He argues that modern educational reform movements have tended to undermine these intellectual domains in order to present a more humanistic view of science, but that this latter approach is actually designed to achieve crude instrumental purposes in society, rather than the intellectual development of the student. The danger of this, in Donnelly's opinion, is that science education will come to serve the political ends of those who determine the curriculum, rather to promote the growth of the individual towards becoming ñcritical, autonomous, and informedé in his or her dealings with the worldò (Donnelly, 2006, p.625).

Could the trend in the new NCS towards a more traditional approach, with stronger classification of biological knowledge, serve to promote the development of these qualities in South African learners?

7.5 Some methodological issues

In this study I have joined the set of authors who have attempted over the years to find appropriate methods of analysing and comparing school curriculum policy documents. My eclectic approach confirmed to me that a range of methodologies may be required, both inductive and deductive, qualitative and quantitative, and representing research "for" and "of" policy.

Without a single, given set of core concepts in biology, or of the goals of a school biology education, these had first to be inductively derived before they could serve as deductive categories for analysis. The sources I used for these purposes obviously represent only a very small subset of all possible sources, and valid arguments against my selection could be raised. Nevertheless, the categories derived proved on the whole to be workable for my purposes. The ñcore conceptsò in biology translated fairly easily into themes for the analysis of the canonical material of the curricula, while Mayrôs ñwhat, how and whyò system served, rather unexpectedly, not only as a means of organising an hierarchical arrangement of the core concepts, but also to reveal strengths and weaknesses in the balance of these themes in the different curricula.

The ñfive objectives of a school biology educationò proved to be more problematic as categories ï possibly because a number of analysts were involved ï and it tended to be easier to collapse them into the categories ñcanonicalò and ñhumanisticò biology, although the results for the original categories were retained as they revealed more subtle differences between the curricula.

While many of my findings were qualitative, the quantitative results facilitated more powerful comparisons between the curricula.

Finally, the third part of the study represented research ñofò policy, but could perhaps suggest some implications ñforò future studies, which I propose below.

7.6 Limitations and recommendations

While I believe this study has provided evidence that the latest version of the life sciences curriculum represents a significant improvement on its predecessors according to a number of criteria, further improvements to the document could possibly be made. For example, the *caveat* regarding the number of topics to be studied could be tested. If research reveals that the range of topics is too broad to allow time for in-depth coverage, decisions need to be made as to what topics could be omitted without compromising the coherence of the curriculum. Ideally too, the fourth knowledge area would be renamed the more specifically biological term ñEcologyò in place of ñEnvironmental Studiesò.

But throughout my research, a refrain has sounded that *what really counts in education is what happens in the classroom*. This study was limited to the levels of the field of production of biological knowledge and the official recontextualising field of the school curriculum, the ñintendedò curriculum. Writing about curriculum reform in the 1970s and 1980s, MacDonald (2003, p.141) noted that "[c]urriculum innovations were invariably transformed between conception and implementation, and local forces, including the teacher and the school environment, played a key role in the apparent 'slippage' between conception and practice"[6]. In order to be able to make any kind of prediction about the effectiveness of a new curriculum, research at the level of the classroom into how the curriculum is taught and learned - the "implemented" and "attained" curricula - is obviously required.

The current 'roll-out' of the new NCS presents opportunities for follow-up studies to the present one. In particular the focus should be on the teaching of the topic of evolution, where a lack of knowledge, experience and confidence on the part of teachers will almost certainly play a major role in limiting its effectiveness[7]. Morais, Neves and Pires (2004) studied aspects of pedagogy to determine which were most favourable to the acquisition of knowledge and competence in science by students of different social backgrounds, and found that the *scientific competence of the teachers* was the primary condition for students' success. Most South African educators will be at a disadvantage when it comes to teaching evolution due to their own educational histories, and in terms of the resistance they could well face because of the prevailing belief systems, whether their own, their learners', or those of the community at large. Yet the country itself is rich in material for teaching this section. Perhaps partnerships need to be created between schools and experts who could assist in bringing this topic to life for South African learners and indeed their educators (see Branch, 2009).

7.7 Summary and concluding remarks

This study has been concerned with how formal biological knowledge is transformed when it is recontextualised in the school curriculum. I approached this by means of three sub-questions, directed at three levels: the level of academic biology (the field of production of biological knowledge), the level of the school biological curriculum in the developed world (the official recontextualising field), and the particular case of biology curriculum revision in post-apartheid South Africa. Findings at the first two levels provided criteria for analysing the South African curricula.

