A Semantic Gravity perspective on South African school chemistry curriculum alignment

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A Semantic Gravity perspective on South African school chemistry curriculum alignment

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by

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Declaration

Submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Science Education, at the University of KwaZulu-Natal, Pietermaritzburg, South Africa.

I, Kavish Jawahar, declare that:

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Dedication

for the pleasure of

Sri Adhishakthi Bhuvaneshwari…

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Abstract

South Africa experiences crippling challenges in the recruitment and retention of Science, Technology, Engineering and Mathematics (STEM) students in Higher Education, with major implications for such things as socioeconomic development. In the country's school curriculum, it is Grade 10 which marks the beginning of a learner's potential STEM career trajectory. A deeper understanding of South Africa's Grade 10 curriculum literacy challenges and associated curriculum alignment in the key STEM field of chemistry is needed for enabling forms of epistemological access (such as semiotic access) that are critical for the empowerment of future scientists.

Chemistry as an academic discipline, is sustained by many individuals with shared ways of knowing facilitated by a system of semiotic resources such as visuals and text, referred to as discourse. Despite chemistry playing an important role in our lives and in school curriculum, the abstract nature of chemistry discourse poses challenges to students. The visuals and text of chemistry discourse contribute to chemistry curriculum demands imposed on students. While there is clear justification for promoting literacy practices in classrooms, the reading involved in school science has received less attention, and recommendations from literature point to the need for defining discipline-specific curriculum literacies and identifying implicit literacy practices. Such recommendations are further supported by the broader call made by sociologists of education for overcoming knowledge blindness in education.

This case study of South African Grade 10 Chemistry curriculum utilised document analysis for exploring the alignment of school chemistry curriculum literacy demands between the syllabus, textbook and exemplar examination in terms of abstraction. The Legitimation Code Theory conceptualisation of degree of abstraction in knowledge practices as Semantic Gravity (SG), provided a theoretical perspective for characterising visual and textual curriculum literacy demands of school chemistry curriculum documents. One translation device was developed specifically for exploring SG of visual items and a second translation device was devised specifically for exploring SG of textual items. The SG of visuals in the exemplar examination paper and textbook were tabulated and graphed in order to identify areas of stronger and weaker alignment between the visual literacy demands of these two documents of the pedagogic recontextualising field. Similarly, the SG of textual items in the syllabus, exemplar examination paper and textbook were compared to identify areas of stronger and weaker alignment between the textual literacy demands of the pedagogic and official recontextualising fields.

The methodological contribution of this study lies in it demonstrating the utility of SG as a mode of analysing curriculum alignment of subjects with hierarchical knowledge structures. The empirical findings reveal an overall high level of alignment for visual chemistry curriculum literacy demands, and for textual chemistry curriculum literacy demands at the lower levels of abstraction. Visual literacy demands were found to be higher than textual literacy demands, due to emphasis on visuals at the highest level of abstraction while the curriculum documents displayed a more even distribution of focal lexical items across levels of textual abstraction. This thesis argues that while exploring the alignment of visual and textual chemistry curriculum literacy demands between different curriculum documents is useful, it is equally important to consider how evenly the visual and textual items are distributed across the SG continuum as this has cognitive and affective implications for academic achievement and life chances of chemistry learners.

Keywords: school chemistry curriculum documents, abstraction, curriculum alignment, epistemological access, chemistry discourse, Legitimation Code Theory, Semantic Gravity

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List of Abbreviations and Symbols

1D	one-Dimensional
2D	two-Dimensional
A	Mass number
C2005	Curriculum 2005
CAPS	Curriculum and Assessment Policy Statement
CASS	Continuous assessment
CHE	Council on Higher Education
CiC	Chemistry in Context
COVID-19	Coronavirus disease 2019
DBE	Department of Basic Education
DoE	Department of Education
EPD	Epistemic pedagogic device
ER	Epistemic relations
FET	Further Education and Training
GET	General Education and Training
L^1	Internal language of description
L^2	External language of description
LCT	Legitimation Code Theory
n	Numbers of moles or energy level, depending on context
N_A	Avogadro's constant
NCS	National Curriculum Statement
NS	Natural Sciences
NSC	National Senior Certificate
OBE	Outcomes-based education
ORF	Official Recontextualising Field
PRF	Pedagogic Recontextualisation Field
RNCS	Revised National Curriculum Statement
s	solid
SA	South Africa
SD	Semantic Density
SEC	Surveys of Enacted Curriculum
SG	Semantic Gravity
sp	Spectroscopic electron configuration
SR	Social Relations
STEM	Science, Technology, Engineering and Mathematics
STP	Standard temperature and pressure

TIMSS	Trends in International Mathematics and Science Study
TIMSS 1995	Third International Mathematics and Science Study 1995
TIMSS-R	Third International Mathematics and Science Study – Repeat
TVET	Technical and Vocational Education and Training
UNESCO	United Nations Educational, Scientific and Cultural Organization
Z	Atomic number

CHAPTER ONE: INTRODUCTION

1.1 Orientation

Chemistry education is so well-recognised worldwide as an important component in general education, that chemistry has "become one of the most important disciplines in the school curriculum" (Ejidike & Oyelana, 2015, p. 605). Abstraction serves the development of scientific knowledge through it affording the creation of relationships and categories which organise the content of a text (Schleppegrell, 2019). It is thus problematic that the abstract nature of chemistry content is a barrier for many students (Ware, 2001). Disciplinary content and disciplinary literacy practices "are inextricably intertwined", and "without literate practices, the social and cognitive practices that make disciplines and their advancement possible cannot be engaged" (Fang & Coatoam, 2010, p. 628). The abstract nature of chemistry content then, is in part constituted by the semiotic resources (such as words and visuals) that are the basis of literacy practices in the discipline.

Rather than literacy practices associated with semiotic modes being generic across subjects, "it is no longer appropriate to talk about 'literacy across the curriculum', or even literacy *and* curriculum. Instead, there is a need to define curriculum literacies" (Wyatt-Smith & Cumming, 1999, p. 29). This is relevant to improving chemistry education considering that subject-literacies contribute to the "demands that a curriculum imposes on students" (Wyatt-Smith & Cumming, 1999, p. 30). Lemke (1998, p. 247) revealed that the literacy demands of the scientific curriculum in the final years of secondary school are at a maximum when students need to integrate specialised literacies (such as verbal and visual literacies) "quickly and fluently in real time".

While Lemke (1998; 2000) explored the multiliteracy demands of enacted curriculum in the science classroom, there was still a need for characterising the literacy demands of intended curriculum (as evident in such things as syllabi, textbooks, and exemplar assessment) which frame what is enacted in classrooms. Furthermore, there was a paucity of knowledge regarding the nature of alignment between the literacy demands imposed by different curriculum documents for science subjects such as chemistry, and the implications of this.

This introduction chapter makes the case for exploring the nature of alignment of South

African Grade 10 chemistry curriculum literacy demands in terms of the chemistry discourse feature of abstraction. For the purpose of orientating the reader to the overall thesis and to this introductory chapter, this section first provides a chapter overview (section 1.1.1), before presenting the study focus (section 1.1.2) and purpose of the study (section 1.1.3). These lay a foundation for framing the broader context of the study (section 1.2).

1.1.1 Overview of Chapter

Librero (2012) mentioned a general consensus between different authors of research texts about the importance of a thesis introduction making the research problem clear. In addition, he acknowledges that declaring the research focus from the outset is not straightforward since the nuance in meaning of the particular research problem is dependent on the wider context of the study (Librero, 2012). Such things as relevant historical developments, the rationale for the study, and an overview of how it was conducted are also important aspects of situating a thesis in the broader landscape of research literature (Librero, 2012). For this reason, section 1.1 serves to first orientate the reader to the study with the subsequent sections of this chapter providing more fine-grained detail.

Section 1.2 provides the contextual framework which begins by considering international competitiveness and South African tertiary science education, before discussing school science education in post-apartheid South Africa (SA) and associated school curriculum reform. Section 1.3 outlines each of the three curriculum documents that provided data for the document analysis undertaken in this study: a syllabus, related textbook, and associated exemplar examination paper modelling summative assessment. Section 1.4 introduces the notion of scientific literacy by differentiating between the derived and fundamental senses of science literacy and discusses literacy practices in science education. Section 1.5 outlines the notion of curriculum alignment and section 1.6 details the rationale for undertaking the study, as well as potential benefits of the study. Finally, section 1.7 will conclude the introduction chapter by providing an outline for each of the thesis chapters.

1.1.2 Focus of the Study

An academic discipline (such as chemistry) is created and sustained by many individuals with shared ways of knowing that are facilitated by a system of semiotic resources referred to as discourse (Airey & Linder, 2009). For instance, the discourse of science subjects includes semiotic resources such as images and words (Lemke, 1998). This implies that students' access to chemistry knowledge, is dependent upon semiotic modes such as the visual and textual modes.

Morrow (2009) reveals that achieving epistemological access to an academic practice allows one to be emancipated from particular forms of domination. Since access to an academic discipline is a social justice issue, so too is access to disciplinary discourse (Gray, 2017; Martin et al., 2019). Of relevance to the current study, Gray (2017, p. 98) highlighted that "access" is a problematic issue in contexts such as South Africa, where it is multifaceted and includes "semiotic dimensions". It is these semiotic dimensions of access to chemistry discourse which are most salient to this thesis. In terms of semiotic access, Hand et al. (2003) posited that the social practices that make science possible cannot be engaged in without text or reading. The education implication for chemistry, is that chemistry curriculum needs to adequately develop learners' chemical literacy in order for them to participate in chemistry discourse towards the goal of accessing chemistry knowledge.

Each subject has its own specific combination of literacies, and so there are various curriculum literacies (Wyatt-Smith & Cumming, 2003). The implicit expectations which curriculum embodies for students' engagement with semiotic modes such as the textual and visual mode, can be construed as curriculum literacy demands. Rather than being consistent throughout schooling, curriculum literacy demands facing school students intensify from one grade to the next (Halliday & Martin, 1993). For example, the school texts which engender disciplinary discourse practices become more abstract over time (Fang et al., 2006). Ultimately, as Lemke (1998, p. 247) revealed, "students in the final years of the secondary curriculum must meet stringent demands for mastery of multiple literacies at an advanced level".

Wyatt-Smith and Cumming (2003, p. 47) highlighted "the need for exploring the coherence of literacy demands that students encounter in managing their learning in different contexts and disciplines". While students' ability to meet curriculum literacy demands is critical for their access to chemistry knowledge, schoolteachers have historically shown concern that curriculum components such as textbooks are too demanding (Vachon & Haney, 1991). Textbooks, however, are just one curriculum component and the need for exploring literacy demands is also relevant for such curriculum components as syllabi/curriculum statements and exemplar assessments.

Curriculum statements or syllabi are the official texts, with textbooks and exemplar examination papers being examples of the pedagogic texts (Singh, 2002) which encode disciplinary knowledge. Textbooks and exemplar assessments are pedagogic recontextualisations of the official curriculum statement or syllabus in the knowledge recontextualisation field of Bernstein's pedagogic device (Bertram, 2012) as will be discussed in Chapter Two (see section 2.4.6). It makes sense that the different curriculum documents of the recontextualising field should be consistent in terms of content and cognitive demand. Such congruence or coherence of various elements of a schools' curriculum is referred to as curriculum alignment (Crowell & Tissot, 1986). As Gray (2017, p. 94) argued: "curricular coherence and thus disciplinarity are essential to various forms of 'access'". However, the nature of curriculum alignment beyond the level of content and cognitive demand is less clear-cut. This thesis focuses on exploring the characteristics of chemistry curriculum literacy demands and describing the nature and implications of alignment between related curriculum documents in terms of these literacy demands.

1.1.3 Purpose of this Study

According to Elmas et al. (2020), it is critical to understand the intellectual demands associated with intended curriculum, since they shape guidelines for other curriculum levels. Through an understanding of intellectual demands, greater alignment can be achieved between teaching and learning strategies, and objectives of the intended curriculum. Research on intellectual demands of intended curriculum thus informs the work of various stakeholders such as ministries, curriculum developers, and textbook authors (Elmas et al., 2020). The purpose of exploring a curriculum's intellectual demands is the mapping of expected levels of learning for a discipline and grade, and such research are facilitated by the use of taxonomies such as Bloom's taxonomy (Elmas et al., 2020). Once the intellectual demands of the intended curriculum are elucidated, alignment studies can be carried out to identify differences between the intended curriculum and other levels of curriculum (Edwards, 2010 in Elmas et al., 2020). This confirms the need for characterising such things as curriculum literacy demands, and subsequently exploring the nature of curriculum alignment as was undertaken in the study reported on in the current thesis.

Maton (2014, p. 2) revealed that "Knowledge is described as a defining feature of modern societies, but what that knowledge is, its forms and its effects, are not part of the analysis''. Such knowledge-blindness extends to educational research despite it being the intellectual field expected to address knowledge explicitly. Consideration of the paradox of knowledge blindness in education as highlighted by Maton (2014), warrants attempts to bring knowledge back into education. The current study contributes to this broader research agenda. While abstraction is a core feature of science discourse (Fang, 2005; Martin et al., 2019), the abstract nature of chemistry discourse is problematic even to students initially interested in the subject (Espinosa et al., 2013), when it is a barrier to accessing chemistry knowledge (Gabel, 1999). The literature presents various definitions for abstraction (often related to the discipline and/or particular theoretical lens being used), but it commonly involves one or more of the following: omission of detail, generalisation, and decontextualisation (Williams et al., 2017). The degree of abstraction of chemistry visuals and text in curriculum documents thus refers to the degree to which detail is omitted, the degree of generalisation, or degree of decontextualisation evident in these semiotic modes.

After reviewing the literature about South African school chemistry curriculum documents at the time of writing this thesis, two gaps became clear where studies had not yet been done:

- Characteristics of literacy demands in terms of the degrees of textual and visual abstraction implicit in chemistry curriculum documents for particular grades.
- The nature of alignment of chemistry curriculum literacy demands between different curriculum documents that together inform chemistry education for particular grades.

The purpose of this study was to help address these knowledge-gaps, by analysing the following curriculum documents:

- the Grade 10 chemistry component of the current South African school physical sciences syllabus;
- the Grade 10 chemistry component of a related textbook; and
- an associated Grade 10 exemplar chemistry examination paper.

The study is framed by the Semantics dimension of Legitimation Code Theory (LCT) (the focus of Chapter Four), which addresses the degree of abstraction of knowledge practices and relates it to cumulative knowledge building (Maton, 2014). Cumulative knowledge building is particularly necessary for learning hierarchical knowledge structures (discussed in section 2.5.2) such as chemistry. More generally "cumulative knowledge-building in research, teaching and learning are at the heart of education" (Martin et al., 2019).

1.2 Contextual Framework

This discussion of the context of the study begins at a broad level in order to first highlight why the stakes are high when it comes to school Physical Sciences education in South Africa. Section 1.2.1 contributes to this contextualisation by discussing international competitiveness and acknowledging its relationship to tertiary science education. This provides a basis for section 1.2.2 which narrows the focus down to South African school science education. Section 1.2.3 addresses school curriculum reform in South Africa since the country became a republic in 1994, and sets the scene for introducing the current school curriculum documents that are of relevance to this study in section 1.3 (a detailed description of these documents is provided in Chapter Five).

1.2.1 International competitiveness and South African tertiary science education

Science is a central feature of discussions about international competitiveness since it is widely accepted that science (together with technology and engineering) has an impact on national economic growth and individual quality of life (Pistorius, 2001). In resource-rich South Africa for example, chemistry plays such a dominant role in the success of major industrial sectors such as mining, food, water, and pharmaceuticals, that it can be regarded as the "core of South Africa's economy" (Steyn, 2011, p. 1). The close relationship between scientific advancement and economic growth explains why good quality science education, is viewed globally as an indicator of economic success (Cho et al., 2012).

More specific to chemistry, a country's achievement of sustainable economic development hinges upon its chemical industry's production of a diverse range of products (Hjeresen et al., 2000). Despite growing investment in science by the South African government, the lack in growth of the scientific workforce threatens the country's ability to compete in the knowledge economy (Diab & Gevers, 2009). For instance, the foremost challenge facing South Africa's chemical industry is the shortage of chemical engineers (Majozi &

Veldhuizen, 2015).

Policymakers and the public in general have shown growing interest in statistics enabling comparison of countries on a range of matters such as economic and educational performance. These two are of special concern to policymakers due to the perceived link between economic prosperity and education (Harlen, 2001). While national policy of a country such as South Africa may recognise the significance of competitiveness and innovation, such contexts have a history of disappointing performance in ratings of international competitiveness (Pistorius, 2001). An example of this is the Trends in International Mathematics and Sciences studies (discussed in section 1.2.2). More recently, Koopman (2017, p. 26) affirmed that the position South Africa holds in local and global knowledge economy is still problematic, and explains that the premium placed on school science is a result of this.

Related to the issue of quality of life as highlighted by Pistorius (2001), the Declaration of Budapest proposes that the distinction between the poor majority of people/countries and the wealthier minority is not only based on possessions but also on exclusion of the majority of citizens from the creation and benefits of science knowledge (UNESCO, 2010). It makes sense therefore, why one aspect of the education reform in South Africa by its first democratic government in 1994 was the importance of science being emphasised for the first time in the country through policies such as the White Paper on Education and Training (Department of Education [DoE], 1995) and National Strategy for Mathematics, Science and Technology education (DoE, 2001). However, Reddy (2006a) pointed out that while SA has many policies and programmes for improving the state of science education in the country, the ultimate success indicator is student performance.

Hornsby and Osman (2014) explained that due to such things as the moral imperative of transformation and constraints around fiscal resources, higher education institutions in South Africa have been under increasing pressure to massify course offerings. Massification and democratisation of entrance to the 25 public universities and 50 public Technical and Vocational Education and Training (TVET) colleges in South Africa has contributed to increased enrolments (Maringe & Osman, 2016) and brings into focus the distinction between formal and epistemological access. Morrow (2007) referred to gaining admission into institutions of higher learning as *formal access* and distinguishes it from *epistemological* *access* – the acquisition of knowledge, skills, and practices via a curriculum.

The challenges encountered by many students in their first year of college or university results in a high dropout rate (Jacobs et al., 2015) contributing to low overall throughput – a cause for much concern (Council on Higher Education [CHE], 2010). For example, some completion rates in regulation time reported within the past decade were as low as 23% for science and engineering degrees; as low as 14% for science diplomas; and as low as 5% for engineering diplomas (CHE, 2013). This is highly problematic considering that South Africa has not been producing sufficient science graduates to meet its economic development objectives (Department of Higher Education and Training, 2013), or to enhance its ability to compete in the global knowledge economy (Diab & Gevers, 2009). Since increased diversity warrants consideration of factors contributing to some students facing a higher risk of academic failure than others (Rusznyak et al., 2017), massification is only meaningful if epistemological access is valued alongside formal access.

Due to the potential benefits of increased formal or physical access to tertiary science studies being strongly constrained by low throughput rates, a major factor contributing to South African students dropping out of tertiary science programmes will now be considered. The education system has many interlocking components, and "it is widely accepted that student underpreparedness is the dominant learning-related cause of the poor performance patterns in higher education … it is the school sector that is most commonly held responsible" (CHE, 2013, pp. 16-17). The failure of many students in first year university chemistry courses is attributed to gaps between school and university chemistry (Mumba et al., 2002). The reality is that many students enter university with a poor understanding of basic high school chemistry (Gadd, 2000 in Mumba et al., 2002), bringing South African school science education and curriculum into question.

1.2.2 South African school science education

The education system of many countries such as South Africa includes some compulsory science education in primary and early secondary schooling. This is usually followed by learners in the latter part of secondary schooling being afforded an opportunity to choose whether or not to continue studying science through the final years of schooling. The optional science subjects in the Further Education and Training (FET) phase of upper secondary schools (Grades 10-12) in South Africa are Life Sciences – covering biological topics, and Physical Sciences – covering chemistry and physics. We will return to the discussion of Physical Sciences after considering the performance of South African students in science prior to Grade 10.

The compulsory science subject studied by South African General Education and Training (GET) Grade 7 to 9 students is Natural Sciences (NS) which covers four content strands: life and living; energy and change; matter and materials; and planet earth and beyond (South Africa. DBE, 2011). As will be discussed in Chapter Four (see section 4.5), the current study focuses on Grade 10 chemistry. However, the hierarchical knowledge structure of science subjects (detailed further in section 1.5.2) warrants consideration of the poor performance of South African Grade 8 and 9 Natural Sciences students in addition to the performance of grade 12 Physical Sciences students in order to understand the broader context of South African school science education.