The recontextualisation of knowledge in the curriculum was related to the deeper issue of the promotion of social justice. Certain authors have argued that the more closely the knowledge in a curriculum reflects the structure of its parent discipline, the more successfully will learners be inducted into its realms, and the better will the social justice imperative be served. The comparative analysis of the life sciences curricula implemented in South Africa since 1994 showed that there has been an improvement in the way biological knowledge has been recontextualised in the successive documents, and that of the three, the new NCS is most faithful to the structure of its parent discipline. It was acknowledged that any conclusions about the new NCS's capacity to promote social justice in this regard can only be speculative, particularly as the study was limited to intended curriculum, rather than its implementation and acquisition in schools.

Nevertheless, a curriculum represents the official framework for what learning is to take place in schools, "the chief instrument for aligning the work of the multiple sets of actors who deliver teaching and learning" (Taylor & Vinjevold, 1999, p.107). It serves as the primary resource for the vast numbers of South African educators who themselves were poorly educated at apartheid-era schools and teacher-training colleges, and it also informs the textbooks on which they rely heavily. In conjunction with appropriate and ongoing support for teachers, then, a curriculum which adequately reflects its parent knowledge structure while demonstrating the relevance of the subject to everyday life, as does the new NCS, must surely represent a positive contribution towards the goal of transforming education and society in South Africa.

NOTES

[1] In this sense biology represents so much more than mere ñstamp-collectingò, Ernest Rutherfordøs infamous dismissal of the non-physical sciences. This was surely the notion which Mayr (e.g. 1988, 1997, 2005) was so committed to refute in his frequent emphasis on biologyøs autonomy and simultaneous equality with the so-called ñhard sciencesò of physics and chemistry (see Chapter 3).

[2] Darwin received a mention as a ñleading biological figureò in the senior grades of South African biology syllabi from 1947 up until the mid-1950s, when references to him were gradually removed as Christian National Education became the overriding educational doctrine (Lever, 2002).

[3] In fact ñall the necessary components to understand Darwinian evolutionò were not actually introduced in the NCS: the concepts of ñcommon descentò and ñgradualismò which Mayr (1997) regarded as two crucial components of Darwinøs theory of evolution (see Chapter 3) did not appear in the core content of the NCS as the authors state, though they were implicit in the ES. Moreover the topic of biogeography, which serves as evidence for common descent, received no mention in the NCS, though it did appear in the ES.

[4] The term ñhuman-centeredò is not intended to mirror the concept of ñhumanisticò. By the former I mean regarding only the human species as the exemplar of mammalian (or even animal) biology.

[5] It is of course possible that there should be different emphases for the two different stages of science education in schools - the compulsory years (typically up to grade 9, known as ñNatural Sciencesò in the current South African curriculum), versus the elective years (typically grades 10-12; in this case the life sciences curriculum, which has been my focus here). Logic may suggest that the curriculum for the compulsory years should pursue a more

ñscience for future citizensò or humanistic approach, which would at least give all students a preliminary sense of the relevance of science to their lives, while the elective years, which could be argued to be geared more towards those who intend to further their studies in the field of science, should adopt a more ñscience for future scientistsò or traditional approach to equip them for their tertiary studies. This idea is also expressed by Neves and Morais (2001).

Yet according to the arguments of Aikenhead (2006) and others (e.g. in Bennett, 2003), a more humanistic approach is preferable in the elective years, in order to increase interest and enrolment in the subject amongst seniors, and because these are the students who theoretically are better mentally equipped to deal with the sorts of socioscientific issues raised in such a course. This debate between the value of a traditional versus a humanistic approach will doubtless continue for many more years, if not all future years of the subjectøs existence in school curricula.

[6] Neves and Morais (2001) found, by contrast, that ñalthough teachersô space of change is quite considerable, teachers tend to use it less than could be desirable and mostly stick to the directions given in the syllabuses [sic] specific guidelines for the disciplineò (p.554).

[7] In the matriculation examinations of 2008, the first year the topic of evolution was examined under the NCS, the questions on evolution were on the whole either very poorly answered, or not even attempted (Edith Dempster, pers. comm., 20 October 2009).

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Appendix 1: Johnson, K., Dempster, E., & Hugo, W. (2005, 27-30 October). *Conceptual progression and knowledge boundaries in the curricula for Natural and Life Sciences.* Poster presented at the Kenton Education Conference, Mpekweni (see separate CorelDrawX3 file).

Appendix 2: Johnson, K. (2007, 25-28 October). *Troubling negative assumptions about education in South Africa: a case study of the Life Sciences curriculum.* Kenton Education Conference, P[h]umula. (See separate Microsoft PowerPoint file).

Appendix 3: Sample pages from South African life sciences curriculum documents implemented post-1994

a) The Interim Core Syllabus (p.7)

HIGHER GRADE

STANDARD 8

2. THE CELL

An introductory study of certain aspects of cellular structure and organisation. The main structural features of selected components of cells as revealed by the light microscope and by electron micrographs.

2.1 Biological importance of protoplasm. General appearance, physical characteristics and chemical composition; relevant functions of water and proteins.

2.2 Membranes enclosing cells and forming intracellular partitions: properties, structure and functions. Structure: simple fluid mosaic model only. Properties. Functions.

2.3 Nucleus: composition and functions. Composition: membranous envelope with pores; nucleoplasm containing chromatin and nucleoli; chromatin network composed of many chromosomes which, during cell division, become visible as strands bearing genes; nucleoli as dense regions consisting of nucleic acids. Functions: overall controller of structure and properties of cell in that genes regulate the synthesis within the cell of structural proteins and of enzymes; role in heredity. (No study of nucleic acid composition)

2.4 Ribosomes: location and function. Location: in cytoplasmic matrix, often attached to membranes of E.R. Function: sites at which proteins are synthesized

2.5 Plastids
2.5.1 Chloroplasts: location, structure and function. Location: in cytoplasmic matrix of some cells, usually positioned to obtain adequate light. Structure: variable shapes; enclosed by membranes; lamellae with grana containing chlorophyll; stroma. Function: sites of photosynthesis
2.5.2 Leucoplasts: location, mention of function
2.5.3 Chromoplasts: location, mention of function

2.6 Mitochondria: location, structure and mention of function. Location: in cytoplasmic matrix of most cells. Structure: double membrane; cristae. Function: site of final stages of respiration.

b) <u>The National Curriculum Statement (pp.34-35)</u>

TISSUES, CEL LS AND MOLECULAR STUDIES

Learning Outcome 1: Scientific Inquiry and Problem-solving Skills

The learner is able to confidently explore and investigate phenomena relevant to Life Sciences by using inquiry, problem solving, critical thinking and other skills.

Grades 10 - 12

ÿ Research in a field of biotechnology (e.g. chemotherapy).
ÿ Microscopic skills or other comparative methods and resources.
ÿ Investigation of (community) diseases: conduct surveys, collect data (e.g. on fungal, viral, animal and plant
diseases, genetic diseases).
ÿ Collection of latest research information on diseases (e.g. malaria resistance, TB incidence in South
Africa).

Learning Outcome 2: Construction and Application of Life Sciences
Knowledge

The learner is able to access, interpret construct and use Life Sciences concepts to explain phenomena relevant to Life Sciences

Grade 10

ÿ Cell structure.
ÿ Cell division (mitosis).
ÿ Tissues.
ÿ Related diseases (e.g. cancer).

Grade 11

ÿ Micro-organisms (viruses, bacteria, protists and fungi):
Ådiseases (e.g. rust, blight, rabies, HIV/AIDS, cholera, tuberculosis, malaria, thrush);
Åimmunity.

Grade 12

ÿ DNA, protein synthesis.
ÿ Chromosomes, meiosis, production of sex cells, diseases (e.g. Down syndrome).
ÿ Genes, inheritance, genetic diseases.

Learning Outcome 3: Life Sciences, Technology, Environment and Society

The learner is able to demonstrate an understanding of the nature of science, the influence of ethics and biases in the Life Sciences, and the interrelationship of science, technology, indigenous knowledge, the environment and society.