Recognition that quality science education is an indicator of economic success internationally, necessitates monitoring of science education quality. International comparisons are commonly used to identify practices linked to high performance and avoid those linked to low performance (Harlen, 2001). For example, the Trends in International Mathematics and Science Studies (TIMSS) have provided participating countries with a useful means of ranking their school maths and science student achievement (Cho, Scherman, & Gaigher, 2012). South Africa participated in a number of TIMSS over the past three decades and has been consistent in its very low ranking.

Natural Sciences learners in South Africa achieved the lowest average score of all the countries participating in the Third International Mathematics and Science Study 1995 (TIMSS 1995), Third International Mathematics and Science Study – Repeat 1999 (TIMSS-R 1999) and Trends in International Mathematics and Science Study 2003 (TIMSS 2003) (Reddy, 2006b). South African Natural Science learner performance was ranked one above the lowest level in the Trends in International Mathematics and Science Study 2011 (TIMSS 2011), but was again ranked the lowest of all participating countries in the Trends in International Mathematics and Science Study 2015 (TIMSS 2015) and Trends in International Mathematics and Science Study 2019 (TIMSS 2019) (Reddy et al., 2020). In general, the preparedness of South African learners entering Physical Sciences at Grade 10 level is thus questionable.

As mentioned earlier, Physical Sciences is a non-compulsory South African school subject in Grades 10-12 which covers physics and chemistry content (DBE, 2011). Interestingly, physics and chemistry are taught as separate subjects in many other African countries such as Ghana, Kenya, and Zambia compared to their being taught together within the subject of Physical Sciences in South Africa. Furthermore, while one or more science subjects are compulsory for all school students in the aforementioned African countries, Life Sciences and Physical Sciences are both elective subjects from Grades 10-12 in South Africa (Umalusi, 2008). The country's schooling system thus allows students to choose whether or not to study any science in the last three years of schooling. Furthermore, for those studying Physical Sciences, the amount of time allocated for chemistry and physics content is thus lower, relative to countries where they are taught as separate subjects.

In South Africa, the Grade 12 summative examination that plays a gate-keeper role for formal access to tertiary study, is named the National Senior Certificate (NSC) examination. As shown in Table 1.1, learners' overall performance in the NSC Physical Sciences examinations has shown some improvement over recent years. The decrease in student performance from 2019 to 2020 is attributed to the 2020 school closures due to the COVID-19 pandemic (Motshekga, 2020). The effect of school closures during the pandemic is considered further in Chapter Two (see section 2.2). Despite some improvement over recent years, student performance in Physical Sciences is still problematic considering that approximately 40-50% of the physical science students achieved a mark over 40% and fewer than 5% of students achieved a distinction pass (a mark in the 80-100% range) in the last five years.

Table 1.1: Physical Sciences learners' overall results for National Senior Certificate exams in recent years (Motshekga, 2019; 2020; 2021)

Year	Enrolment (number of students)	% of students achieving 30% and above	% of students achieving 40% and above	% of students achieving distinction (80-100%)
2016	192 618	62.0	39.5	3.7
2017	179 561	65.1	42.2	4.4
2018	172 319	74.2	48.7	4.7
2019	164 478	75.5	51.7	4.7
2020	174 310	65.8	42.4	3.7

Since university entrance depends on the total number of points achieved across Grade 12 examinations, low Physical Sciences marks contributes to fewer students achieving admission to tertiary study in general, and not just admission into science degrees. The fraction of students completing Grade 12 who achieved admission to a bachelor's degree study was only 26.6% in 2016, 28.7% in 2017 and 33.6% in 2018 (Motshekga, 2019). Again, while some improvement is evident from year to year, this means that only about one third of 2018 matriculants qualified for first year university study in 2019 (Motshekga, 2020).

While poor school science results are a problem in many countries (UNESCO, 2010), it has long been acknowledged that the majority of learners performing poorly in school science live in developing countries (Lewin, 1993). South Africa is an example of this, as evident from the poor performance of Natural Sciences students in consecutive TIMSS', and Physical Sciences students in the NSC examination results over recent consecutive years. The poor performance of learners in school science subjects alludes to the significant challenges facing science education in South African schools, some of which will now be considered.

Discussing the teachers' exodus from South African schools, Lumadi (2008) highlighted the fact that teachers in Africa (and particularly in South Africa) face monumental challenges from the national level down to the classroom level. These include inadequate resources such as science laboratories and textbooks. For example, in Lumadi's (2008) study the textbooks found to be in use by teachers were obsolete and in the more extreme cases, it was found that one textbook was being shared between up to 10 students. Furthermore, Physical Sciences and similar subjects were being taught theoretically, with practical components being ignored since they required laboratories with apparatus. It was further revealed that many challenges facing science teachers related to recurring changes in syllabus (Lumadi, 2008), as outlined in section 1.2.3.

While it is accepted that scientific knowledge is provisional, much of it is so well supported that it is regarded as fixed (Osborne & Dillon, 2010). This makes it possible to design school science curriculum at a national level. The design choices made and subsequent emphasis of a school science curriculum are based in part on considerations around the purpose of school science education. For example, the three purposes which chemical education can serve are: preparation of chemistry researchers and chemical-industry staff; contributing to the general education of society; and acting as an exemplar in terms of practices and outcomes of science (Gilbert et al., 2003).

In particular, preparation of a chemistry workforce and general chemistry education for society relates to the broader debate in science education about whether it should aim at developing a scientifically literate nation that can engage with public science issues and use science in their everyday lives (humanistic science) or at preparing future scientists for the science workforce (canonical science) (Umalusi, 2015). As Osborne (2007) puts it, there is a tension between the needs of a minority (those who will continue to study science at tertiary level) and the needs of the majority (those who will not study science beyond school level). South African school science curriculum does not currently differentiate between these categories of science students.

1.2.3 School curriculum reform in South Africa since 1994

South Africa is a part of sub-Saharan Africa. The changes in sub-Saharan African education over the past three decades are described as diverse and complex due to both the component country profiles and the forces (internal and external) shaping the changes, being heterogenous (Chisholm & Leyendecker, 2008). Reflecting the global tendency towards democracy, many African countries such as South Africa undertook multi-party elections in recent decades which laid the foundation for educational reform. Spaull (2013) reminded us that the integration (social, economic, and political) of South African people and especially those who had been marginalised during apartheid, was central in the national agenda subsequent to the political transition in the country. The post-apartheid government needed to facilitate economic growth, reduce unemployment, and expand service delivery in a system characterised by decades of racial exclusivity. Towards achieving this transformation and towards the goal of social cohesion, education expansion and reform was prioritised (Spaull, 2013).

For education reform in general, curriculum planning and development is a core priority (Henson, 2015). This is no less true for science education reforms more specifically, where it is evident that curriculum design and implementation continue to appear at the forefront (Toldsepp, 2009). Hence, rather than being fixed, curriculum is constructed, negotiated, and renegotiated across different levels over time (Goodson, 1994). The fact that political ideology is one of the many factors influencing curriculum makes sense when one considers that curriculum is a central concern in education (Su, 2012), and that education is always political (Msila, 2007). Even researchers with different theoretical perspectives agree that national curricula are usually closely related to national political visions (Harley & Wedekind, 2004). The usefulness of curriculum as a tool in political reform is worth noting in this contextual framework.

The association of political ideology and curriculum is strongly evident in South Africa, where apartheid was previously employed as a tool for strategically dividing society (Harley & Wedekind, 2004; Msila, 2007). Apartheid education was characterised by schools being divided on the basis of race, with curricula deemed by many as irrelevant and monocultural because they strengthened citizenship of one race group over others (Msila, 2007). The unequal education system prior to the election of a democratic government in 1994 was evident from the various provinces, homelands, and groups in the country being catered to via 18 different education departments (Harley & Wedekind, 2004). However, some recognised that if curricula could divide society and differentially prepare groups for predetermined social, political, and economic rankings in apartheid South Africa, then curricula could also be used for the purpose of uniting citizens as equals in a democratic South Africa (Harley & Wedekind, 2004). As highlighted by Green and Naidoo (2008, p. 236), "With political change in SA, radical curriculum change was advocated by national curriculum policy".

The transformation of school curriculum was a key strategic and symbolic challenge facing the post-apartheid government. Norms and standards were the focus of the national department while curriculum implementation was the domain of provincial departments –

structurally representing the traditional policy/practice divide (Harley & Wedekind, 2004). According to Harley and Wedekind (2004), the actual curriculum reform followed a clear sequence. During the first wave of reform after the 1994 elections, differences in curriculum followed by the various education departments were ironed out. The second wave involved existing syllabi being purged of content that was outdated, sexist or racially offensive, while new curriculum policy was being written. The result was an interim syllabus for each subject intended for use across provincial education departments while new curriculum policy documents were being developed (Green & Naidoo, 2006). These rushed curriculum adjustments were criticised by Jansen (1999) as being superficial on the basis of them having little to do with school curriculum, and more to do with a government being in transition and seeking legitimacy.

Curriculum 2005 (C2005) was the "new curriculum" launched in 1997 to be progressively phased in from 1998 in order to cover all of the schooling sectors by 2005. The design feature of outcomes-based education (OBE) was so central to C2005, that it became synonymous with the curriculum itself (Harley & Wedekind, 2004). For instance, Chisholm (2005) described C2005 as a form of outcomes-based education. She elaborates further that while this form of OBE in South Africa included local adaptations and responses, its origin and evolution hailed from the competency debates in Canada, the United States, Australia, New Zealand, and Scotland (Chisholm, 2005). This third wave of curriculum reform moved the focus away from content and onto assessment, with continuous assessment (CASS) being introduced into schools during 1996 (Harley & Wedekind, 2004).

According to Chisholm (2005, p. 86), C2005 proponents in SA viewed the guiding philosophy of OBE as "the pedagogical route out of apartheid education". In focusing on outcomes being achieved by all at differing paces and times rather than on content-laden subjects, C2005 embodied a clear movement away from what was limiting in apartheid education content and pedagogy (Chisholm, 2005). However, Chisholm and Leyendecker (2008) highlighted that as a tool intended for reversing the injustices of apartheid education, OBE served economic, social, and political goals rather than educational goals. Its identity in opposition to apartheid education necessitated characteristics such as being non-prescriptive and requiring teachers to develop their own learning programmes and support materials (Chisholm, 2005).

Harley and Wedekind (2004) agreed that C2005 was a political rather than pedagogical project, with a range of implementation weaknesses such as the curriculum policy being complex and teacher development being inadequate. With the curriculum arising from a political agenda rather than from debates around appropriate pedagogy or a situation analysis of the diverse and unequal schooling contexts, teachers and teacher-educators faced "a new curriculum world" (Harley & Wedekind, 2004, p. 199). Allais (2007) argued that qualification frameworks that are outcomes-based prioritise the economy over the academy. Drawing on the work of Bernstein, she pointed out that OBE undermines formal education which has at its heart, the socialisation of students into a field, discipline, or content area.

Harley and Wedekind (2004) revealed that the response from schools to C2005 was uneven. With such a resource-hungry curriculum, it was no surprise that well-resourced schools thrived. A later study on teachers' responses to OBE (Matshidiso, 2007) confirmed this, mentioning the importance of resources such as textbooks, more specifically. In contrast to wealthier schools, the historically disadvantaged schools lacked resources such as textbooks for the effective implementation of curriculum 2005 (Chisholm et al., 2000). A range of authors thus concluded that instead of the new curriculum narrowing the gap between schools characterised as historically advantaged or disadvantaged, the sophistication of newer policies widened the gap (Harley & Wedekind, 2004). A Ministerial Review Committee was appointed in 2000 which recommended a major revision of C2005 to make it more understandable (Chisholm, 2005), and this constituted a fourth wave of curriculum reform, following from the three mentioned by Harley and Wedekind (2004). The revision ultimately resulted in the development of the Revised National Curriculum Statement (RNCS) which became policy in 2002. The RNCS covered subjects in the GET band (which extends up to Grade 9) since the phasing in at FET level had not yet begun.

From 2006, the National Curriculum Statements were phased in at Grade 10 level. The National Curriculum Statement (NCS) for Physical Science (Grade 10-12) for example, had its implementation in Grade 10, 11, and 12 taking place in 2006, 2007, and 2008 respectively (Green & Naidoo, 2006). The relevance to the current thesis, of South African school curriculum reform until this point, is that none of the waves described thus far prioritised bringing knowledge back into debates on curriculum as argued for by social realists such as Michael Young (2008).

The class of 2008 were the first matriculants for the National Curriculum Statement. However, just one year later (2009), a ministerial committee was appointed for the purpose of investigating the nature of the challenges faced in the curriculum's implementation. Of relevance to this thesis, is that one of the improvements considered crucial was greater alignment in curriculum processes (Motshekga, 2009). In acknowledging the strong criticisms against outcomes-based education in South Africa, the Minister of Basic Education (Angeline Motshekga), "signed the death certificate of OBE (as reported in the media) in 2010" (Le Grange, 2014, p. 471).

Nakedi et al. (2012) highlighted a recommendation that was made by the ministerial committee reviewing the NCS. A new curriculum statement would be developed for each subject that would embody definitive support for teachers. These new curriculum statements would also contribute to addressing complexity and confusion arising from vagueness, lack of specification, proliferation of documents, and misinterpretation. The minister of basic education subsequently appointed a project committee for each subject, tasked with designing one Curriculum and Assessment Policy Statement for each subject, to be phased in at Grade 10 level in 2012. This fifth and most recent wave of curriculum reform resulted in new syllabus documents which retained the name NCS, with the addition of the Curriculum and Assessment Policy Statement (CAPS) in order to differentiate the current curriculum (NCS - CAPS) from the previous version (NCS). An example of this is the current NCS Curriculum and Assessment Policy Statement: Physical Sciences (Department of Basic Education [DBE], 2011).

The NCS-CAPS were published in 2011, phased in at Grade 10 level in 2012 and thus reached Grade 12 implementation in 2014. Accompanying the phasing in of the new syllabus, textbook publishers released a new range of textbooks and the department of education (DoE) also released exemplar examinations papers for use with the NCS-CAPS. The question that remains, is the extent of alignment between these current curriculum documents, which will be considered further after an overview of the documents themselves.

1.3 South African School Science Curriculum Documents

The current South African school curriculum is specified in multiple NCS-CAPS, which detail the syllabus for each school subject. In line with substantial changes during the post-apartheid curriculum reforms, new textbooks were published for use with each new curriculum statement. The textbooks currently in use at South African schools were thus developed specifically for the NCS-CAPS. Furthermore, exemplar examination question papers were distributed by the DoE to model summative assessment for the current syllabus. In this thesis, the term "curriculum documents" is used to collectively refer to school syllabi (or curriculum statements), associated textbooks, as well as exemplar examination papers. This is supported by the fact that various models of curriculum recognise it as a multi-layered construct incorporating each of these documents, as discussed further in Chapter Two (see section 2.4).

1.3.1 Curriculum statements (syllabi)

Questions related to quality of a curriculum and its implementation are still relevant globally (Grussendorf et al., 2014). Provision and implementation of strong science curricula towards national development is a trend in many developing countries, including South Africa (Dahsah & Coll, 2007). In fact, historically, school chemistry curricula have been shaped in response to social changes (Wei, 2019). As outlined earlier, since South Africa's first democratic elections in 1994, the government's DBE undertook multiple reforms focusing on improved teaching and learning for subjects like Physical Sciences (Gudyanga & Jita, 2018). The NCS-CAPS raised new challenges, as exemplified by Gudyanga and Jita (2018) undertaking a study to map South African Physical Sciences teachers' concerns regarding the NCS-CAPS. Their study found that most of the participant physical sciences teachers were grappling with self-concerns (how the curriculum innovation affected them as teachers) and certain task concerns (daily teaching obstacles such as large classes and lack of resources) even five years into the implementation of the NCS-CAPS.

Ottevanger (2001) revealed that while curriculum reform is a learning process for teachers, support for their implementation of changes in curriculum is usually limited. The accompanying in-service training is mostly in workshop form and short-lived (two or three years). The lack of sustained in-service training for continuous professional development is a major hindrance to effective science education reform (Ware, 1992). Successful implementation is constrained by well-known obstacles such as inadequate grasp of content knowledge and foundation teaching skills, the challenge posed by language to both teachers and students, a lack of teaching resources, and misalignment between curriculum goals and assessment (De Feiter et al., 1995).

In the context of many un(der)qualified science teachers and limited in-service teacher support it becomes evident why, as Ball and Cohen (1996) pointed out, development and use of curriculum materials are significant strategies for curriculum implementation. Ottevanger (2001) defined teacher support materials as materials which can assist teachers' implementation of curriculum reforms in classrooms, and uses the metaphor of such materials as catalysts for science curriculum implementation. Although it is reported that student textbooks are commonly the only support material available to students and teacher in the African context (Ottevanger, 2001), both student textbooks and exemplar examinations serve as teacher support materials, as will be outlined now and discussed further in Chapter Two (see sections 2.6.2 and 2.6.3).

1.3.2 School science textbooks

Textbooks are one of the most critical factors when it comes to the support or hindrance of science learning (Leite, 1999; Hubisz, 2003). This is not surprising, considering that school science textbooks are an important source of knowledge for science students and are often the most accessible reference sources for them (Devetak & Vogrinc, 2013). Research has indicated that despite their being primarily aimed at student use, teachers are strongly reliant on them (Leite, 1999). For example, science textbooks are employed by science teachers to help them implement a science curriculum (Ogan-Bekiroglu, 2007; Young & Nguyen, 2002). The fact that textbook-oriented approaches to teaching and learning are dominant in high school (Roth et al., 2005) also reflects the important role they play in the work of teachers and learners (Lemmer et al., 2008; Mahmood et al., 2009). Furthermore, it explains why they both spend a substantial amount of time working with textbooks (Nicol & Crespo, 2006).

For science disciplines, which involve the extensive use of complex classification systems, graphics, and taxonomies (otherwise needing to be illustrated via such things as charts, chalkboards or whiteboards), the role of textbooks is especially significant (Lee & Spratly, 2010). It is thus no surprise that the use of science textbooks as a basic resource by science educators for guiding their teaching, is a worldwide phenomenon (Chiappetta et al., 1991; Hubisz, 2003; Leite, 1999). Hubisz (2003, p. 50) pointed out that through textbook use, even underqualified science teachers, "can keep ahead of most of their students and learn as they go. It is not a good situation but it could work”. The central role of textbooks in science education and the fact that textbooks are even more useful to the many South African science teachers with little experience or training, is also recognised by Lemmer et al. (2008). Although dependence on textbooks is associated with underqualified teachers, many qualified teachers also rely on textbooks since they may not have the time or training to prepare new learning materials (Ornstein, 1994).

While it is widely recognised that school science textbooks are associated with school science syllabi, Ornstein (1994, p. 70) argued that “textbooks have come to drive the curriculum”. Since good science textbooks help both teachers and students better understand a science curriculum (Mahmood et al., 2009; Stoffels, 2007), it is understandable why new textbooks are often developed following a change in curriculum. For example, Green and Naidoo (2008), reminded us that new textbooks are developed with new South African curriculum policy documents and recommend that “textbooks and their use in South African education needs to be examined through research” (p. 236). Demonstrating curriculum research focusing on textbooks, Smith (2012) presented a framework of curriculum where the link between curriculum materials (which include textbooks) and the intended and assessed curriculum was acknowledged. This supports the notion of textbooks as objects of analysis in curriculum alignment studies such as the one reported on in this thesis, and it also flags the consideration of exemplar assessment.

1.3.3 Exemplar examination papers

Barnes et al. (2000) argued that irrespective of the metaphor used for describing the function of assessment either within or on curriculum, there is universal acknowledgement of the centrality of assessment. As alluded to earlier, observable and measurable indicators such as test scores have risen in significance not only as measures of students’ academic performance, but also of teachers and more broadly, nations (Ro, 2018). Of particular importance for contexts such as South Africa in which there have been several curriculum reforms over the past few decades, “attempts at curriculum reform are likely to be futile unless accompanied by matching assessment reform; and assessment can be the engine of curriculum reform, or the principal impediment to its implementation” (Barnes et al., 2000, p. 632). This feature likens exemplar assessment to textbooks, in terms of its potential for driving curriculum implementation.