Grades 10 - 12

ý Historical developments (e.g. discovery of genes and DNA).
ý Ethics and legislation:
Åtissue culture;
Åcloning;
Ågenetic engineering;
Åethics.
ý Indigenous knowledge systems and biotechnology:
Åmicro-organisms and biotechnology in the food industry (e.g. cheese, beer);
Åtraditional technology (e.g. traditional medicines and healers);
Åmedical biotechnology (e.g. immunity, antibiotics, hormones like insulin);
Ågenetic engineering and its use in medicine and agriculture (e.g. genetically-modified crops);
Åcloning;
ÅDNA, fingerprinting and forensics.
ý Beliefs, attitudes and values:
Åbeliefs and attitudes concerning diseases;
Ågenetic counselling.

c) **The Elaborated Syllabus Grade 10 (p.10)**

TISSUES, CELLS AND MOLECULAR STUDIES

Cell Structure

3 weeks

CONTENT	ELABORATION/ SUGGESTED SEQUENCE
Introduction	❑ Discuss the history of the invention of microscopes ❑ Discuss the history of the discovery of cells
Microscope	❑ Describe the use of microscope in different fields of study ❑ List the different parts of the light microscope and state the function of each part ❑ Discuss magnification of the different lenses of the microscope ❑ Describe the steps involved in the use and care of the microscope
Microscopic skills	❑ Set up and use a light microscope ❑ Prepare a wet mount of plant or animal cells ❑ Draw the cell as observed under the light microscope ❑ State the rules to be followed when making biological drawings and representations
Structure of the cell	❑ Describe the structure, functions and structural adaptations to their functions, of the following organelles:- • cell wall • cell membrane • cytoplasm • nucleus • endoplasmic reticulum • ribosome • nuclear membrane • chromatin material • chloroplast • mitochondrion • vacuole

d) The new NCS (p.14; slightly modified)

STRAND: Life at the molecular, cellular and tissue level

Grade 10: Molecules to organs

All living organisms are made of atoms which combine to form molecules, and these make up the basic unit of life i.e. cells. Plant and animal cells have a complex organisation which enables them to carry out the basic properties of life, i.e. movement (movement in and around the cells and some cells move), nutrition (cells produce food or obtain food from elsewhere), respiration, excretion, growth, reproduction, and responding to stimuli. These cells are specialised and form tissues which perform particular functions. The tissues are arranged in organs which are also specialised to carry out particular functions. This strand introduces learners to life at the molecular, cellular, tissue and organ level.

LO1 Investigating phenomena in the Life Sciences	***LO2 Constructing Life Sciences knowledge***	***LO3 Applying Life Sciences in Society***
	Cells: the basic unit of life	
Explain and demonstrate how a light microscope works. *[If microscopes are not available, use diagrams.]* Investigate the structure of animal and plant cells using microscopes and/or other resources e.g. micrographs, models. Record observations in biological diagrams.	Molecular make-up: Cells are mostly made of proteins, carbohydrates, lipids, nucleic acids and water **Cell structure and function:** Introduce the idea of a cell as the smallest unit that has a complex organisation and carries out the properties of life e.g. Cell wall ï support structure Cell membrane ï boundaries and transport Nucleus, chromatin material, nuclear membrane, nucleopores, nucleolus ï the control centre Cytoplasm ï storage, circulation of materials Mitochondria ï powerhouse of the cell, releases energy Ribosomes ï protein synthesis Endoplasmic reticulum (rough and smooth) - transport systems Golgi body ï packaging centre Plastids ï production & storage of food, pigments Vacuole, lysosomes, vesicles ï storage, digestion, osmoregulation. **Cells differ** in shape, size and structure in order to carry out specialised functions *[link to tissues]*	History of microscopy: from lens to light and then electron microscopes. How the development of microscopes by Hooke, van Leeuwenhoek and others enabled people to see cells and then structures within cells and led to cell theory: All living things consist of cells. All cells arise from pre-existing cells.

Appendix 4: Wording of task for the analysis of objectives of three South African life sciences curriculum policy documents

Table 1 below elaborates on five major objectives of a western school Science/Biology curriculum, which I derived from journal articles from the last 25 years.

Following this table are lists of the stated objectives of three high school Biology curricula which I am studying for my Masters in Education.

Please consider each of the objectives for the three curricula and then classify them in terms of the categories given in table 1. Write the number of each objective in the relevant cell in the Results table given at the end. Some objectives may relate to more than one category, in which case the objective number should be written more than once, in each cell to which it corresponds.

If you feel you need to comment on this process, e.g. on any objective which was difficult to score, please feel free to do so in the form of brief notes after the table.

Please email the table and your notes, if any, back to me at this email address, along with your title and institution name.

Thank you very much.