Nakedi et al. (2012) referred to the *backwash effect* that summative assessments have on classroom practice. This occurs in situations (such as in South Africa) where school ratings depend on pass rates. In such situations, teachers tend to teach towards their students succeeding in examinations (as opposed to student understanding). Prodromou (1995) defined the notion of backwash in terms of the effects (direct or indirect) that exams have on teaching methods and Gates (1995) extended this definition beyond teaching to include the effects of testing on learning. Ultimately, national examination papers and memoranda become a part of the documentation informing teaching and learning, allowing them to play a similar role to syllabi and textbooks in this regard. The South African Department of Basic Education released national exemplar examination papers after the NCS-CAPS were published, to guide teachers in setting their own examination papers for their students. Exemplar or model assessments are associated with 'feed-forward' approaches in light of the constraints of 'feedback' (discussed further in section 2.6.3. of Chapter Two).

The scenario of assessment exerting a strong influence on what is taught, is encoded in the metaphor of "the assessment tail wagging the curriculum dog" (Barnes et al., 2000, p. 624). While usually seen as undesirable, Barnes et al. (2000) reminded us that it is fully appropriate when the performances which assessment privileges are exactly those constituting curriculum goals (alignment between assessment and curriculum). The authors point out that credibility of curriculum and assessment is likely enhanced if they are in alignment – an important consideration in order to prevent the hampering of a reform agenda (Barnes et al., 2000).

Chisholm (2005, p. 87) highlighted a previous "lack of alignment between curriculum and assessment", affirming the importance of exploring such documents as national exemplar examination papers in South African curriculum alignment studies. Nakedi et al. (2012) referred to textbooks and exemplar examination papers collectively, as "*illustrated curriculum*" which lies at the interface between *envisioned* and *enacted* curriculum (discussed further in section 2.4.7 of Chapter Two). As mentioned in section 1.1, subject-literacies contribute to the "demands that a curriculum imposes on students" (Wyatt-Smith & Cumming, 1999, p. 30). It is appropriate at this stage, to shift our attention to the broader notion of scientific literacy.

1.4 Scientific Literacy

1.4.1 Fundamental and derived science literacy

Most science teachers agree that the purpose of school science is to develop learners' scientific literacy (Bybee, 1995; Smith, 2012). Scientific literacy has both macro and micro-level benefits. Advantages of scientific literacy on a macro level, include such things as benefits to a country's economy, to the domain of science itself, to science policymaking, to democratic practices as well as to society in general (Laugksch, 2000). On a micro level, the benefits of scientific literacy include citizens being in an advantageous position to access high-paying technological and professional careers (DoE, 1995). Laugksch and Spargo (1999) conducted a study to measure the scientific literacy of Grade 12 South African learners and found that in South Africa, the school subject Physical Sciences, plays a significant role in improving scientific literacy (Laugksch & Spargo, 1999).

Providing a more nuanced explanation, Norris and Phillips (2003) referred to two 'senses' of scientific literacy, reminding us of Miller's explanation from two decades earlier (Miller, 1983). The "fundamental sense" refers to the "ability to read/write science text" and the "derived sense" is explained as "knowledgeability about science". The fact that the "derived" sense of science literacy relies on the "fundamental sense" is made clear when one considers that learners ideally progress from the "learning to read" stage to the "reading to learn" stage (Fang, 2006, p. 491). Gee (2005) distinguished between language use in a context as discourse (lower case d) and ways of being as Discourse (upper case D). Thus, epistemological access to science Discourse (ways of being) depends on semiotic access to science discourse (language practices).

There are implications of the derived sense of scientific literacy (knowledgeability about science) depending on the fundamental sense of scientific literacy (which is associated with the semiotic modes involved in curriculum documents such as science syllabi, science textbooks and exemplar exams). The nature and extent of alignment of the curriculum literacy demands in these documents is thus of significance to science education. As Sharma and Anderson pointed out, "the current discourse in science education is too heavily tilted towards helping students become scientifically literate in the derived sense of knowing science content rather than in the fundamental sense of acquiring control over science discourse" (2009, pp. 1268-1269).

The notion of texts includes both spoken and written language, and texts are viewed as authentic products of social interaction (Eggins, 2004). Roth and McGinn (1998) differentiated between *representations* as traditionally involving individual mental activity, and *inscriptions* – graphical forms recorded in and available to the public through different media, thus being social objects. The framework of inscriptions thus focuses the meaning of texts in such a way that spoken language is excluded, but the inscriptions framework agrees with the perspective that texts are products involving social interaction. From the sociological perspective on science, the term 'inscription' is used instead of 'representation' when referring to socially shared representations (Latour, 1987).

Inscriptions categories include graphs, tables, lists, photographs, diagrams, spreadsheets, and equations (Latour, 1987). From the perspective of inscriptions, knowledgeability "is indicated by the degree to which individuals participate in purposive, authentic, inscription-related activities" (Roth & McGinn, 1998, p. 37). The evolution of science subjects is inextricably linked to the evolution of inscription practices (Roth & McGinn, 1998). Furthermore, "scientific knowledge has an essential dependence on texts, and the route to scientific knowledgeability is through gaining access to those texts" (Hand et al., 2003). This supports the conclusion drawn from the earlier discussion – that inscriptions are central to science literacy due to derived and fundamental science literacy relying on texts as social objects. Inscriptions are thus also central to epistemological access to science discourse and Discourse.

1.4.2 Literacy practices in science education

The concept 'literacy' has an open texture and usually relates to the sequence of conventional symbols for reproducing such things as speech and thought either partially or fully (Freebody et al., 2013). It is necessary to distinguish between the kinds of literacy demands facing learners as either foundational capabilities underlying literacy across curriculum areas or literacy demands distinctive to particular curriculum domains (Freebody et al., 2013). As evident from earlier sections of this chapter, it is the literacy demands particular to chemistry that are the focus of this thesis. Of relevance to this chapter, Freebody et al. (2013) reiterated that this aspect of literacy and more specifically the silences around it, test the ability of teachers and students on a daily basis.

Incorporating the curriculum literacies of each discipline explicitly in instruction and assessment, requires that they first be characterised. The multiliteracy demands of enacted science curriculum were explored by Lemke (2000) who analysed video-recorded data from one student's day of chemistry and physics classes. The results included that the student had to often integrate and coordinate various literacies simultaneously or in close proximity. The implication of the semiotics aspect of scientific literacy for science education is that "students need to not just do hands-on science and talk and write science in words; they also need to draw science, tabulate science, graph science and geometrize and algebraize science in all possible combinations" (Lemke, 2004, p. 8). While this perspective is useful, it does not directly address literacy demands arising directly from chemistry curriculum documents.

In terms of chemistry specifically, Criss (2016) proposed the notion of chemical fluency, noting multiple examples of analogies between chemistry and language such as by Markow (1988) decades ago, and by Laszlo (2013) more recently. She posited that chemical language is inadequately addressed by scientific literacy and so she coined the term 'chemical fluency' for referring to "the proficient ability in which an individual can demonstrate autonomy in acquiring, expressing and even synthesizing knowledge through chemical language" (Criss, 2016, p. 14). Markow (1988) described chemical symbols as equivalent to an alphabet – just as alphabet letters are the building blocks of a language, so too are chemical symbols the building blocks of chemistry knowledge. Molecular formulae composed of chemical symbols are akin to words composed of letters. Chemical reactions are then analogous to sentences, and stoichiometric balancing of chemical equations equates with the need for sentences being grammatically correct. Laszlo's (2013) analogy was similar but includes chemical functional groups as syllables and alternate chemical representations of compounds (e.g. via molecular formula, nomenclature or structural projections) as linguistic dialects.

Howes et al. (2009) declared that literacy practices should be central to science teaching on the basis of reading, writing, and speaking being central to scientists' work, and to non-scientists' comprehension of scientists' work. This is echoed by Hand et al. (2003) who mentioned that science teachers must see themselves as teachers of fundamental science literacy needed for working with scientific texts. In order to achieve science literacy for all, one goal that needs to be shared by various research communities is the identification of the implicit literacy practices in science literacy (Hand et al., 2003). This thesis contributes to answering this call by exploring chemistry curriculum literacy demands from the perspective of abstraction.

1.5 Alignment of Curriculum Literacy Demands from the Perspective of Abstraction

1.5.1 Curriculum alignment with a focus on literacy demands

Alignment refers to an agreement or a match between categories (Squires, 2012). The core aspects of an education system must function together in order to support students in achieving better levels of scientific understanding (Webb, 1997). There is growing recognition by teachers that misalignment between education policy elements results in the system being fragmented, sending mixed messages and being less effective (Newman, 1993). A possible explanation for the disjuncture between science curriculum and student skills as proposed by Smith (2012), is misalignment between intended outcomes, curriculum materials such as textbooks, and assessment.

It is thus not surprising that constructively aligning different levels of curriculum can actually improve student achievement (Squires, 2012). There are various models for curriculum alignment and these can be categorised as low complexity, moderate complexity or high complexity, as discussed in Chapter Two (see section 2.5.1). It is worth highlighting at this stage, that curriculum alignment models traditionally explore alignment between classroom practice or knowledge and curriculum standards (syllabi). It cannot be assumed that alignment of all aspects of official and pedagogic curriculum documents is desirable, conflating the implications of alignment of such things as standards and content with other aspects of curriculum. The paucity of knowledge that needs to be addressed, relates to the nature of alignment of visual and textual literacy demands within aspects of intended curriculum, and the implications of this.

1.5.2 The chemistry discourse feature of abstraction

Many students (both secondary and tertiary) find even the fundamental ideas of chemistry difficult. Numerous researchers, teachers, and science educators attribute the difficulty that chemistry poses to such factors as “the abstract nature of many chemical concepts, teaching styles applied in class, lack of teaching aids and the difficulty of the language of chemistry” (Woldeamanuel, Atagana, & Engida, 2014, p. 32). Awareness of the challenges which abstraction poses to chemistry education is not new – it has long been recognised that many students generally find learning chemistry difficult because of its abstract nature (Espinoza et al., 2013; Treagust & Chandrasegaran, 2009).

Illustrating the relevance of the term *abstraction* in different contexts, Saitta and Zucker (2013) distilled five possible features evident from its use across disciplines ranging from art to mathematics. These are: abstraction as distance from the material world; as coinciding with or being a close variant of generalisation; as the hiding of information; as maintaining relevant aspects while disregarding irrelevant ones; and as a type of reformulation. Due to interrelatedness between some of these features, it is evident why the definition by Williams et al. (2017) presented earlier in this chapter (of abstraction involving the omission of detail and/or generalisation and/or decontextualisation) captures all five features in a more succinct way.

Although abstraction poses a challenge to chemistry education (Sirhan, 2007) it cannot simply be avoided, due to it being a key feature of chemistry discourse itself. Science subjects such as chemistry have hierarchical knowledge structures – this means that they are systematically principled and developed through integration of knowledge at lower levels across a growing range of phenomena (Bernstein, 1996). In subjects such as chemistry then, knowledge spirals towards higher levels of abstraction. While the abstract nature of science subjects such as chemistry poses challenges to students and impacts negatively on chemistry education, such context-independent (or theoretical) knowledge is powerful (Young, 2013), and may account for chemistry being viewed as having the potential to solve real-world problems (discussed in section 2.2 of Chapter Two).

As mentioned earlier, and distinct from formal or physical access, the ability to effectively participate in the discourse or way of being in academic disciplines (such as chemistry) is referred to as epistemological access (Arbee et al., 2014). Despite improved physical access through massification and democratisation of higher education in South Africa, the high dropout rate in first year science courses at tertiary level points to a problem in terms of epistemological access. It makes sense that epistemological access to professional science careers occurs through post-schooling science courses, and that epistemological access to tertiary science is scaffolded by school science.

Given the relevance of abstraction to the visuals and text in chemistry and chemistry education, it is worthwhile employing this discourse feature as the perspective through which to explore chemistry curriculum literacy demands. Legitimation Code Theory (discussed in Chapter Three) conceptualises the degree of abstraction in knowledge and knowledge practices, as Semantic Gravity (SG). It also relates degree of abstraction to cumulative knowledge building – a critical education consideration for hierarchical knowledge structures such as chemistry. For these reasons, the current study adopted LCT as the theoretical framework for exploring the alignment of chemistry curriculum literacy demands in terms of abstraction.

1.6 Rationale

The rationale for undertaking the study was based on the research problem and potential benefits of the study, which will now be discussed.

1.6.1 Research problem

The literature includes numerous studies on curriculum alignment in terms of content and cognitive demand (as will be evident from Chapter Two). However, there are silences regarding the characteristics of visual and textual literacy demands of intended chemistry curriculum, and the nature of alignment of these demands between different curriculum documents. These silences are problematic since there are possible implications for learners' epistemological access to chemistry discourse. Some research (including comparative and alignment studies reviewed in Chapter Two) has been conducted towards achieving a deeper understanding of the current South African school curriculum. However, despite the importance of chemistry education and the challenges which the chemistry discourse feature of abstraction poses to chemistry education, the nature of alignment of curriculum literacy demands through the lens of abstraction has remained unexplored. It is this paucity of knowledge in the existing body of scholarship which the proposed study aimed to help address.

1.6.2 Potential benefits of this study

It was anticipated that exploring the alignment of school chemistry curriculum literacy demands (in terms of abstraction) would make an empirical contribution to bringing chemistry knowledge back into curriculum discussions focused on improving epistemological access to chemistry discourse. Furthermore, it was expected that the study would make a methodological contribution in terms of the analytical tools (referred to as translation devices, as will be explained in section 4.7 of Chapter Four) which needed to be developed for analysing visual and textual data in the chemistry curriculum documents.

1.7 Overview of Thesis Chapters

This thesis consists of seven chapters. An overview of each chapter is provided here, as the conclusion of Chapter One.

1.7.1 Introduction (Chapter One)

This chapter introduces the thesis. It began by providing an orientation to the overall study and outlining the foci of the thesis, which explores the nature of alignment of school chemistry curriculum literacy demands from the perspective of abstraction. The contextual framework began with consideration of international competitiveness and South African tertiary science education, to elucidate why the stakes are high when it comes to South African school science education. Post-apartheid school curriculum reform was then discussed in order to highlight the proliferation of school curriculum documentation since 1994. The notion of alignment of school science curriculum literacy demands from the perspective of abstraction was then considered, before the rationale for the study was directly specified in terms of the research problem and potential benefits of the study. The chapter concludes with this overview of the thesis chapters.

1.7.2 Literature Review (Chapter Two)

While it is recognised that literature informs all aspects of a study, a review of literature around the key concepts and related studies is presented in this chapter for the purpose of situating the current thesis in relation to existing literature. The chapter begins by considering chemistry education for sustainable development amidst a world in crisis, in order to highlight the critical role of school chemistry education. Literature about the current South African school Physical Sciences curriculum is then explored in more detail before delving into theoretical perspectives on curriculum as an education concept. Perspectives on curriculum alignment, examples of curriculum alignment studies, curriculum alignment methods, and curriculum documents are then discussed further. The issue of epistemological access to science discourse is considered and then literature on abstraction in chemistry is reviewed in order to set the scene for Chapter Three.

1.7.3 Legitimation Code Theory (Chapter Three)

This chapter presents a discussion of the theoretical framework – Legitimation Code Theory. It begins with consideration of the paradox of knowledge blindness in education before detailing the supporting pillars of LCT: social realism, Bernstein's discourses and knowledge structures, and Bourdieu's Field Theory. An overview of LCT is then provided before considering aspects of particular relevance to the current study: the epistemic-pedagogic device, and LCT Semantics (SG in particular).

1.7.4 Research Design (Chapter Four)

This chapter explicates the research design employed in the study. The research questions are detailed before realist ontology, relativist epistemology, case study methodology, and the chemistry curriculum document sampling are discussed. The method of document analysis is discussed with a focus on external languages of description. LCT translation devices can be viewed as products of a study since they are developed iteratively over the course of the data analysis and eventually cater to the specific range of data of an individual study. However, since analytical tools are usually presented in the research design chapter, the translation devices for the SG of visuals and text in the curriculum documents are illustrated and discussed in Chapter Four and repeated for the convenience of the reader in Chapter Six. Coding of the visual and textual data is discussed. Considerations related to trustworthiness and research ethics are then presented.

1.7.5 Description of the curriculum document data sources (Chapter Five)

A rich description of the three curriculum documents explored in this thesis is presented in Chapter Five. This serves the purpose of acquainting the reader with them after the research design chapter and ahead of the discussion of results. The NCS-CAPS: Physical Sciences (DBE, 2011) is discussed as an example of syllabus genre, the *Platinum physical sciences grade 10 learner's book* (Grayson et al., 2011) is discussed as an example of textbook genre, and the Grade 10 exemplar examination paper is discussed as an example of test genre. The detailed description of data illustrates immersion of the researcher in the data prior to the analysis undertaken for answering the research questions. The chapter illustrates that all three documents contain relevant textual data for exploring textual literacy demand. However, the syllabus does not contain a range of visuals, and so the analysis of visual literacy demands only applied to the exemplar examination and textbook data.

1.7.6 Results and Discussion (Chapter Six)

Chapter Six begins with the results of the data analysis. First, the percentages of visual items in the exemplar examination paper and textbook coded to each of the five categories of the visual SG translation device are tabulated and graphed. Second, the proportion of textual items in the exemplar examination paper, curriculum document and textbook coded to each of the six categories of the textual SG translation device are tabulated and graphed. A surface-level description of the trends evident from the results is provided. Thereafter, the results are discussed more deeply in relation to the research questions. This revealed the nature of alignment of visual and textual curriculum literacy demands between the curriculum documents. Implications of the findings are also detailed.

1.7.7 Conclusion (Chapter Seven)

A summary of the results, and a discussion of implications is presented first, in Chapter Seven. The empirical and methodological contribution of the study and associated recommendations for future research are then outlined. Finally, limitations of the study are indicated before the chapter is concluded.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of some literature relevant to the key concepts in the study, and to related studies. Section 2.2 considers the role of chemistry education for sustainable development amidst a world in crisis, to highlight the importance of chemistry education research such as the current study. South African school Physical Sciences is then discussed in more detail in section 2.3. Some literature about curriculum as an education concept is presented in Section 2.4, before the notion of curriculum alignment is unpacked in further detail in section 2.5. In section 2.6, literature around the three focal curriculum documents (NCS-CAPS, textbooks, and exemplar examination question papers) is then reviewed. Section 2.7 focuses on the issue of epistemological access to science discourse. Literature around the issue of abstraction in chemistry is then reviewed in section 2.8 in order to set the scene for the theoretical framework of Legitimation Code Theory in Chapter Three. The chapter ends with concluding comments in section 2.9.

2.2 Chemistry Education for Sustainable Development Amidst a World in Crisis

The beginning of the twenty-first century was accompanied by the expectation that the severe dissonance between the wealthier nations of the global north and the poorer nations of the global south would be minimised, hastening potential prosperity for humanity (Yunus, 2009). However, our twenty-first century world characterised by the convergence of a range of crises such as climate change, rising food and oil prices, and dwindling freshwater reserves impacts even more negatively on the poverty-stricken (Yunus, 2009). Particularly worthy of noting, is the Coronavirus disease 2019 (COVID-19) declared by the World Health Organisation to be a pandemic on 12 March 2020 (Viner et al., 2020). This was followed by school closure being implemented in many countries as one of the social distancing measures towards reducing transmission of COVID-19 (Van Lanker & Parolin, 2020).

Van Lanker and Parolin (2020) noted that children in lower income households likely experienced more education challenges in comparison to those in higher income households due to such things as little or no access to space for studying in the home, and online learning resources such as computers and internet access. The negative consequences of school closures particularly for the most vulnerable students extend beyond just the loss of education time, towards such things as nutrition problems for those children relying on free meals from school (Viner et al., 2020). School meals are associated with improved academic performance, while food insecurity is associated with poor academic performance over and above the physical and mental risk which it poses to children. It is thus evident why long-term school closure is acknowledged as potentially exacerbating inequalities between lower and higher income families (Van Lanker & Parolin, 2020). The COVID-19 pandemic consequences are a current example highlighting how worldwide crises have uneven effects on the wealthy and poor, and it provides a basis for considering science education (and more specifically chemistry education) for sustainable development.