Kathy Johnson

Table 1 *Objectives of a Western school science/biology education, as derived from literature of the past 25 years*

Category of objectives	Elaboration
Knowledge	Scientific facts, concepts, generalisations, principles, hypotheses, theories and laws, answering the question ñWhat do scientists know?ò
Skills	Includes those skills, abilities, methods, techniques and processes specifically concerned with the study of Science/Biology, answering the question, ñWhat do scientists do?ò, for example skills associated with doing scientific investigations, such as observation, hypothesis formation, data collection and processing, laboratory procedures, and the communication of scientific findings; ñdeveloping the capacity to do researchò; as well as generic skills such as critical thinking and problem solving, communication and co-operation.
Attitudes and values	Incorporates what are considered to be ñscientificò attitudes and values such as objectivity, respect for evidence, critical thinking, openness, honesty and so forth, but also the fostering of positive attitudes towards the subject, aesthetic appeal, satisfying curiosity, promoting appreciation and respect for nature, and recognising the value of co-operation in solving problems.
Applications	Both personal, for example understanding and solving problems regarding the scientific or technological aspects of daily life; preparation for further studies or a career in the field; and societal, for example the production of a scientifically literate populace, training of future scientists, the relationship between science and technology, science as a means for solving problems in society and the environment, as well as the limits of science in solving problems, and the potential for the applications of science and technology to harm the individual and the environment.
Science as a human enterprise	How science functions as an intellectual enterprise; science as a means of generating knowledge about the world; the nature of evidence and the relationship between evidence and theory; the tentative, changing and self-correcting nature of science; the history of science and scientific discoveries, science as a product of human endeavor, as part of our intellectual heritage; the dichotomy between òwestern modern scienceò and ñindigenous knowledgeò; multiculturalism; different interpretations of phenomena by different cultural and religious groups, such as the creation-evolution debate; ethics and biases. May include aesthetic, philosophical, sociological, economic and political aspects.

Stated objectives of curriculum A

1. An understanding of fundamental biological principles based upon a study of living organisms.
2. An awareness of biological relationships.
3. An ability to make critical, accurate observations of biological material, and to make meaningful records of such observations.
4. An ability to analyse and evaluate biological information, to formulate hypotheses and to suggest procedures to test them.
5. An ability to communicate clearly when reporting information and expressing ideas.
6. A respect for all living things and an urgent awareness of man's responsibilities in the preservation of life, particularly in the S.A. context.
7. A love and appreciation for the South African fauna and flora and a recognition of the urgent need for nature conservation.

Stated objectives of curriculum B

1. Explore those concepts that are essential for understanding basic life processes and the interrelationship and interdependence of components of the living and the physical world
2. Develop inquiry, problem solving, critical thinking and other skills, and use them to interpret and use Life Sciences concepts in explaining phenomena
3. Apply scientific knowledge in their personal lives and as responsible citizens in ways that will contribute to a healthy lifestyle and the sustainable management of resources
4. Develop an understanding of the nature of science, the influence of ethics and biases, and the interrelationship of science, technology, indigenous knowledge, environment and society
5. Understand biological, physiological, environmental, technological and social processes that impact on the environment (eg. food production, distribution and consumption, health promotion, conservation, sustainable

living and genetic engineering.) All these have implications for the socio-economic and technological advancement of society.

6. Exploring indigenous knowledge systems related to science exposes learners to different worldviews and allows them to appreciate, compare and evaluate different scientific perspectives

Stated objectives of curriculum C

At the end of Grade 12, learners should have:

1. Developed their knowledge of core biological concepts, processes, systems and theories.
2. Devised and evaluated investigations in biological processes and systems, following the principles of scientific investigations
3. Demonstrated knowledge of the nature of science, its benefits and its limitations.
4. Demonstrated an ability to critically evaluate and debate investigations, practices, issues and popular articles in terms of their scientific validity and credibility.
5. Identified ways in which biotechnology and biological knowledge have benefited humans.
6. Identified ways in which humans have impacted negatively on living organisms.
7. Developed a deep appreciation of the unique diversity of biomes in southern Africa, both past and present, and the importance of conserving these biomes.
8. Develop an awareness of the contributions that South African scientists have made to biological understanding.
9. Developed a level of academic and scientific literacy that enables learners to read, talk about, write about, and construct diagrams that illustrate biological processes, concepts and investigations.

10. Developed an awareness of what it means to be responsible citizens in terms of their own bodies and using the environment responsibly.

Results: A categorisation of objectives of three high school Biology curricula, based on Table 1.

Category of objectives	knowledge	skills	attitudes and values	applications	nature of science and science as a cultural enterprise
curriculum A					
curriculum B					
curriculum C					

Comments (if any):

Name and Title:

Institution:

Appendix 5: Ethical clearance approval

(in hard copy of thesis)