Industrialisation since the eighteenth century has benefited the economies of many countries, but it has also catalysed natural resource depletion and environmental degradation due to pollution (Mohan Das Gandhi et al., 2006). This has ultimately led to the notion of sustainable development – humanity's ability to meet its own needs now without compromising future generations' ability to meet their needs later rising in prominence (Robert et al., 2005), further emphasising the significant role of science and science education. Science is increasingly being recognised as an essential component of sustainable development endeavours (Cash et al., 2003) and science education is recognised as complementing the tenets of education for sustainable development (Akpan, 2017). Increasing international attention and investment in education subjects such as science in order to increase the number of students choosing to study these (McDonald, 2016) is thus not only important for the economic development of countries as mentioned in Chapter One (see section 1.2.1), but also towards achieving sustainable development goals.

Tobin (2015, p. 1) made the case for "connecting science education to a world in crisis". With reference to issues such as pollution, climate change, and disease, Lerman (2014) highlighted the major role played by chemistry towards finding solutions for the problems facing the planet and the development of Africa. In developing countries such as South Africa, chemists have the potential to make an even larger contribution through such avenues as improved chemistry education, food availability, water safety, and medication (Govere, 2017). Since the supply of chemists depends on chemistry education, it is understandable why “chemistry education is considered to have central role in education for sustainable development” (Jegstad & Sinnes, 2015, p. 656).

Curriculum is one of the vehicles through which a country provides its citizens with knowledge, skills, attitudes, and values for empowerment towards personal and national development (Kabita & Ji, 2017). This is evident for example, in a central aim of the current South African school curriculum being to equip students with the knowledge and skills required for them to both contribute to the development of the country and live self-fulfilling lives (DBE, 2011). Such a perspective on curriculum warrants studies such as the one undertaken by Tsakeni (2018), which explored opportunities in the school chemistry curriculum for teaching sustainable development. Tsakeni (2018) found that the current chemistry curriculum included a range of opportunities for integrating various pillars (social, economic, environmental, citizen skills, and pedagogical). Challenges arising from chemistry curriculum literacy demands are thus also challenges to education for sustainable education.

2.3 Physical Sciences in South African Schools

Globally, there is a trend of declining numbers of students pursuing post-compulsory science (McDonald, 2016). Not only is this problematic for the economic development of individual countries, but also for a world in crisis due to science being pivotal for problem-solving and achieving sustainable development goals. Possible reasons for the global decline in science enrolment include low student interest and motivation due to pedagogical approaches that are transmissive or teacher-centred, the perceived irrelevance of school science to the real world, a challenging and content-focused science curriculum, a curriculum bias on preparing the academic elite, and inadequate attention to the human aspects of science (McDonald, 2016).

Some of these reasons for declining enrolment in post-compulsory school science are associated with narrower and traditional definitions of curriculum, while pedagogical approaches and relevance to the real world are considered in broader and more contemporary definitions of curriculum. The fact that all of these have links to curriculum helps us understand the point made by Toldsepp (2009), that when it comes to science education reforms, curriculum design and implementation continue to appear at the forefront. Furthermore, it explains why school science is arguably the curricular area that is most frequently revised (Donnelly, 2006).

As highlighted in Chapter One (see section 1.2.2), in South Africa, school chemistry and physics are taught together in the subject of Physical Sciences in Grades 10-12. Despite the intentions being noble, South Africa has been criticised for its post-Apartheid school curricula being introduced "without careful consideration of long-term consequences, and effects before implementation" (McDonald & Van Der Horst, 2007, p. 1). In light of dwindling science enrolment being associated with curriculum concerns as mentioned by McDonald (2016), it is worth considering the way in which Physical Sciences is presented in South African schools.

Koopman (2017, p. 25) elucidated the distinction between "science for life" and "science of government", and argued that Physical Sciences in South Africa reflects the latter. With the "science for life" approach involving "knowledge *in* science" for the purpose of stimulating creativity and critical thinking, the focus is not on scientific knowledge alone but also on how it is developed and applied to real life. This resonates with the notion of humanistic science mentioned in Chapter One (see section 1.2.2). In contrast, the "science of government" approach involves knowledge about science being primarily static, conceptual, and cognitive (Koopman, 2017, p. 25) and resonates with the notion of canonical science described in Chapter One. The subject being presented in an abstract way, foreign to the lives of students is problematic from a social justice perspective (as mentioned in section 1.1.2) due to the abstraction limiting access to physics and chemistry knowledge.

According to Koopman (2017, p. 38), the NCS and NCS-CAPS can be "regarded as the educational route out of the sterility of apartheid education" but match Apartheid curriculum in terms of the underlying approach to curriculum planning. Researchers have critiqued the NCS-CAPS due to it being overly prescriptive and retrogressive by allowing too little room for teacher innovation and critical engagement with content. For example, Khoza (2015) commented on it forcing teachers to operate as technicians covering content in a specified time since there is less flexibility available for them to structure their lessons. Extending this concern to include the constraining effect of continuous assessment on students, Koopman (2017, p. 40) averred that "the treatment of physical science as a science of government, coupled with the effect of policing and control through the learning and testing regimes, stifles the intellectual development of learners and the innovative and creative abilities of teachers". The South African school science policy statements thus control actual teaching and learning very strongly, possibly anchoring the negative impacts of challenges posed by the curriculum.

The Physical Sciences NSC results for Grade 12 learners over 2014 and 2015 showed that the shift from the NCS: Physical Sciences to the NCS-CAPS: Physical Sciences did not significantly improve learner performance and that despite substantial financial investment by the government, the status quo of poor learner results remained unchanged. It is thus not surprising that the number of South African students choosing to study Physical Sciences has declined in recent years (Koopman, 2017). Koopman stated, “Just as in the allegory of Plato’s Cave, the prisoners could only see the shadows, we see the ‘illusions’ of science without understanding the knowledge of science. In other words, our knowledge of science resembles distortions that are strung together like a pattern of appearances that we are made to believe is reality” (2017, pp. 40-41).

The various South African school Physical Sciences curriculum iterations since 1994 show shifts either away from or towards disciplinary content knowledge. After the content-driven interim core syllabi (the first post-independence curriculum) were the outcomes-driven NCS syllabi, before the shift back to a content-driven curriculum in the form of the NCS-CAPS (Khoza, 2015; Le Grange, 2014). Various authors (e.g. Grussendorff et al., 2014; Nakedi et al., 2012) directly pointed to the need for slowing the pace of curriculum change in SA in favour of achieving a common understanding of what needs to be taught and learned. In relation to the most recent curriculum transition for example, Khoza (2015) further emphasised the importance of understanding how a competence curriculum such as the NCS (outcomes-driven) differs from a performance curriculum such as NCS-CAPS (content-driven).

While reliance on textbooks was discouraged in favour of teacher-produced materials during the OBE reform, under the NCS-CAPS curriculum “the textbook has made a comeback” (Sibanda, 2014, p. 155), being recognised as indispensable towards consistency, coverage, pacing, and quality content teaching (Motshekga, 2009). This provides strong support for the claims by Musitha and Mafukatha (2018) that late and non-delivery of textbooks is the main factor hindering effective implementation of the NCS-CAPS. However, even when textbooks are made available, the extent of their usefulness depends on how understandable they are to learners (Allington, 2002). Textbooks that are beyond learners’ reading competence in terms of such things as their vocabulary will result in frustration and not lead to learning because active engagement with them by learners is unlikely to take place. Textbook vocabulary therefore needs to be pitched at the right level (Sibanda, 2014).

Stinner (2001, p. 326) acknowledged the critique of "the dogmatic nature of textbook-centred science education" by Thomas Kuhn (an influential science philosopher and historian), but also noted Kuhn's agreement "that textbook-centred science teaching has been very successful in producing proficient scientists". It is the problem-solutions that students face either in laboratories, textbooks, or examinations – exemplars, that Kuhn believed is central to education (Stinner, 2001). This further supports the consideration of textbooks as well as exemplar examination papers alongside the syllabus, as data sources in the current study.

2.4 Some Theoretical Perspectives on Curriculum as an Education Concept

2.4.1 Origin and evolution of curriculum

Curriculum is a central and multifaceted concern in education (Goodson, 1994). It is complex due to the varied perceptions of curriculum held by different stakeholders with their own agendas (Su, 2012). The precise nature of the concept is elusive since it is abstract, and there is a lack of consensus on its definition and components (Van den Akker, 2003). This warrants its description as an umbrella term having many definitions and covering many issues (Su, 2012). The lack of uniformity in its definition and description justifies clarification of the term when it is employed in endeavours such as empirical studies (Su, 2012). This argues for consideration of its origin, evolution, and range of meanings in the current thesis.

Henson (2015) pointed that the word 'curriculum' has Latin origins and Su (2012) elucidated that it is derived from the Latin verb *currere* meaning 'to run'. It subsequently evolved into a noun meaning racing chariot or racetrack according to Su (2012), or racecourse according to Henson (2015). The word later found application in the terms *curriculum vitae* meaning "the course of one's life" (Henson, 2015, p. 9), and *curricula mentis* meaning "the (educational) course of the mind" (Su, 2012, p. 153). Interestingly, rather than the notion of curriculum being a purposeful development for the accomplishing of educational goals, it arose more as a "historical accident" (Longstreet & Shane, 1993, p. 7) in response to growing complexity in education decision making. Some authors such as Barrow and Milburn (1990) and more recently Van den Akker (2003), pointed out that the meanings associated with curriculum are sometimes narrower and at other times broader. This is evident in various curriculum models, such as those that will now be considered.

2.4.2 Curriculum dichotomies/typologies

Curriculum has never had a standard definition (Henson, 2015), which may explain why most earlier definitions tended to be more general. These presented curriculum as an end unto itself (learning outcomes), as a broader programme of studies (such as the sequential list of courses within a programme of study), or totality of schooling experiences for learners including but not limited to content and skills. However, curriculum also embraces some more specific forms and meanings, such as the actual documents which describes a school's science programme (Henson, 2015). The diverse views on what is meant by curriculum according to various authors were presented by Henson (2015) in terms of the following dichotomies:

- Curriculum as the means (such as planned instruction and learning) versus curriculum as an end (planned learning outcomes);
- Curriculum as content (such as disciplinary knowledge) versus curriculum as experiences (under the guidance of teachers or auspices of a school);
- Curriculum as a process (learning opportunities) versus curriculum as a plan (intended instructional and learning activities).

2.4.3 Hierarchical curriculum conceptualisations

In relating the various notions of curriculum from narrower to broader perspectives, Su (2012) presented five conceptualisations of curricula. These are: curricula as sets of objectives; curricula as courses of study/content; curricula as plans; curricula as documents; and curricula as experiences. Figure 2.1 shows how they are related hierarchically – worth noting is that each successive conceptualisation subsumes and extends beyond the previous, more narrower ones.

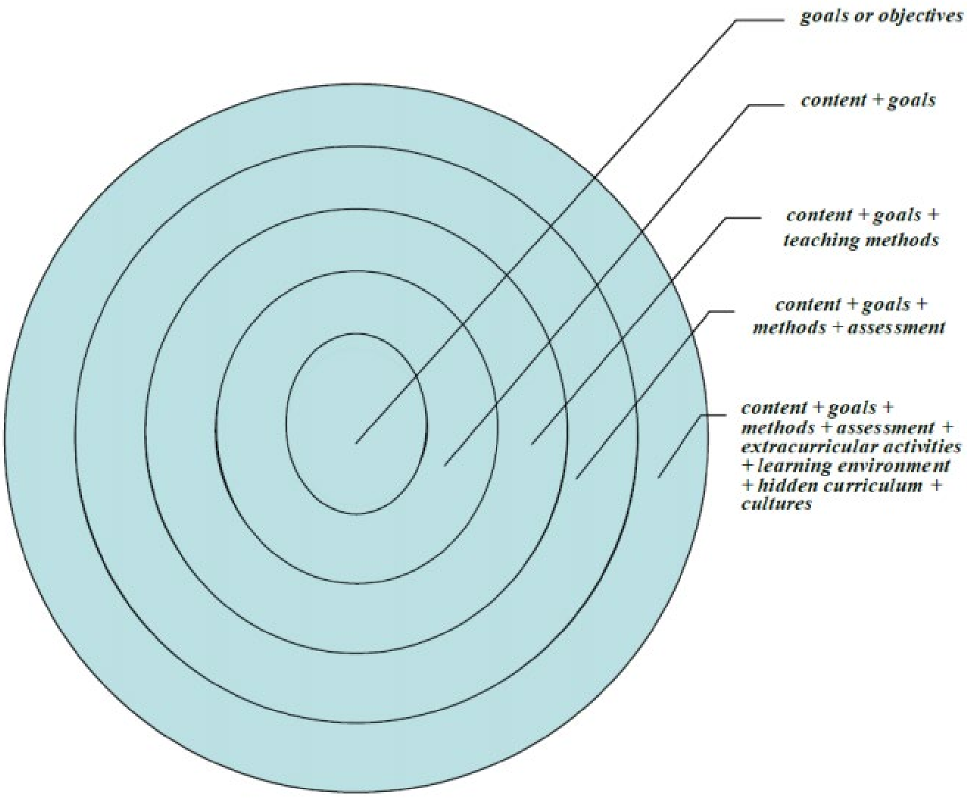


Figure 2.1: Hierarchical relation of curriculum conceptualisations (Su, 2012, p. 156)

The conceptualisation of curriculum as goals or objectives frames it as a checklist of desirable outcomes with the focus being on the product (Su, 2012). In this case the curriculum may be teacher orientated or administratively oriented (set by politicians without consulting teachers and possibly resulting in them not feeling ownership of what they are teaching). Curriculum as a course of study or content focuses on the actual content and range of courses in a programme offered by an institution or undertaken by a student. This extends beyond just goals or objectives. Conceptualising curricula as plans frames them as blueprints for systematic implementation. Rather than just including goals or objectives and content, instructional methods are also considered. The conceptualisation of curricula as documents is related to official written programmes published by education ministries and departments. It stems from the need for a written document stating objectives, course content, instruction methods, and assessment. This published form of curriculum for guiding teaching, allows synonymy between the notions of curriculum and syllabus (Barrow & Milburn, 1990).

More holistically, curricula can be conceptualised as programmes for experience. In agreement with Henson (2015), Su (2012) pointed out that curricula as experience includes both the planned and unplanned happenings in an academic environment (not just inside the classroom). This experiential curriculum covers such things as school clubs, excursions, assemblies, and academic competitions. It is associated with the notion of hidden curriculum – implicit social rules and expected behaviour hinging on such things as location, age, and motives of curriculum architects (such as teachers and school authorities). There is a strong association between hidden curriculum and culture.

2.4.4 Curriculum levels

Van den Akker (2003) posited, on the basis of learning being the core activity in the education context, that an obvious interpretation of the word curriculum is a course or plan for learning. He further recognised that while this short definition lies at the core of subsequent elaborations, its simplicity makes a distinction between various curriculum levels useful. The four levels he suggested, with an additional level – the Supra level, being included later (Van den Akker et al., 2009), are the:

- Supra level, of international curriculum;
- Macro level, of system/society/nation/state;
- Meso level, of school/institution;
- Micro level, of classroom; and
- Nano level of individual/person.

At the broader macro level, curriculum development is usually generic in nature, while at the other narrower levels it is usually site-specific (Van den Akker, 2003). The current South African school curriculum (NCS-CAPS), in terms of Thijs and Van den Akker's (2009) curriculum levels, raises a micro/meso level curriculum to macro (national) level. While the additional specification of details in the NCS-CAPS compared to earlier versions of South African school curriculum may have resulted in an initial increase in quality, it is possible the system may remain locked at this point due to the constraints cemented into the curriculum document itself (Grussendorff et al., 2014). This emphasises the need for research focusing on the NCS-CAPS documents themselves, and not just on the teaching and learning relating to them.

2.4.5 Curriculum representations and layers

According to Porter and Smithson (2001), the distinction between intended (as per policy), enacted (in practice), and learned curricula arose from international comparative student achievement studies as far back as three decades ago. While describing the intended curriculum as policy tools (such as the curriculum standards, guidelines, or framework), Porter and Smithson (2001) also raised the importance of exploring both the curriculum described in the documents and the documents themselves. The actual curricular content that students work with in classrooms is encompassed in the enacted curriculum. The learned curriculum refers to both the content learned, and the proficiency level related to test scores.

Van den Akker (2003) referred to a similar typology, drawing from the seminal work of Goodlad et al. (1979) on curriculum representations, and highlighted that they are especially useful for understanding problems related to curriculum reform. He referred to the enacted curriculum as the implemented curriculum and provided a further refining of the three main categories, in which the learned curriculum is one aspect of the attained curriculum as shown in Table 2.1 (Van den Akker, 2003). This distinction between the intended, implemented, and attained curriculum is a typical one, albeit with alternate names for levels such as planned curriculum, delivered curriculum, and experienced curriculum (Prideaux, 2003).

Table 2.1: Curriculum representations

INTENDED	***Ideal***	Vision (rationale or basic philosophy underlying a curriculum)
	Formal/Written	Intentions as specified in curriculum documents and/or materials
IMPLEMENTED	***Perceived***	Curriculum as interpreted by its users (especially teachers)
	Operational	Actual process of teaching and learning (also: curriculum-in-action)
ATTAINED	***Experiential***	Learning experiences as perceived by learners
	Learned	Resulting learning outcomes of learners

Source: Van den Akker, 2003, p. 3

Khoza (2015) referred to the intended, implemented, and attained representations as layers, and elaborates that the first layer (intended) is synonymous with the notion of planned/prescribed curriculum, which includes formal or written policy informed by education theories as well as intentions for teaching and learning. The second layer (implemented) is the enacted or practiced interpretation of the first layer. The third layer (attained) is the achieved or assessed curriculum. While the second layer reflects teachers' perceptions of the first layer, the third layer reflects learners' perceptions of the second layer (Khoza, 2015). Nakedi et al. (2012) referred to the formal or written aspect of the intended curriculum as the *published* curriculum, as will be discussed in section 2.4.7.

The study by Edwards (2010) (as will be discussed in section 2.5.2), demonstrated the analytical usefulness of recognising assessed curriculum as distinct from the intended or learned curriculum. She investigated alignment between the previous intended Physical Sciences curriculum – the Physical Sciences NCS (DoE, 2003) and the assessed curriculum – the high stakes Grade 12 examination paper (Edwards, 2010). Edwards emphasised the importance of curriculum alignment studies in the context of a reformed curriculum and such a context has recently arisen in South Africa with the phasing in of CAPS in Grades 10-12 from 2012 to 2014. Furthermore, her study reflected curriculum alignment research focusing on different curriculum documents (syllabus and examination paper).

2.4.6 Curriculum in Bernstein's pedagogic device

Singh (2002, p. 571) described Basil Bernstein as "one of the most influential and widely discussed theorists in the sociology of knowledge". One of Bernstein's foci was the specific principles giving rise to noteworthy stability or uniformity across the education systems of nations such as those in Western Europe. According to Bernstein (1996), the production, reproduction, and transformation of culture is controlled by the pedagogic device. This refers to the ordering and disordering principles of knowledge pedagogisation (Bernstein, 2000). It offers explicit rules to describe the structuring of knowledge and is a model for analysing how expert knowledge (specific to a discipline or domain) is pedagogised into school knowledge (Singh, 2002).

Kelly-Laubscher and Luckett (2016) explained that Bernstein's pedagogical device is a conceptual one, consisting of three main knowledge fields: knowledge production, knowledge recontextualisation, and knowledge reproduction. The fields are constituted by agencies or institutions (such as education departments or schools) which are in turn constituted by the agents working within them who “may contest, maintain, and/or challenge the ordering/disordering principles of the pedagogic device” (Singh, 2002, p. 573). According to Singh (2002), the concept of ‘field’ in the work of Bernstein is similar to that of Bourdieu (1992), for whom they are social spaces of conflict due to participants competing for the capital of value in the field and the power associated with controlling it. In the pedagogic device, the production field is where knowledge is created. This knowledge is decontextualised from the site of production and recontextualised into curriculum, becoming a form of educational knowledge in the recontextualising field (Shay, 2013). In the reproduction field, the recontextualised knowledge is then reproduced through the transmission of knowledge to learners (Singh, 2002).

Singh (2002) presented Bernstein’s pedagogic device as the ensemble of rules and procedures through which knowledge is transformed into such things as classroom talk, curricula, and online communication. The device regulates the development of school curriculum in the recontextualisation field and how it is transmitted into pedagogy in the reproduction field via the hierarchically related distributive, recontextualising, and evaluative rules. The recontextualising rules are regulated by the distributive rules while the evaluative rules are regulated by the recontextualising rules (Bernstein, 2003).

Distributive rules both regulate and distribute various forms of knowledge and practice to particular social groups resulting in different forms of consciousness. Recontextualisation rules regulate how specific pedagogic discourse is formed. The principle of pedagogic discourse delocates, relocates, and refocuses other discourses from their original site to a pedagogic one. The principle of recontextualisation creates recontextualising fields – an Official Recontextualising Field (ORF) and a Pedagogic Recontextualisation Field (PRF). The former is governed by states and ministries such as those of government while the latter consists of teacher education, journals, and authors of textbooks. Evaluative rules constitute pedagogic practices and account for which realisations of instructional texts (such as curriculum content) and regulative texts (such as social conduct and character) are recognised as valid. Bernstein (1996) recognised four players in curriculum implementation: producers, who create curriculum; recontextualisers, who formulate the realisation rules (such as teachers, government officials, and academics); reproducers, such as teachers who implement curriculum in the classroom; and acquirers, who are the learners.

2.4.7 Published and illustrated curriculum

In relating curriculum theory to the fields of Bernstein's pedagogic device, Nakedi et al. (2012) pointed out the relationship between the curriculum representations described by Van den Akker (2003) and three of Bernstein's (1996) four agents involved in curriculum implementation. Implemented curriculum is enacted by reproducers and the attained curriculum is achieved by the acquirers. Recontextualisers appear absent in the three curriculum representations, necessitating a deliberate focus on what Nakedi et al. (2012) termed illustrated and examined curricula, which recontextualisers produce. The two-phase curriculum change model of Nakedi et al. (2012) is shown in Figure 2.2.

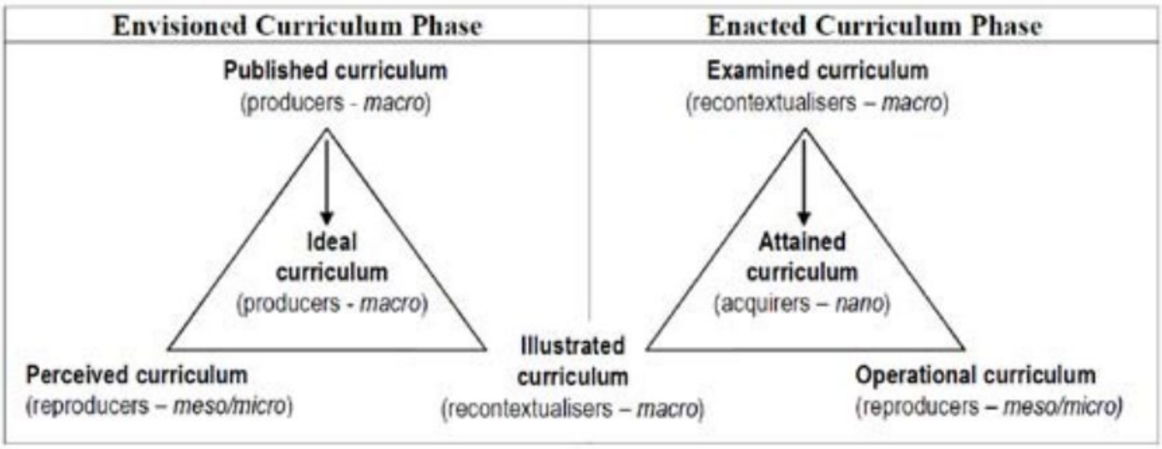


Figure 2.2: Two-phase curriculum change model (Nakedi et al., 2012, p. 275)

In terms of curriculum representations, intended curriculum is developed by producers who have a vision (ideal curriculum) which they communicate via the published curriculum. Bridging the envisioned and enacted curriculum phases are the recontextualisers who provide an illustrated curriculum. Nakedi et al. (2012) used "published curriculum" to refer to the actual curriculum documents such as the NCS and NCS-CAPS document and "illustrated curriculum" to refer to textbooks and exemplar examination papers. Reproducers (teachers) apprehend the illustrated curriculum as the perceived curriculum which they implement as the operational curriculum. Learners acquire the attained curriculum and are assessed through examined curriculum (developed by recontextualisers). In terms of curriculum levels, nationally or provincially examined curricula have their published, illustrated, and examined curricula operating at a macro level. Perceived and operational curricula manifest at meso level in schools and a micro level in the classroom. Finally, the attained curriculum is situated at the nano level.

Published curriculum appears at the apex in the envisioned curriculum phase and examined curriculum appears at the apex in the enacted curriculum phase. Just as the published curriculum provides a lens on the ideal curriculum in the envisioned curriculum phase, so too does the examined curriculum provide a lens on the attained curriculum in the enacted curriculum phase. In effect, the published curriculum serves as the main curriculum driver in the envisioned curriculum phase. Due to the backwash effect of the examined curriculum into the classroom (outlined in section 1.3.3 of Chapter One), "while the published and illustrated curricula should drive the enacted curriculum phase, the examined curriculum effectively becomes the main driver for this phase" (Nakedi et al., 2012, p. 276).

Nakedi et al. (2012) explained that the two phases should ideally be mirror-images, with the ideal curriculum being reflected in the attained curriculum, the perceived curriculum being reflected in the operational curriculum, and examined curriculum reflecting the published curriculum. However, real world limitations and constraints result in small shifts during the translation in each step of the curriculum process which may cumulatively result in significant curriculum drift between the ideal and attained curriculum. The model presented by Nakedi et al. (2012, p. 276) "suggests that congruency between the macro elements of a curriculum, i.e. the published, illustrated and examined curricula, is critical for effective curriculum change. This means that the messages communicated by the illustrated curriculum should be consistent with the published curriculum". While Nakedi et al. (2012) recognised various studies of the NCS Physical Sciences curriculum as being useful, they flagged the gap in literature around congruence across macro curriculum elements (published, examined, and illustrated curriculum).

Nakedi et al. (2012) indicated a retreat from the original vision of skills, relevance, and content having equal weighting in the NCS. This retreat resulted in the published, illustrated, and examined curricula being incongruent. They noted that the chemistry examiners tended to use “pseudo contexts” – with the contextualisation being unnecessary for answering the question and simply involving additional reading for the students. Thus, Nakedi et al. (2012) did not view such questions as pertinent to the relevance-related outcome (about the nature of science and the relationship it has to technology, society, and the environment). The authors reminded us of the two major goals of science education according to Fensham (1988) being a workforce that is scientifically based and citizenry that is scientifically literate. Since science for future scientists requires strong boundaries between everyday and scientific knowledge while science for all necessitates weak boundaries, examinations focusing on traditional content result in strong boundaries which benefit epistemological access to further science study but may detract from science literacy goals.

2.5 Curriculum Alignment

2.5.1 Perspectives on curriculum alignment

Prior to Nakedi et al. (2012) suggesting more specifically that alignment between curriculum documents is critical for effective curriculum change, other authors also recognised the importance of such alignment. For example, Van den Akker (2003) highlighted the importance of alignment between assessment and other curriculum elements, and Barnes et al. (2000) emphasised the importance of alignment between published and examined curricula for enhancing curriculum credibility. There are in fact, various models that have been used over time for understanding curriculum alignment that warrant mention in this thesis.

According to Bhola et al. (2003), models for curriculum alignment range from low to high complexity. Low-complexity models are the basis for other models and involve content experts determining the extent to which assessment items match the relevant content standards. The degree of alignment (ranging from no match to complete match) is often indicated using a Likert scale. Moderate-complexity models stem from the view that alignment is more than a simple content match and involves content panellists judging the alignment between content and assessment from the dual perspective of content alignment and cognitive complexity alignment. An example of this is the Surveys of Enacted Curriculum (SEC) model in which information from the alignment matrices is converted into graphs, charts, and statistics which include an alignment index (Porter, 2002).

An example of a high complexity model is that of La Marca et al. (2000) which used the interrelated dimensions of content match, depth match, emphasis, performance match, and accessibility. Webb (1999) described alignment of assessment to standards for four criteria within the content category – depth of knowledge consistency, categorical concurrence, range of knowledge consistency, and balance of representation. The Achieve (2001) model proposed methods for dealing with differential weighting of standards. It employs the following six criteria: accuracy of test blueprint, content centrality, performance centrality, challenge, balance, and range. Bhola et al. (2003) argued that while Webb (1999), La Marca et al. (2000), Achieve (2001), and Porter (2002) had developed promising alignment models, all of these have problems. The broad categories of challenges include problems associated with specificity of alignment criteria, with alignment and classification of students into performance categories, and with training. Of relevance to this thesis is the fact that where there are foci that extend beyond simple content match, these do not consider disciplinary discourse features such as abstraction in the case of chemistry.

Biggs (1996; 2012) presented a model for constructive alignment as a tool for the design of curriculum. His work has also been influential in many countries including South Africa and so warrants consideration in this literature review. The constructive alignment approach highlights the need for curriculum to be designed in a way that serves students' demonstration of achieving learning outcomes. From this perspective, there needs to be a clear connection between learning outcomes, classroom activities, assessment, and evaluation. While the constructive alignment approach lends itself to hierarchical knowledge structures such as chemistry, it does require that learning outcomes have a central role in curriculum which is no longer the case with the current school curriculum in South Africa (as outlined in Chapter One of this thesis). Furthermore, its focus is on the enacted curriculum rather than on curriculum knowledge (which is foregrounded in the current thesis). As such, it has weaker potential for overcoming the paradox of knowledge blindness in education (discussed further in section 3.2 of Chapter Three) which is a contributing factor to the knowledge gap regarding science curriculum discourse features such as abstraction.

2.5.2 Examples of curriculum alignment studies

One example of an international curriculum alignment study is that of Liu et al. (2009) which measured and compared the alignment of different levels (intended and assessed) of physics curriculum in Jiangsu, New York, and Singapore. The Webb alignment method assumes specific content standards which are used as a basis for analysing alignment. However, different countries have different content standards and so the Webb alignment model was not found useful for international alignment comparison studies. Since the Porter alignment method (Porter, 2002; Porter et al., 2007) is independent of content standards, it was found to be useful in the study by Liu et al. (2009). Findings of their study included that there was statistically significant alignment of intended and assessed physics curriculum for New York. The misalignment for Chinese and Singapore physics curriculum was due to the shift towards higher levels of cognitive reasoning skills from content standards to standardised tests. Liu et al. (2009) pointed out that ongoing study of alignment between science content standards and standardised tests is necessary for any education system and that alignment studies provide a basis for teacher professional development that could improve student achievement.

An example of a South African national curriculum alignment study alluded to earlier, is that of Edwards (2010) which analysed the alignment between the Grade 12 chemistry and Physics examinations to the NCS: Physical Sciences. The study employed matrices of content and cognitive levels for comparing the alignment of core curriculum and exam papers in terms of the Porter alignment index. An alignment index of 0.8 was calculated for physics and of 0.6 for chemistry. Discrepancies were found in both the cognitive levels and content areas for both physics and chemistry with the "remember" level of Blooms taxonomy being under-represented in chemistry and physics, while the "understand" and "apply" cognitive levels were over-represented in chemistry. Edwards (2010) argued that the shift to higher cognitive levels is in line with the reported increase in cognitive complexity of the Physical Sciences curriculum being employed at the time (NCS: Physical Sciences, which was replaced with NCS-CAPS: Physical Sciences in 2012). The study took a first step towards the establishment of quality relationships between South African Physical Sciences intended and assessed curriculum. However as alluded to earlier, existing alignment models seem to ignore disciplinary discourse features such as abstraction, which is of relevance to chemistry curriculum.

A more recent example of a South African curriculum alignment study, is reported by Clarence (2017), and proposes a complimentary approach to the constructive alignment approach of Biggs. She acknowledged the relevance of Biggs' alignment model to hierarchical knowledge structures made it less suitable for disciplines such as political science which was the focus of her study. Drawing from LCT, she used a case study on political science to illustrate how the LCT dimension of Specialisation provides a mode of analysing curriculum alignment for subjects that are not aggregative in the way that science subjects are, according to Bernstein's (1999) account of knowledge structures. Clarence's (2017) analysis uncovered the organising principles underpinning political science and how the aims of the course aligned with these.

The significance of her study is that it reveals the utility of a LCT dimension (in this case, the dimension of Specialisation) for exploring curriculum alignment. This study is similar to that of Clarence (2017) in terms of LCT as the theoretical framing for exploring curriculum alignment. However, her study was situated at university level, focused on a horizontal knowledge structure (political science) and also considered knowledge reproduction while the current study is situated at school level, focuses on a hierarchical knowledge structure (chemistry), and does not include a focus on knowledge reproduction. The LCT dimension of Specialisation was not relevant to the current thesis since science subjects such as chemistry are hierarchical knowledge structures with challenges to cumulative knowledge building (such as challenges related to abstraction) which Specialisation does not address. In order to address the issue of chemistry curriculum literacy demands in terms of abstraction, the current study looked to the Semantics dimension of LCT (as section 3.6.3 in Chapter Three will expand on).

2.5.3 Curriculum alignment methods

Orpwood (2001) averred that curriculum development should include appropriate assessment for use by teachers in the classroom as well as for summative purposes. He acknowledged that due to curriculum policy and learning materials being developed by different institutions there may or may not be consistency. Webb (1997) mentioned three methods for aligning documents: sequential development, expert review, and document analyses. Sequential development involves such things as expectations and assessment being aligned by design, where the former converts directly into specifications that inform the latter. The process of developing expectations and assessments, however, is sometimes dynamic and recursive. In such instances, expert review can be employed to improve alignment (Webb, 1997). Committees are selected which either approve or reject assessment items for inclusion based on their alignment to goals and objectives. Webb (1997) confirmed that alignment can also explored via document analyses involving coding and analysing relevant curriculum documents. Document analysis will be discussed further in the research design of this thesis (see section 4.6 in Chapter Four), but it is appropriate at this stage to consider in more depth the curriculum documents that would provide relevant data for such analysis.

2.6 Curriculum Documents

2.6.1 Curriculum policy/syllabi

Nation and Macalister (2010) alerted us to the fact that a distinction is made between curriculum and syllabus by some curriculum designers. Their model suggested that a syllabus has a narrower focus than a curriculum – in other words, curriculum factors extend beyond just the syllabus. Some earlier authors concur – Nunan et al. (1988) for example stated that curriculum focuses on planning, implementing, evaluating, managing, and the administration of education programmes, while syllabus has a narrower focus on the selection and grading of content. They further averred that syllabus design is an aspect of the curriculum development planning phase (Nunan et al., 1988).

Woods et al. (2010) highlighted that no clear delineation between curriculum and syllabus has been made, either in practice or in policy, even though the distinction is not trivial. Furthermore, the authors averred that "current curriculum debates have tended to focus on ideological, cultural, and scientific curriculum content, with little or no discussion on or about the technical form of the curriculum or syllabus documents" (Woods et al., p. 362). In distinguishing the curriculum from syllabus, Woods et al. (2010) contrasted the broad range of resources (scientific, intellectual, cognitive, and linguistic) constituting curriculum, with the syllabus as an attempted system of parameters for a curriculum. Curriculum can be viewed as including both official and unofficial documents, textbooks, and resources/materials – "It is the constitutive cultural and scientific content of education that is transmitted by the message systems of pedagogy and assessment" (Woods et al., 2010, p. 362). Syllabus on the other hand, "is a defensible map of what is valued as core skills, knowledge, competences, capacities, and strategies to be covered within a particular context at a particular time, usually with affiliated statements of standards, which are used for accountability" (Woods et al., 2010, p. 362).

These definitions align syllabus to the curriculum-as-document conceptualisation by Su (2012), written/formal aspect of intended curriculum in terms of Van den Akker's (2003) levels, and the published curriculum in the model by Nakedi et al. (2012), situated in the official recontextualising field of Bernstein's pedagogic device (Bernstein, 1996). Furthermore, even though the NCS-CAPS includes micro level (classroom) detail, they are positioned at the macro level in terms of Thijs and Van den Akker's (2009) curriculum levels (Grussendorf et al., 2014). The implication is that both strengths and weakness of the micro level details are cemented at national level as pointed out by Grussendorff et al. (2014). This theorising provides support for recognising the identity of the NCS-CAPS: Physical Sciences document as a syllabus.

A syllabus is amongst the most recognisable examples of academic genre and facilitates socialisation of students and teachers into an academic discourse community (Collin, 1997 in Afros & Schryer, 2009). Afros and Schryer (2009) argued that the most salient features of academic genre in general and syllabi in particular, are intertextuality and interdiscursivity. The authors defined intertextuality as both explicit and implicit relations between a text/utterance and prior, contemporary or (potential) future texts (including but not limited to textbooks) (Afros & Schryer, 2009). Hyland (2004 in Afros & Schryer, 2009) explained interdiscursivity as the use of textual elements within a text that carry meanings (institutional and social) from other discourses. Both syllabi and textbooks are interdiscursive in their drawing from or reflecting conventions and practices of neighbouring discourses. For this reason, it was also worth reviewing some literature on textbooks which are another type of curriculum document that can be involved in document analysis for ascertaining curriculum alignment, according to Webb (1997).

2.6.2 Textbooks

Even though textbooks may be argued to be "the heart of schools", there is no simple way to define the concept of textbooks (Mikk, 2000, p. 17). As with curriculum, definitions exist which are either broader or narrower. One example of a broad definition is provided by Laws and Horseley (1992 in Mikk, 2000) who considered them to be any written material used in learning. Another broad definition provided by Vanecek (1995 in Mikk, 2000) described them as text specially written for learning and teaching, and thus meeting criteria such as alignment with curriculum and elaborating on content didactically.

Being "the ultimate source of science knowledge in many science classrooms" (Penney et al., 2003, p. 418), science textbooks are fundamental tools in science education and a critical factor in developing science literacy. According to Penney et al. (2003), the ability to read science text begins, in part, with science textbooks and for many students they are the embodiment of science. They are one of the reasons why science reading is crucial to science education (Penney et al., 2003). Dependence on textbooks is likely to continue in light of education systems facing challenges such as those associated with increasing class sizes, decreased equipment budgets, and increasing safety concerns. This strong positioning of textbooks allows them to profoundly influence students' learning experiences and perception of science.

It may be argued that textbooks provide the most thorough representation of a curriculum (Mikk, 2000), or even determine science curriculum (Penney et al., 2003). This is supported by the fact that to school students, textbooks are representations of the school disciplines. As is the case with curriculum, textbooks present a particular selection from culture and a curriculum might be defined more by its textbooks than by official curriculum documents (Apple, 1989 in McKinney, 2005). A possible reason for this becomes evident when one considers that texts aligned to curriculum are good policy messengers since they represent ideas from policy in a familiar and concrete form and because teachers prefer engaging with them rather than with a curriculum policy document (Ball, 1990).

Stoffels (2007) cited Huberman and Miles (1984) who made the point that the life and death of large-scale change involving innovations depends on the quality of assistance teachers receive during the change process. Although powerful, textbooks of high quality have previously been recognised as an under-researched teacher assistance instrument (Powell & Anderson, 2002; Pingel, 1999 in Stoffels, 2007). It is well known that textbooks play a powerful social function, not only in socialising children but also in the legitimation of cultural norms, sanctioned values, and knowledge. Due to their setting up 'pedagogic pathways' for teachers and learners, they are particularly useful in developing countries where learner-centred pedagogy is valued. The figures in textbooks are one of the prominent opportunities for students to engage with visual representations, and educators rely on them in classroom practice (Offerdahl et al., 2017).

As a science curriculum variable in South Africa, textbook-use was found to be statistically significant (Cho et al., 2012). However, despite benefits such as their providing an effective way to access science knowledge for teaching and learning especially in developing countries, one study found that science textbooks in South Africa had a negative relationship with performance (Cho et al., 2012). This points to the possibility of textbook literacy demands preventing semiotic access to science knowledge. A more recent chemistry-specific study in Sweden (Bergqvist & Rundgren, 2017) confirmed the findings by previous researchers, that textbooks have a strong influence on teachers' decisions around what and how to teach. Interestingly, this was also true for teachers with several years of teaching experience.

Penney et al. (2003) drew on literature to explicate how textbooks pose challenges to many students on the basis of such things as the amount of information and new terminology which they include. Due to them including vast amounts of information (breadth), the coverage (depth) may be superficial, constraining higher order thinking. Their structure may implicitly portray science as a collection of static facts instead of as a dynamic exploratory process generating theory. Due to science textbooks presenting information in a piecemeal and incoherent way, readers may end up with inaccurate or incomplete interpretations. As can be expected, English second language speakers, especially, are disadvantaged by these difficulties. This raises concerns about textbooks when it comes to the social justice agenda of countries such as South Africa.

Drawing from Woods et al. (2010) curriculum includes documents such as textbooks, allowing for textbooks to be characterised in the same way as syllabi which are also curriculum documents. In terms of Van den Akker's (2003) curriculum representations, textbooks can be situated as the perceived aspect of intended curriculum since they reflect textbook writers' interpretations of the intended curriculum (particularly the formal or written curriculum). However, in contexts where teachers (experienced or inexperienced, qualified or unqualified) rely on textbooks rather than the syllabus for guiding day-to-day teaching, it could be argued that textbooks are raised to the level of intended curriculum. This warrants the critical need for strong alignment between textbooks and related syllabi (formal or written aspects of intended curriculum) assuming that the syllabi themselves are not flawed.

In consideration of Van den Akker's (2003) curriculum levels, one can infer that as with international syllabi, textbooks which are not country specific (such as those related to syllabi offered across countries) are situated at the supra level. A clear positioning of textbooks related to syllabi which are country-specific (such as the NCS-CAPS), is at the macro level. This is supported by the fact that textbooks endorsed by the South African DoE appear on a national catalogue of textbooks.

From the perspective of Su's (2012) curriculum conceptualisations, textbooks are an aspect of *curriculum as documents* and the distinction between them and syllabi is evident when one considers Van den Akker's (2003) curriculum model. Textbooks shift away from the intent and content aspects emphasised in syllabi towards teaching and learning activities, providing a steppingstone from the syllabus document towards implementation in the classroom. As with syllabi, textbooks are aspects of the recontextualising field in Bernstein's (1996) pedagogic device, but syllabi are components of the official recontextualising field while textbooks are components of the pedagogic recontextualising field. Nakedi et al. (2012) characterised textbooks as components of illustrated curriculum, bridging the envisioned and enacted curriculum. While examinations used for formal assessment towards promotion or certification are examples of assessed curriculum in the model by Nakedi (2012), exemplar examination papers fall into the same category as textbooks – that of illustrated curriculum.

2.6.3 Exemplar assessment

Assessment is a significant curriculum element (Cheung, 2000) or component (Mak et al., 2018; Van den Akker, 2003). Both overt and covert forms of assessment (usually on the basis of written language) construe ideal forms of scientific knowledge and ideal pedagogical subjects in contrast to which less-than-ideal subjects are denied access to further levels of study (Veel, 2000). Given the high-stakes nature of summative assessments which act as gatekeepers to further study as mentioned earlier, the backwash effect of examinations on teaching and learning becomes even more significant. In emphasising the significance of high-stakes summative assessment, Ogunniyi and Rollnick (2015, p. 67) referred to the "stranglehold effect of national examinations on the whole education system".

Offerdahl et al. (2017) noted that students pay attention to assessment to the extent that they adjust their learning approaches accordingly. Furthermore, they influence students' ideas about the disciplinary practices of science, and so analysing assessments sheds light on the extent to which concepts and skills are being reinforced (Momsen et al., 2013). Luxford and Holme (2015) pointed to the possibility of chemistry exams serving as historical artefacts from which the nature of content coverage at particular points in time can be gleaned. Modern education trends involve using explicit articulation of standards and assessment criteria so that the measurement of student achievement is legitimised, and exemplars are one way of achieving this articulation (Newlyn, 2013).

In addition to the importance of articulation of standards, there has been bourgeoning recognition of the importance of providing feedback to students based on their assessments. Scoles et al. (2013) revealed that there has been an ongoing growth in literature about such things as attitudes to feedback, good practice around feedback, challenges related to feedback, and future directions for feedback. However, there is an anomaly between the emphasis on feedback for coursework and the enduring use of unseen, time-limited exams in the assessment strategy for many subjects (Scoles et al., 2013). One reason for examinations being poorly situated for generating effective feedback is that they are often employed at the end of a unit of teaching and learning, summatively (Yorke, 2003). As a solution to the challenge of providing feedback on examinations, Scoles et al. (2013) proposed a move away from emphasis on feedback to an emphasis on feedforward via the use of exemplars.

Scoles et al. (2013) provided a definition of exemplars which revolves around real examples of students' work products, usually across a range in quality. In other words, "exemplars" can mean authentic student answers that illustrate how scoring is applied. On the other hand, they have been defined more generally as core examples chosen as representative or typical of designated quality or competence levels (Sadler, 1987). The notions of exemplars and model answers are similar. An exemplar can mean a model, an ideal, a pattern to be copied or imitated, or something typical or representative, while model answers usually refer to specific examples of a 'perfect' answer (Newlyn, 2013). In South Africa for example, there are many commercially available booklets comprised of examination papers from previous years and the related model answers. While the subject Physical Sciences is only assessed nationally for Grade 12 learners, the South African DoE published Grade 10 and 11 exemplar examination papers after the NCS-CAPS were released in 2011.

Newlyn (2013) provided a review of literature making the case for exemplar use and these reasons will now be considered. The first reason for their use, and mentioned earlier in this section, is that feedback provided on marked assessments occurs too late for students to benefit from them during the assessment (even though they may be useful for similar forthcoming assessments). Another reason is the well-documented "overwhelming desire" from students to receive exemplars (Newlyn, 2013, p. 28). While it is almost impossible to conclusively demonstrate that the use of exemplars improves students' marks, Newlyn (2013) confirmed that a number of studies do support this claim. A fourth reason is that exemplars provide transparent communication of the expected level of quality, making criteria more explicit (Newlyn, 2013).

In providing a balanced view on the use of exemplars in education, Newlyn (2013) also considered reasons for not employing them. The first reason provided is that developing an exemplar takes time since they must align to established criteria or standards. In the case of the exemplar being comprised of previous students' work, transcription into typed format and annotation by the teacher or lecturer may consume even more time, in addition to obtaining consent from the students who authored the model for ethical reasons. Additional factors contributing to their construction requiring time, include them needing to be as generic as possible without integrity or usefulness being compromised. Another reason in the case against using exemplars is that they "give students the answer" (Newlyn, 2013, p. 31) and in so doing, contribute to plagiarism and suppression of creativity. However, these disadvantages may be more relevant to assessments such as essays and less relevant to hierarchical knowledge structures such as chemistry. Thus, the disadvantages of using exemplar examinations in chemistry education are arguably outweighed by their advantages.

As mentioned earlier, Khoza (2015) alluded to Van den Akker's (2003) attained curriculum as being related to the assessed curriculum. However, in contrast to summative assessment such as the actual end-of-year examinations used for the purpose of formal assessment and promotion to the next level of education, exemplar examination papers such as those published by national departments of education might be more usefully situated as aspects of the formal or written curriculum (of the intended curriculum). Since there are no national Physical Sciences examinations written at Grade 10 or 11 level in South Africa, exemplar examinations play an important role in sensitising students and teachers to summative assessment expectations. In terms of Bernstein's (1996) pedagogic device, they share elements of curriculum documents in both the official recontextualising field (such as syllabus) and pedagogic recontextualising field (such as textbooks). While they are *official* in the sense of their being issued by the country's education department, they are *pedagogic* in the sense that they are also used by learners to enhance their learning (in the way that textbooks are, and as opposed to syllabi documents which students do not directly work from).

Nakedi et al. (2012) described exemplar examinations as an aspect of the illustrated curriculum (together with textbooks), designed by recontextualisers, and operating at the macro level. Both textbooks and exemplar examination papers contribute to the envisioned curriculum as captured in the published curriculum (syllabus) developed by producers (and also operating at macro level), being translated into the enacted curriculum. The current thesis thus focuses on the exemplar examination paper as an aspect of the pedagogic recontextualising field. Lotz-Sisitka (2009) framed the quality of assessment and feedback as a question of epistemological access supporting the considerations raised in Chapter One.

2.7 Epistemological Access to Science Discourse

The topic of epistemological access in South African education is still fairly under-researched (Du Plooy & Zilindile, 2014). According to Du Plooy and Zilindile (2014), Wally Morrow who played a notable role in South African education reform, first used the term "epistemological access" in 1992 when describing two dimensions of access to higher education – formal access to higher education institutions of learning, and epistemological access to the knowledge that higher education distributes. He later elaborated: "To register as a student at a university is not yet to have gained access to the knowledge that the university distributes" (Morrow, 2009, p. 77). Formal access does not automatically guarantee epistemological access. As mentioned earlier, the high dropout rates from South African tertiary science programmes neutralises the potential benefits of massification. Furthermore, access to knowledge at tertiary level is dependent on access to knowledge at high school level for hierarchical knowledge structures such as chemistry. The issue of epistemological access to science discourse is thus relevant to this thesis.

Epistemological access can be described as the ability to own not only knowledge and characteristic ways of knowing, but also ways of being related to specific academic disciplines (Morrow, 2003). One aspect of this involves language-in-use for enacting such activities, perspectives, and identities, or discourse (lower case d) as described by Gee (2005). Identities, however, are rarely enacted by language alone and so Gee (2005) employed Discourse (upper case D) to reflect ways of being that include but also extend beyond language use. Ways of being include the use of such things as symbols and tools in appropriate places and at appropriate times for enacting identities. Arbee et al. (2014) directly related epistemological access to Discourse by elaborating that complete epistemological access implies that students can appropriately enact a disciplinary identity enabling them to effectively participate in its Discourse. The desirability of epistemological access in decolonial and transformation contexts has a solid foundation considering that, as Morrow (2009) pointed out, when one achieves epistemological access to an academic practice, one is emancipated from specific forms of domination.

In terms of the work of epistemological access, Morrow emphasised the student's role while others such as Lotz-Sisitka (2009) highlighted the academic activities of institutions. In terms of level of applicability, Morrow's focus was on higher education while a range of other scholars have extended this to schooling (Du Plooy & Zilindile, 2014). The aspects focused on in these differing approaches are not mutually exclusive when one considers that Discourse is associated with identifying oneself as having membership in a social network or socially meaningful group (Gee, 2005). In order for learners to achieve epistemological access to a discipline's Discourse, its aspects need to be taught explicitly via overt instruction and situated learning practices (Ellery, 2011).

From a realist perspective, teachers' pedagogic practice may constrain epistemological access to knowledge in abstract form if they do not include sophisticated strategies for mediation between the abstract and the concrete, or between situated activities and the concepts in the subject matter (Lotz-Sisitka, 2009). In relating epistemological access to curriculum, Kelly-Laubscher and Luckett (2016) explored differences in biology knowledge structure as presented in high school and university biology curricula. They averred that epistemological access to biology at the university level may be restricted due to differing knowledge structures in school and university biology curricula.

Epistemological access is also shaped at levels lower than curriculum knowledge structure. Rose (2000, p. 42) elaborated on scientific English as being “concerned with chemical, physical and biological processes involved in explaining, classifying and manipulating natural phenomena, with the goal of applying these explanations and classifications to industrial production”. Drawing on Bernstein’s (1990) model of how the fields of economic production and education are related in modern industrialised economies, Veel (2000) discussed the correspondences between the nature of discourse at different levels of industry and education, exemplifying discursive relationships between the discourses. Transmission and acquisition of scientific discourse happens selectively across the levels constituting education systems.

Veel (2000) pointed to the existence of at least three components of recontextualised scientific discourse in secondary school. The first component consists of basic procedures which guide students in activities related to the topic. Students who only acquire this ‘doing’ component of recontextualised scientific discourse, are unable to enter either technical vocations or further science education (2000). The second component of recontextualised scientific discourse in secondary school involves a range of genre for explaining, describing, and classifying aspects of the natural world. Those able to acquire technical literacy skills may enter technical or workplace training towards vocational careers. The third component of recontextualised scientific discourse in secondary school covers features of abstract scientific discourse. Students who are able to acquire and identify with such abstract construal of science are poised to enter tertiary science towards professional posts in industry (Veel, 2000).

2.8 Abstraction in Chemistry

2.8.1 Two forms of abstraction in chemistry

According to Woldeamanuel et al. (2014), many university and high school students across countries struggle to learn chemistry. Researchers, science educators and teachers regard the subject as difficult due to such things as teaching aids being unavailable, the teaching styles learners encounter in the classroom, the language of chemistry, and the abstract nature of chemistry concepts. It is evident that the former two are contextual factors, while the latter two are characteristics of chemistry discourse. Additionally, the language of chemistry and abstract nature of its concepts are not mutually exclusive since the concepts are communicated through language. Nonetheless, distinguishing between them brings into focus two aspects of abstraction – abstraction in terms of language/representation, and conceptual abstraction.

The issue of abstraction has been gaining currency in science curriculum in recent years. In the USA and UK for example, new curricula place a premium on abstraction and theory compared to traditional curricula which emphasised application and technology (Akpan, 2017). As Young (2008) argued, this may be due to theoretical knowledge being more socially powerful than everyday knowledge. The abstract nature of theoretical knowledge allows it to be applied in multiple contexts and situations (Bernstein, 2000). Ainsworth (1999) referred to abstraction as "a notoriously slippery term" (p. 141), warranting a deeper consideration of abstraction in literature. This follows from the discussions around the fundamental sense of scientific literacy (reading and writing science) and science discourse (language use in context) being foundational to the derived senses of scientific literacy (knowledgeability of science) and science Discourse (way of being). A review of literature on the notion of abstraction both conceptually (independent of semiotic form) and also semiotically (related to semiotic form), will be presented after first discussing how these two forms of abstraction can be gleaned from the chemistry triplet proposed by Johnstone (1982).

2.8.2 Johnstone's (1982) chemistry triplet

Chemistry is about substances and the interactions between them (many of which cannot be perceived by the naked eye). The explanations which it offers are in terms of entities such as atoms and molecules which would be too small to see even if their existence were proven and "this forced the use of a model (symbol) to help people visualize the microworld" (Han & Roth, 2005, p. 177). Halliday (1998) reminded us that science is simultaneously a material and semiotic practice. Chemists view the subject of chemistry on at least three levels, which they are able to easily move between (Johnstone, 1982). Johnstone (1982) also referred to them as levels of thought. Chemistry education employs these as representational systems/levels for describing and explaining chemical phenomena (Johnstone, 1993). Gabel (1993) extended the definition of the chemistry triplet to levels at which chemistry can be taught. These are shown in Figure 2.3 (from Johnstone, 1991, p. 78).

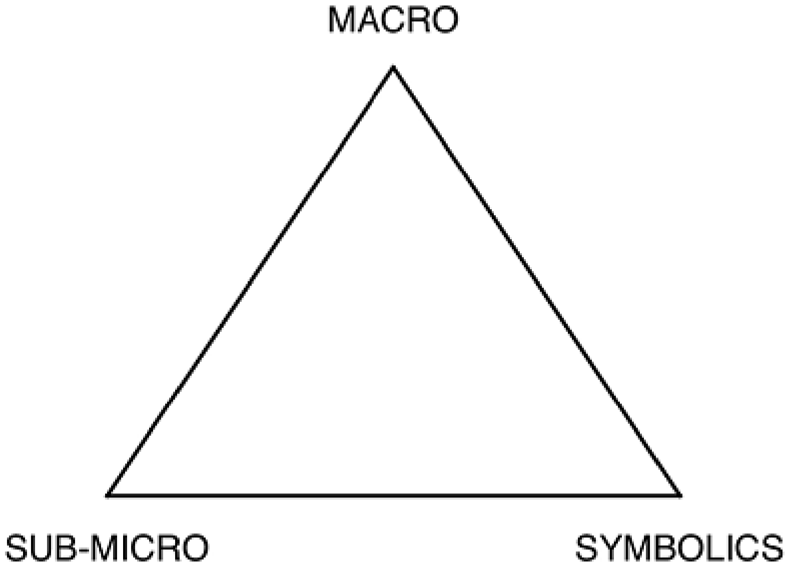


Figure 2.3: The chemistry triplet proposed by Johnstone (1991)

Macroscopic representations "describe bulk properties of tangible and visible phenomena in the everyday experiences of learners when observing changes in the properties of matter, such as colour changes, pH of aqueous solutions, and the formation of gases and precipitates in chemical reactions" (Chandrasegaran et al., 2008, p. 239). According to Mbajiorgu and Reid (2006), the macro level of thought covers the phenomenological, or that which can be perceived by the senses independent of instrumentation and usually refers to concrete entities. In contrast, the submicroscopic level of thought covers that which can only be perceived via the use of instruments or be abstracted from chemical processes via inference (Mbajiorgu & Reid, 2006). Submicroscopic or molecular representations focus on the particulate level, involving atoms, molecules, and ions (Chandrasegaran et al., 2008). Symbolic representations employ such devices as "chemical symbols, formulas and equations" (Chandrasegaran et al., 2008, p. 239).

The three representational systems are interrelated and Krajcik (1991) used the term "integrated conceptual understanding" to describe familiarity with all of them. However, Johnstone (1991) argued that while trained chemists can keep the three levels in balance, learners cannot. Teaching that focuses on only one apex or along one side of the triangle would be manageable to the learner as a novice, but it often occurs within the triangle, demanding that students work across all three levels at once (Johnstone, 1991).

Strong experience in macro level chemistry is needed before the submicroscopic and symbolic levels are introduced (Mbajiorgu & Reid, 2006). According to Mbajiorgu and Reid (2006), a strong foundation can be built at the macro level by relating content to students' previous knowledge and experience. This alludes to decreasing conceptual abstraction via expanding on previous learning and forging links to real-life contexts. Interpretations involving the submicroscopic and symbolic levels should be introduced gradually and with care, in order to avoid information overload (Mbajiorgu & Reid, 2006). This makes sense considering that various studies over the past few decades have revealed that students have difficulty understanding submicroscopic and symbolic representation systems due to them being more abstract (Chandrasegaran et al., 2008). A different form of abstraction becomes more clearly evident at the submicroscopic and symbolic representational levels – one that is semiotic in nature.

Gkitzia et al. (2011) conducted a study which exemplifies the semiotic nature of the three chemistry levels and why they are often referred to as representational levels. The authors analysed five school chemistry textbooks to develop criteria for evaluating chemical representations, which they then applied to another chemistry textbook. The first analysis involved categorising figures as macroscopic, submicroscopic, symbolic, multiple, hybrid, or mixed. Kapıcı et al. (2015) shed light on the differences between these categories as presented by Gkitzia et al. (2011). Macroscopic representations show tangible or observable objects or concepts, while submicroscopic representations illustrate such things as atoms, ions, electrons, and molecular structures that cannot be observed by the naked eye or optical microscope. The symbolic level includes signs, symbols, letters, equations, and mathematical representations or formulae. Johnstone's chemistry triplet allows for illustrating the different forms of abstraction that will now be considered – semiotic abstraction (related to semiotic mode) and conceptual abstraction (unrelated to semiotic mode).

2.8.3 Semiotic abstraction

There is a long history of emphasis on semiotics in education as evident in Wells' (1993) metaphor of schooling as semiotic apprenticeship, and Suhor (1983) making the case for a semiotic basis for curriculum. Science classroom communication is recognised as multimodal (Márquez et al., 2006) with the range of semiotic modes involved including the verbal or spoken mode, gestural mode, visual mode, and written text mode. The verbal and visual semiotic modes are most frequently used by teachers in their teaching (Ryu & Boggs, 2016).

For the case of curriculum documents in the recontextualising field of the pedagogic device, such as the published curriculum (syllabus) in the official recontextualising field and illustrated curriculum (textbooks and exemplar exams) in the pedagogic recontextualising field, the visual and written modes are most relevant. In reviewing literature about the vocabulary of content textbooks, Langhan (1990) identified various factors influencing the readability of textbooks. One of these involved concrete and abstract words – concrete words make text more readable compared to abstract terms revealing that textual literacy demands are related to particular kinds of words. Textual abstraction will now be discussed before considering visuals abstraction.

2.8.3.1 Textual abstraction

Marais and Jordaan (2000) affirmed that understanding chemistry is difficult because it is abstract, and pointed to language as a significant contributor to this. Sibanda (2014) posited that the familiarity of reading material influences how easy it is to read and understand them. In her study of readability of South African Grade 4 science textbooks, Sibanda (2014) coded topics into the categories of very familiar, partially familiar, and unfamiliar or abstract. Her study found that the textbooks were above the reading levels of their intended audience and that this was mostly due to vocabulary that was not explained or exemplified. Her recommendations included that definitions be provided in-text, as well as in glossaries (with the publishers' websites including bilingual or multilingual glossaries). If textbooks already in use are beyond the readability level appropriate for a class of learners, the teacher needs to devise responsive strategies for mediation of the content (Sibanda, 2014).

Several researchers concurred that the biggest barrier to learning science is the language of science. In fact, from the perspective of theories such as Systemic Functional Linguistics, learning the language of science is synonymous with learning science. According to Fang (2005), scientific discourse involves unique features for construing scientific knowledge. These features present challenges to students' comprehension and composition of science texts. Understanding the functionality of the linguistic features of science is crucial for developing science literacy. As indicated in earlier sections of this thesis, abstraction is one of the features of scientific discourse. The language of science "theorizes concrete life experiences into abstract entities" by turning processes (verbs and adjectives) into participants (nouns) (Fang, 2005, p. 239). This is known as nominalisation, and nominalised phrases abstract away from immediate lived experiences to build truths, abstractions, generalisations, and arguments.

Nominalisation is a process of re-meaning that allows for the construction of technical terms in which knowledge is more distilled and usually more conceptually abstract (Fang, 2005). Mbajiorgu and Reid (2006, p. 3) highlighted "the fact that the process of abstraction is inherent in chemistry" and pointed to abstraction via nominalisation in chemistry language as related to the submicroscopic level. The discussion of nominalisation leads to consideration of different categories of science words. According to Wellington and Osborne (2001), many science words are foreign to pupils. They present a categorisation of words encountered in science discourse. The catgories are: non-technical, semi-technical, and scientific. Since science words themselves have a range of different characteristics, they can also be divided into categories for the purpose of teacher awareness around their use. Wellington and Osborne (2001, p. 20) provided such a classification or taxonomy (see Figure 2.4) with each category acquiring meaning in a different way.

BOX 2.4 A taxonomy of the words of science

Level 1: Naming words
1.1 Familiar objects, new names (synonyms).
1.2 New objects, new names.
1.3 Names of chemical elements.
1.4 Other nomenclature.

Level 2: Process words
2.1 Capable of ostensive definition, i.e. being shown.
2.2 Not capable of ostensive definition.

Level 3: Concept words
3.1 Derived from experience (sensory concepts).
3.2 With dual meanings, i.e. everyday and scientific: for example, 'work'.
3.3 Theoretical constructs (total abstractions, idealizations and postulated entities).

Level 4: Mathematical 'words' and symbols

Figure 2.4: A taxonomy of science words (Wellington & Osborne, 2001, p. 20)

The first category is *naming words* which include "identifiable, observeable, real objects or entities" (Wellington & Osborne, 2001, p. 20). Many of these are synonymous with everyday words that pupils are familiar with, such as windpipe for trachea, reflecting an aspect of science education involving provision of new names for familiar objects. There are also instances at a higher level, in which new names are provided for unfamiliar objects which students may not have seen due to scale (such as cell) or being specialised such as laboratory equipment (for example beaker, spatula, and bunsen burner). This category includes chemical names and other nomenclature.

The second category is *process words* and includes subcategories based on words capable of ostensive definition (that are demonstratable, such 'distillation') and those not capable of ostensive definition (such as 'evolution'). The third category is the largest and includes *concept words* derived from experience (sensory) with dual meanings and theoretical constructs ('total abstractions, idealisations and postulated entities') such as fruit, pressure, volume and temperature. Wellington and Osborne (2001) argued the possibility that most learning difficulties occur with words at this level. The fourth and final category involves *mathematical words and symbols* which are so detached that they are "almost independent of the physical world" (Wellington & Osborne, 2001, p. 22). In highlighting that this taxonomy of words denotes levels of abstraction, Marais and Jordaan (2000) showed them on a continuum of abstraction as shown in Figure 2.5.

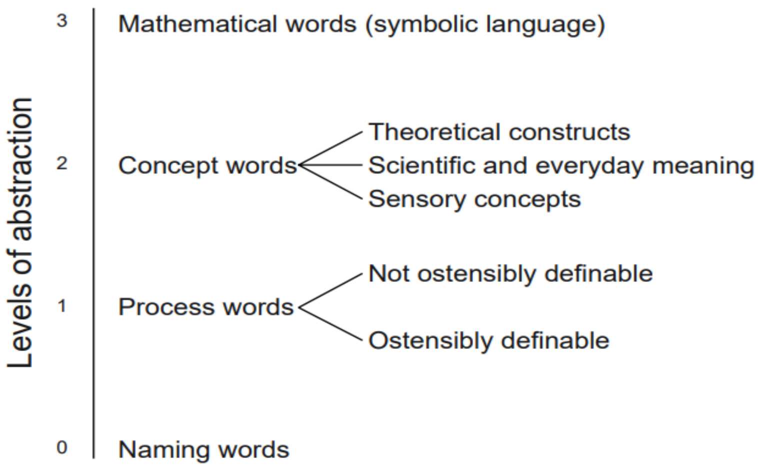


Figure 2.5: Wellington's taxonomy of words at different levels of abstraction (Marais & Jordaan, 2000, p. 1355)

While this framing was initially believed to have potential as an analytical tool in the current study for characterising the abstraction of chemistry text, it can also be critiqued. For example, it may be argued that the nominalisation and process word – 'distillation', which occurs less frequently in everyday contexts is more abstract than the concept word – 'temperature' which is commonplace in everyday discourse. Another example is that the chemical name 'methanol' counts as a naming word in this taxonomy, and as such is positioned at a lower level of abstraction than the concept word – 'fruit'. This is also highly questionable, since the word fruit is more commonly used in everyday discourse than ethanol. Thus, this abstraction continuum by Marais and Jordaan (2000) does not feature in the research design of the current study.

2.8.3.2 Visual abstraction

When it comes to printed materials for communicating scientific ideas, textbooks contain the most graphics (Lee, 2010). Indicating the range of types of chemical inscriptions, Han and Roth (2005) found the following in Grade 7 textbooks: photographs, drawings, diagrams, systems (causal models including natural objects/phenomenon and their relationships), cartoons, concept maps, tables, graphs, equations, and mixed visuals. Pozzer and Roth (2002) highlight the significant role of representation practices in science as reported in various studies (e.g. Knorr-Cetina & Amann, 1990; Latour, 1999). They mentioned that the more information summarised in an inscription the more powerful, complex, and resistant to deconstruction it becomes.

Latour (1987) pointed out that the more information summarised in an inscription, the more abstract it becomes (more contextual detail is removed). Myers (1990 in Pozzer & Roth, 2002), pointed out that a part of the move from the particularity of one observation to the generality of a scientific claim is the elimination of gratuitous detail. On an abstraction continuum for representations (in order of increasing abstraction) in biology textbooks, Pozzer and Roth (2002, p. 5) included photographs, naturalistic drawings, maps and diagrams, tables and graphs, and equations as shown in Figure 2.6.

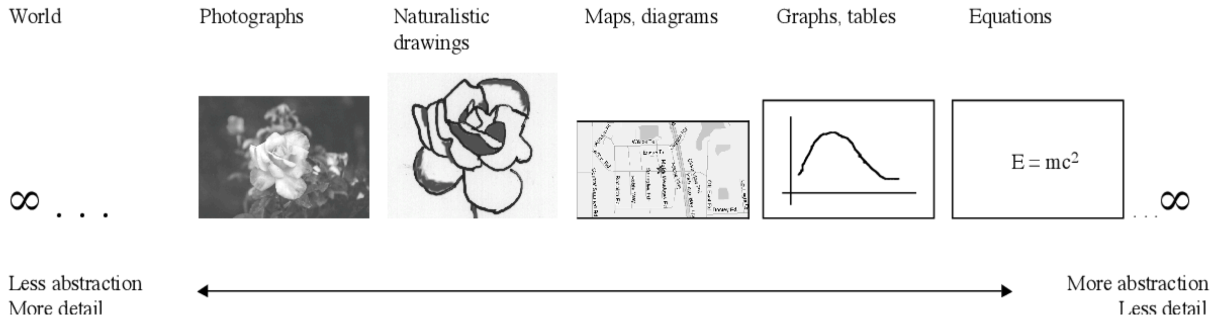


Figure 2.6: An abstraction continuum for representations based on amount of contextual detail (Pozzer & Roth, 2002, p. 5)

The analysis of four Brazilian high school biology textbooks by Pozzer and Roth (2002) revealed that the texts contained more inscriptions (1,9 inscriptions per page) than previously-studied North American high school biology textbooks (1,4 inscriptions per page). Photographs and naturalistic drawings together constituted 0,75 inscriptions per page in the Brazilian textbooks – compared with 0,96 inscriptions per page in the North American textbooks. Thus, while the textbooks relied heavily on inscriptions, most of these were photographs and naturalistic drawings which appear at the low end of the abstraction continuum (Pozzer & Roth, 2002). This framing offered the current study useful insight into the construction of an analytical tool for characterising the abstraction of chemistry visuals.

More recently, Offerdahl et al. (2017) presented a taxonomy of visual abstraction for biochemical and molecular biology representations (Figure 2.9). They employed a constant comparative approach (Glaser & Strauss, 1967; Maykut & Morehouse, 1994) to a set of figures for identifying emergent categories and developing a preliminary coding scheme. At the lowest level of abstraction are realistic representations closely resembling the original subject, and sometimes containing "superfluous contextual information" (Offerdahl et al., 2017, p. 6). This is followed by cartoons, in which particular features or properties (e.g. ball and stick models, and space-filling diagrams) are emphasised. The midpoint in their taxonomy are graphs depicting relationships between data sets (such as for titration curves). The fourth level of abstraction are schematic diagrams involving abstract symbols (e.g. chemical reactions). The most abstract level in their taxonomy are symbolic representations which express information via abbreviations, formulae, and names or labels necessitating translation.

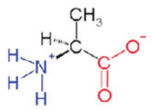
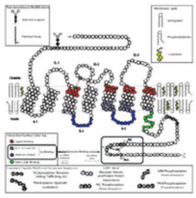
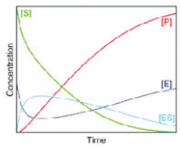
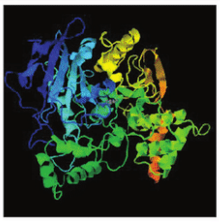
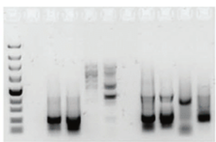
Type of Abstraction		Description	Examples
Symbolic (SYM)		Representation that expresses information using abbreviations, formula, names, or labels, which require translation.	amino acid abbreviations, chemical formula, mathematical equations
Schematic (SCH)		Diagram that uses abstract symbols (lines, arrows, etc.) to represent elements of a system, and often omits details to simplify information it intends to convey.	chemical reactions, metabolic processes, phylogenetic trees, pedigrees, molecular maps
Graph (GRA)		Depiction of relationships between data sets using a series of dots, lines, etc. that are often plotted with reference to a set of axes.	titration curves, Ramachandran plots, reaction coordinates, Lineweaver-Burk plots
Cartoon (CAR)		A drawing or computer-generated image that simplifies or emphasizes particular features or properties.	ball-and-stick models, space-filling diagrams, ribbon diagrams, artist renderings
Realistic (REA)		Representation that closely resembles the original subject, which may contain superfluous contextual information.	electrophoresis gels, electron micrographs, photographs

Figure 2.7: A taxonomy of visual abstraction for biochemical and molecular biology representations (Offerdahl et al., 2017)

This framing also offered the current study useful insight into characterising the abstraction of chemistry visuals. The visual abstraction continua presented by Pozzer and Roth (2002) and Offerdahl et al. (2017) thus informed the analysis of visuals in the current study, as will be evident in Chapter Four. We now turn our attention to the type of abstraction not included in the current study – conceptual abstraction.

2.8.4 Conceptual abstraction

Ultay and Calik (2012) reminded us about the decline in chemistry enrolments at university level in recent years. They mentioned problems facing chemistry education such as weak links to real life, students having difficulty transferring chemical knowledge to unfamiliar contexts, and chemistry curricula being detached from society. The authors positioned context-based chemistry approaches as having been devised for addressing such problems in chemistry education. In their thematic review of studies on the effectiveness of context-based chemistry curricula, Ultay and Calik (2012) stated that the purpose of context-based chemistry education is to make connections between the content of chemistry courses and real life. There appeared to be uncertainty in the literature as to the origin of context-based approaches as evidenced by Ultay and Calik (2012) pointing to the 1970s, while Bennet and Lubben (2006) pointed to the early 1980s. Nonetheless, the starting point is perhaps less significant than the actual reasons for contextualisation in science education.

Lubben and Bennett (2008) averred that the reasons for contextualisation of science teaching in everyday experiences fall into one of three categories. The first category is the perceived purpose of curriculum – such as the provision of pre-vocational awareness towards later career choice decisions. The second category is related to perceptions of learning, such as the use of everyday scenarios from which embedded science concepts can be gleaned. The third category is the effect on achievement, such as context-based courses contributing to a positive attitude towards science learning. Bulte et al. (2006) highlighted that recognisable contexts are appealing to students and provide a rationale for them learning concepts.

Ultay and Calik (2012) mentioned specific context-based curricula which have been employed in various countries such as 'Chemistry in Context' in the USA, 'Salters Advanced Chemistry' in the UK, and 'Chemie im Komtext' in Germany. The use of contexts in chemistry education is not confined to curricula announcing themselves as contextualised. However, where alternative curricula may use chemical applications illustratively, context-based approaches use chemical applications to drive the introduction of chemistry concepts (Schwartz, 2006). The use of context extends beyond the level of curriculum design to the level of classroom teaching for the resolution of particular curriculum problems (Gilbert, 2006). These problems include content overload due to the accumulation of scientific knowledge accelerating, curricula taught as isolated facts with students not knowing how to connect aggregations of facts, lack of transfer of students' problem-solving for problems presented in different ways, lack of relevance, and inadequate emphasis on the scientific literacy goal of curriculum in favour of preparation for advanced chemistry study (Gilbert, 2006).

The perspective of context being able to resolve chemistry curriculum problems is a logical corollary to the notion of abstraction being a major challenge in chemistry education as described in section 1.5 of Chapter One. Considering that context is posited as a means of resolving chemistry curriculum problems, the meaning of the term requires clarification (Gilbert, 2006). Context originates from the latin verb "contexere" meaning "to weave together", and the noun "contextus" refers to "coherence", "connection" and/or "relationship" (Gilbert, 2006, p. 960). Context thus functions to describe circumstances giving meaning to words, phrases, or sentences.

Schwartz (2006) presented a ladder metaphor where chemistry learners are likened to climbers, with some enjoying the experience of climbing the ladder while others do not see the connection between the rungs and thus develop vertigo. The author described how context was addressed in various layers (including the formal or written curriculum) for the Chemistry in Context (CiC) initiative in America. Similar studies were conducted by Bennet and Lubben (2006) for the Salters approach, and by Parchmann et al. (2006) for Chemie im Kontext. Bulte et al. (2006) focused on authentic practices as contexts, Hofstein and Kesner (2006) focused on industrial chemistry as a context for making school chemistry more relevant, and Pilot and Bulte (2006) explored the use of contexts as a challenge in chemistry curriculum.

Duranti and Goodwin (1992) framed a context as *a focal event* that is embedded in a cultural setting and in an educational sense as having four attributes. The first involves a setting – a social/spatial/temporal framework within which mental encounters with focal events can take place. The second attribute involves a behavioural environment within which activities related to the focal event transpire. The third attribute is the use of specific language associated with the focal event – this attribute resonates with the notion of semiotic abstraction (the focus of this thesis). The fourth attribute is a relationship to background knowledge that is extra-situational. Gilbert (2006) used examples to show the relevance of these attributes in addressing the challenges to chemistry curriculum mentioned earlier. He further indicated that for context-based chemistry curriculum to be effective it needs systematic attention and so could be based on the curriculum representations of Goodlad et al. (1979) and Van den Akker (2003) mentioned earlier (see section 2.4.5).

Since the current study explored the alignment of visual and textual literacy demands between curriculum documents, it is semiotic abstraction rather than conceptual abstraction which features in the research design of the study. Furthermore, since abstraction and complexity can be interrelated, it made sense to distinguish between them to avoid them being conflated in the current study. This distinction will now be discussed.

2.8.5 Separation of complexity from abstraction

Chandrasegaran et al. (2008) cited several studies over the past three decades that point to the study of chemistry being difficult due to its complex and abstract nature. This was affirmed more recently by Blackie (2014) who subsequently pointed out that LCT is useful for addressing abstraction separately from complexity. The LCT dimension of Semantics involves both semantic gravity (SG) – which refers to the degree of abstraction, and semantic density (SD) – which refers to the degree of complexity. While SG and SD are often related, they can also be explored independently as required by particular research foci or questions. Both SD and SG are discussed further in Chapter Three. However, the current study is based on the challenge which semiotic abstraction poses in chemistry education, and it is SG which has the potential for exploring visual and textual abstraction in curriculum texts. SG thus features in Chapter Four, independent of SD.

2.9 Concluding Comments

This review of literature began by considering the central role of chemistry and chemistry education for sustainable development amidst a world in crisis to highlight the importance of school chemistry education mentioned in Chapter One. It became evident why challenges arising from chemistry curriculum literacy demands are thus also challenges to broader endeavours such as education for sustainable development. The subject of Physical Sciences in South Africa, in which Grades 10-12 chemistry is taught, was then discussed as well as declining enrolment and the issue of the subject being taught in an abstract way being a social justice concern.

Thereafter, a review of literature regarding theoretical perspectives on curriculum was presented which included the origin and evolution of curriculum, curriculum dichotomies, hierarchical curriculum conceptualisations, curriculum levels, curriculum representations and layers, curriculum in Bernstein's pedagogic device, and published and illustrated curriculum.

Curriculum alignment perspectives, studies and methods were then discussed. This was followed by a deeper engagement with literature about syllabi, textbooks and exemplar assessment, as curriculum documents. Epistemological access to science discourse was then considered in more detail. Literature pertaining to the notion of abstraction in chemistry was then reviewed. This entailed consideration of the chemistry triplet, textual and visual abstraction as examples of semiotic abstraction, and conceptual abstraction (which is not foregrounded in this study since the research questions relate to semiotic abstraction).

Lastly, the distinction between abstraction and complexity was highlighted. Chapter Three provides an overview of LCT as the theoretical framework for this study, and elaborates on the notion of SG which is of particular relevance to semiotic abstraction.

CHAPTER THREE: THEORETICAL FRAMEWORK

3.1 Introduction

This thesis explores the nature of alignment of school chemistry curriculum literacy demands in terms of the chemistry discourse feature of abstraction. The Semantics dimension of LCT operationalises abstraction in terms of SG, which plays a key role in the building of knowledge over time. The usefulness of SG is strongly evident given that "almost everyone in education shares a desire for cumulative knowledge-building" (Martin et al., 2019, p. 81). In order to better appreciate the SG framing of abstraction, this chapter outlines how SG is situated within the broader theory of LCT.

The chapter begins by setting the scene with a discussion of knowledge blindness in education. The foundations of LCT are acknowledged – social realism, Bernstein's discourses and knowledge structures, and Bourdieu's field theory. Thereafter, an overview of LCT is provided, before the discussion moves to the LCT dimension of Specialisation, and Maton's Epistemic pedagogic device. The LCT dimension of Semantics is then presented, with a focus on SG. Semantic profiling, cumulative and segmented learning, and some studies employing LCT Semantics are then considered. It is important to note that while various aspects of LCT are discussed for the sake of completeness, not all are relevant to addressing the research questions of the current thesis as will become evident in the research design of the study. Chapter Four revolves around developing and operationalising SG translation devices for characterising textual and visual abstraction.

3.2 Knowledge Blindness in Education

In recent decades new eras (such as the knowledge era) have been proclaimed, with each having different names and changes associated with them, but all foregrounding knowledge as influencing all aspects of social life (Maton, 2014). Moore and Young (2010) pointed to the fact that while reference is made by politicians to the notion of a knowledge society and more people are being required as knowledge workers, government policy is silent on the nature of this knowledge. Knowledge economies, according to Maton (2014), are based on creating, circulating, and consuming information as opposed to material goods – this requires lifelong learning by workers to keep on track with the fluidity of labour markets. Koopman (2017) affirmed that South Africa faces challenges in terms of its position in the local and global economy, and highlights the premium placed on school science subjects for addressing this.

While the sociology of education recognises the problem of knowledge in curriculum, contemporary trends have treated knowledge in a general way. This weakens our ability to address curriculum challenges related to globalisation and post-compulsory education massification (Maton & Moore, 2010). As Maton (2014) pointed out, accounts of social change are united by an emphasis on knowledge being central, but also by the fact that they lack a theory of knowledge. Therein lies the paradox of knowledge being everything, and yet also nothing (Maton, 2014).

This paradox extends to educational research where it takes the more specific form of knowledge blindness in education. In the current study, this blindness appears in the form of the implicit nature of chemistry curriculum literacy demands, and more specifically the degrees of textual and visual abstraction in chemistry curriculum documents. Such knowledge blindness is problematic because chemistry curriculum literacy demands pose semiotic challenges to learners' chemical literacy, thus impeding their epistemological access to chemistry Discourse. Limited epistemological access in turn limits learners' meaningful participation in further chemistry education and training, which is not only a social justice concern but also a hinderance to sustainable development nationally and globally.

Despite knowledge currently being acknowledged as central to the nature of society, descriptions of social change have lacked a theory of knowledge which explains what knowledge is, what forms it takes, and what its effects are (Maton, 2014). One of the reasons for knowledge being under-researched is the subjectivist doxa of most sociological approaches resulting in knowledge being reduced to knowing. Beyond just a blindness to knowledge, there is knowledge aversion with the sociology of education previously being preoccupied with relations to knowledge at the expense of relations within knowledge. According to Maton (2014), social realism affords an avenue for overcoming knowledge blindness and bringing together relations-to and relations-within. In addition to social realism, Maton's LCT has Bernstein's code theory and Bourdieu's field theory as its central foundations. A brief overview of social realism, Bernstein's discourses and knowledge structures, and Bourdieu's field theory will thus be provided before discussing LCT (and how it frames abstraction) in more detail.

3.3 Social Realism

According to Young (2008), both neo-conservative traditionalism and technical instrumentalism (dominant and contending assumptions about knowledge and curriculum) exclude consideration of knowledge itself and so contemporary theory debates lack a theory of knowledge. Neo-conservative traditionalism sees curriculum as a body of knowledge which schools are responsible for transmitting, while technical instrumentalism challenges this view by positing that curriculum be directed to meet the needs of the economy. Young (2008) explained that where neo-conservatism downplays social and historical aspects of knowledge, instrumentalism emphasises the relationship between curriculum on one hand, and economic change and student employability on the other.

Young (2008) highlighted that postmodernism is critical of both views and instead assumes that knowledge is embedded in the interests of 'knower' groups. However, the argument that knowledge cannot be separated from how it is constructed ultimately leads to the conclusion that all knowledge has equal value. Due to the resulting relativism being widely objected to in the academic community and denial of objective knowledge being possible, authors such as Young, (2008), Moore and Young, (2010), and Maton, (2014) proposed a fourth position. They introduced social realism into the sociology of education for overcoming the 'educational dilemma' of curriculum either being a given or resulting from power struggles between groups holding competing claims for legitimising their knowledge over others. Young (2008) argued that social realism avoids the educational dilemma by providing grounds for:

- avoiding neo-conservative traditionalism in terms of 'a-historical givenness', as well as reliance on relevance, learner-centredness and experience in curriculum decisions;
- maintaining autonomy of curriculum from instrumentalism of economic and political demands;

- evaluating curriculum suggestions in terms of balancing of goals, for example addressing social exclusion and increasing participation without compromising cognitive interests involved in producing, acquiring, and transmitting knowledge;
- re-shaping curriculum standards debates from specification of learning outcomes and extending testing, to identifying cognitive interests and supporting them through development of specialist codes of practice, networks, and communities.

Social realism can be considered a broad school of thought in the sociology of education and it refers to a variety of movements, being heterogeneous in terms of the intellectual contributions that constitute it (Maton & Moore, 2010). While social realist theory has critical realism as its foundation, one school of thought emerged from various scholars uniting around the need for a theory of knowledge. This illustrates a 'coalition of minds' with the associated theorists taking knowledge as an object seriously, and also engaging in dialogue that models knowledge as an object of study (Maton & Moore, 2010). Protagonists include Karl Maton, Michael Young, John Beck, Rob Moore, and Joe Muller, but "the most immediate influence on social realism, however, has been the sociology of Basil Bernstein" (Maton & Moore, 2010, p. 12). The social realist perspective is gaining prominence across many national contexts including South Africa.

In addition to social realism recognising knowledge as an object of study, it reveals knowledge as both social and real (having properties, powers, and tendencies with effects) (Maton, 2014). In maintaining that *relations-to* and *relations-within* knowledge are complementary in offering explanatory power, it defies the epistemological dilemma – "a false dichotomy between positivist absolutism and constructivist relativism" (Maton, 2014, p. 6). This is significant considering the damaging implications of the false dichotomy for understanding education, for policy and practice, and more broadly for social justice (Maton & Moore, 2010). Social realism rejects positivism by recognising that the social character of knowledge is inescapable, and it rejects constructivism by virtue of its anti-positivist stance not equating to relativism. It acknowledges rational objectivity in knowledge as fact, as a social phenomenon, and as fallible (as opposed to absolute or relative). The result is that knowledge comes into view in its own right and centrally, addressing the challenge of knowledge as an object having been absent from dominant approaches in the sociology of education.

The damaging effects from the epistemological dilemma, such as for our understanding of education and the results of education, are exemplified by changes in recent decades being focused on knowers or knowing, with knowledge having been side-lined (Maton & Moore, 2010). Consequences for curriculum are evident in such things as the constructivist beliefs that disciplinary basis is arbitrary and specialist expertise is just a power play, that knowledge is undifferentiated, and that the basis of selection and sequencing in curriculum is arbitrary. Maton and Moore (2010) highlighted that the attempt by social realism to recover knowledge serves the goal of social justice, with the driving force being the creation of more powerful forms of knowledge (epistemologically) and the means for making them accessible to all. This showcases the value of the current study adopting a social realist stance considering that it needed to reconcile the abstract nature of chemistry discourse making it powerful, while also being a major challenge to epistemological access to chemistry discourse. We will now turn our attention to different forms of knowledge in order to better understand why knowledge structures such as chemistry spiral towards abstraction.

3.4 Bernstein's Discourses and Knowledge Structures

Young (2008) purported that the relationship between everyday and theoretical concepts is at the heart of pedagogy and curriculum. He explains that French sociologist, David Emile Durkheim used the term "profane" to refer to the practical, immediate, and particular ways in which people respond to the everyday world. Such knowledge is sometimes referred to as "mundane" (Wheelahan, 2010, p. 94). In contrast to the profane everyday world, is the "sacred" world of religion which Durkheim sees as invented, arbitrary in being detached from specific objects/events, and collective (Young, 2008). Sacred knowledge is sometimes referred to as "esoteric" knowledge – including theoretical and conceptual knowledge (Wheelahan, 2010, p. 94). The systems of concepts constituting the sacred are unobservable but related and hold an objectivity due to shared social character and being external to individual perception. One of the ways in which religion is significant to Durkheim, is as a model for all kinds of abstract thought constituted by unobservable concepts (including science). "In other words, the totems of the aborigines and the gas laws of the physicist were, in form at least, identical for Durkheim" (Young, 2008, p. 41).

Durkheim pointed to two key features of the sacred: it allows for the connection of objects and events that do not directly appear related on the basis of everyday experience (a capability crucial to scientists), and it allows for projecting possible futures (to predict outcomes based on scientific hypothesis and their evidence). These features distinguish theoretical knowledge (religious or scientific) from everyday knowledge (Young, 2008). According to Durkheim, abstract or theoretical thought is not a characteristic of particular individuals but a feature of all societies. Furthermore, both Durkheim and Bernstein averred that there is a universal distinction between esoteric and mundane knowledge, while their content is specific (both culturally and historically) (Wheelahan, 2010). Basil Bernstein took Durkheim's ideas further, applying them to curriculum (Young, 2008) together with his own ideas, in the distinction he made between horizontal and vertical discourse (Bernstein, 2000).

Bernstein (2000) argued that the structuring of meaning is fundamentally similar across all societies. His elaboration on Durkheim's distinction between esoteric and mundane knowledge involves him describing the former (conceptual, abstract knowledge) as a form of vertical discourse and the latter as a form of horizontal discourse (Wheelahan, 2010). The form taken by abstraction postulates and relates the material (everyday or mundane) and immaterial (transcendental) worlds. Common or mundane knowledge is associated with horizontal discourse, and esoteric or sacred knowledge is associated with vertical discourse. The terms horizontal and vertical discourse are used by Bernstein to describe the two knowledge types relating to the two worlds. While mundane knowledge involves meanings from physical encounters with the material world, crude thinking, and practical wisdom, esoteric knowledge is disciplinary knowledge developed in philosophical communities such as those of scientific researchers (Bernstein, 2000).

Bernstein (2000) argued against the unequal access to abstract, esoteric knowledge due to the importance of this knowledge, evident in its difference from mundane knowledge. The notion of mundane knowledge is associated with specific contexts or events, making such knowledge meaningful only within the material base of those particular contexts. Such knowledge cannot easily be applied in different contexts and consequently provides a weak impetus for change. Horizontal discourse has a segmented structure due to its realisation across a range of different contexts. The notion of esoteric knowledge is associated not with context, but with explicit knowledge in the form of specialised symbolic structures (Bernstein, 2000). Such knowledge is indirectly linked to a material base, consequently having a stronger potential for changing social power distribution. Vertical discourse involves knowledge integration through the integration of meanings. The two main forms of vertical discourse are horizontal knowledge structures (such as in the social sciences and humanities) and hierarchical knowledge structures (such as the natural sciences). Acquiring vertical discourse requires that one be able to integrate knowledge through systems of meanings that transcend context – "students need to learn the systems of meaning" (Wheelahan, 2010, p. 97).

Knowledge structures differ according to verticality (how a theory develops its internal language of description) and grammaticality (how a theory deals with the world – the external language of description) (Young, 2008). In term of verticality, theory in hierarchical knowledge structures develop "through the integration of propositions, towards ever more general sets of propositions" while theory in horizontal knowledge structures "develops through the introduction of a new language (or set of concepts)" (Young, 2008, p. 209).

Hierarchical knowledge structures can thus be represented by unitary triangles while horizontal knowledge structures are plural. Knowledge structures with stronger grammaticality have stronger ability to generate empirical correlates and are less ambiguous due to a more restricted field of referents. Knowledge structures with weaker grammaticality have weaker ability to generate empirical correlates and are more ambiguous due to a broader field of referents. Verticality determines the capacity of theory to grow its explanatory sophistication while grammaticality determines a theory's capacity to grow its worldly corroboration (Young, 2008). In order to improve education, a curriculum based on differentiating school knowledge from non-school knowledge is needed (Young, 2008).

3.5 Bourdieu's Field Theory

In sociological theory, accounts of social action have traditionally focused on analysis at the macro or micro level. An alternative is provided by field theory, since it is concerned with "how a set of actors orienting their actions to one another do so in a meso-level social order struggle" (Kluttz & Fligstein, 2016, p. 185). Bourdieu is recognised as the most prominent sociologist in France (Sallaz & Zavisca, 2007) and "the contemporary sociologist most often associated with field theory" (Kluttz & Fligstein, 2016, p. 188). His research trajectory includes a focus on the role played by education in reproducing inequality in France. Bourdieu's theoretical ideas are recognised as bridging the philosophical divide between structuralism (which privileged the formal models of scientists over common-sense understandings) and existentialism (which focuses on individual meaning). According to Sallaz and Zavisca (2007), his novel contribution is the synthesis of objectivist and subjectivist epistemologies with important concepts in his theory including capital, field, symbolic power, and habitus. Each of these concepts will now be considered.

Field theory recognises various forms of capital (Sallaz & Zavisca, 2007). Economic capital includes monetary income, accumulated wealth, and productive assets. Cultural capital is competence in a practice that is socially valued. Social capital refers to sustained relationship networks through which individuals are able to mobilise power and resources. Any of these forms of capital have the potential to serve as symbolic capital provided their unequal distribution is viewed as legitimate (Sallaz & Zavisca, 2007). Field is a concept referring to the local social world which actors are embedded in and orient their actions toward. "Fields are arenas of struggle" (Kluttz & Fligstein, 2016, p. 189). An example of the application of Bourdieu's field theory is demonstrated by Maton (2005), illustrating the usefulness of Bourdieu's notion of field for analysing higher education policy.

Bourdieu's writing involves field as a topological space (of positions), a site of relational forces, and a battlefield in terms of contestation – the latter is strongest, as evident in the frequency of the game metaphor (Sallaz & Zavisca, 2007). Field is likened to a game with its rules, stakes (capital), and related strategies. The form of power most effective in the game is the capacity of dominant groups to advance a definition of the social world aligned to their interests – this was referred to by Bourdieu as symbolic power (Sallaz & Zavisca, 2007). Bourdieu's concept of habitus refers to a system of dispositions that are transposable and durable. In acknowledging the 'slippery' nature of the term, Sallaz and Zavisca (2007, pp. 24-25) offer the following three characteristics as essential. In terms of disposition it is not so much a set of conscious strategies and preferences as it is an "embodied sense of the world and one's place within it" (ibid.); though never immutable, individuals internalise it through early socialisation and so it is durable; it is transposable in being carried with people when they enter new settings.

While Bourdieu's field theory is arguably the best framework for some forms of analysis around social power, Maton (2014) highlighted some of its limitations. For example, the notions of capital, field, and habitus cannot evoke descriptions of the components of education. With its 'flat ontology', the theory does not explain what generates fields and in order to develop field theory, Maton (2014) selectively built on Bernstein's pedagogic device in advancing his LCT as will now be discussed.

3.6 Legitimation Code Theory

3.6.1 Overview of LCT

Maton (2010) critiqued the trend of situating approaches as oppositional or incommensurable. He used the example of the perceived tension between the approaches of Basil Bernstein and Pierre Bourdieu. Their work is often compared and contrasted for the purpose of choosing a winner despite both arguing for a sociology of education that is scientific and cumulative. Maton overcame the false dichotomy by showing how insights from both can be integrated into one conceptual framework. While Bourdieu's field theory allows for describing intellectual and educational fields in terms of struggles over status and resources, Bernstein's code theory allows for conceptualising the structure of knowledge (Maton, 2000) – the former offers a sociology of knowledge while the latter offers a theory of knowledge (Maton, 2010). Bourdieu focused on how fields of practice (intellectual and educational) structure knowledge by embracing questions of who, where, when, how, and why (Maton, 2000). Bernstein focused on the structuring significance that knowledge has for those fields, by emphasising the neglected issue of 'what' (Maton, 2000). "Between them, their approaches conceive of knowledge as a structured and structuring structure" (Maton, 2010, p. 37).

Maton (2009) highlighted that a possible criticism of Bernstein's knowledge mapping is its suggesting dichotomous ideal types with strong differences. Questions arising from the dichotomous ideal types include whether all horizontal discourse is the same, whether there are quantum shifts between the two discourses and knowledge structure forms, and where some disciplines and curricula fit in the model. Its concepts alert us to the kind of discourse or knowledge structure that research might reveal but not what makes discourse horizontal or vertical, or knowledge structures hierarchical or horizontal (Maton, 2009). Muller (2007) argued that code theory concepts are more suggestive than explanatory. Overcoming the dichotomies required a new framework to theorise the underlying principles which generate discourses, knowledge structures, curriculum structures, and forms of learning (Maton, 2009).

LCT extends from social realism which recognises knowledge as being both based on an external reality, and socially constructed (Macnaught et al., 2013). As indicated earlier, it extends and integrates the approaches of Bernstein and Bourdieu (Maton, 2014). According to Maton (2010, p. 37), since the knowledge claims or practices of actors reflect claims of legitimacy, they can be understood as "languages of legitimation". Maton (2000, p. 149) defined languages of legitimation as "claims made by actors for carving out and maintaining intellectual and institutional spaces within education". His focus on legitimation considers both insights as well as blind spots in previous studies of intellectual fields, in an attempt to "establish educational knowledge as an independent object of study with its own specialised procedures in order to provide an adequate epistemological basis for the sociology of education" (Maton, 2000, p. 164).

LCT views "practices and beliefs of actors as embodying competing claims to legitimacy, or messages as to what should be considered the dominant basis of achievement within a social field of practice" (Maton, 2009, p. 45). Such competing claims to legitimacy or languages of legitimation are analysed in terms of their underlying structuring principles known as legitimation codes. The theory advances a Legitimation device comprised of five codes or dimensions thus far, each with related concepts for the analysis of organising principles, and associated principal modalities/legitimation codes (Maton, 2014). The five dimensions are Autonomy, Temporality, Density, Specialisation, and Semantics. Concepts related to the Semantics codes, for example, are SG and SD and the principal modalities or legitimation codes are SG+/- and SD+/- (these will be explained later in this chapter). Similarly, concepts related to Specialisation codes are social relations and epistemic relations with the associated legitimation codes being SR+/- and ER+/-, as will now be discussed.

3.6.2 Specialisation and Maton's epistemic-pedagogic device

In LCT, Maton (2014, pp. 43-44) described the practices of actors "as representing languages of legitimation in struggles for the status and resources at stake within social fields of practices". He alerted us to some related questions. One question is around what grounds the struggles between different actors' practices are being fought on – in other words, the nature of the social field in question. Another question relates to what the various actors are struggling over. In addressing these, he presented the epistemic-pedagogic device (EPD) as an extension of Bernstein's Pedagogic Device which was detailed in section 2.4.6 of Chapter

Two.

Bernstein (1990) described the pedagogic device as comprising of three fields of practice (field of production, field of recontextualisation, and field of reproduction), together creating an arena of struggle. As Bernstein explained, each field has its own structure, with the intrinsic grammar of the device consisting of distributive rules governing knowledge production, recontextualising rules governing knowledge recontextualisation, and evaluative rules governing knowledge reproduction (Maton, 2014). The organising principles of dispositions and practices of actors are analysed via pedagogic codes based on the notions of classification ("relative strength of boundaries between contexts or categories") and framing ("the locus of control within contexts or categories") (Maton, 2014, p. 29).

In Maton's EPD, actors' dispositions and practices are analysed via specialisation codes. Rather than the specialisation dimension of LCT involving a breaking away from Bernstein's notions of classification and framing, specialisation integrates and extends them. Specialisation is based on the analytical distinction between "epistemic relations between practices and their object or focus (that part of the world to which they are orientated); and social relations between practices and their subject, author or actor (who is enacting the practices)" (Maton, 2014, p. 29). The relative strengths of epistemic relations (ER) and social relations (SR) can vary independently between stronger (+) and weaker (-), resulting in a range of possible specialisation codes as shown in Figure 3.1.

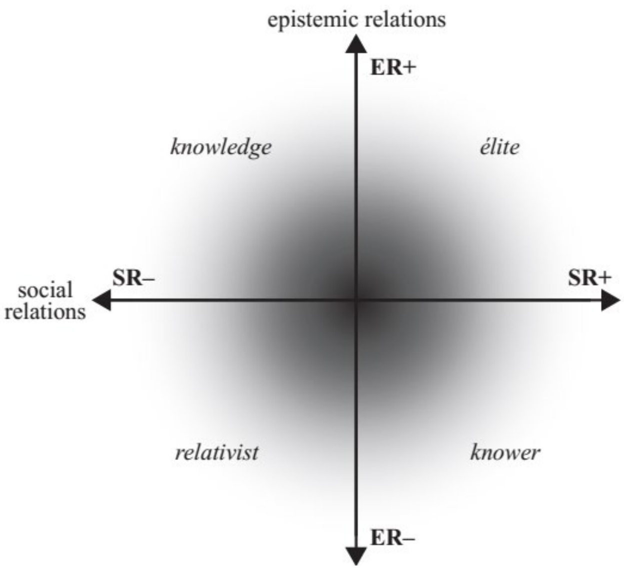


Figure 3.1: The Specialisation plane and associated codes (Maton, 2014, p. 30)

In arguing for the move from the pedagogic device to the epistemic-pedagogic device, Maton (2014) presented the arena created by the EPD as shown in Figure 3.2. The rules can be seen as redescribed, being termed logics to avoid them suggesting practices are deterministically rule-governed. Curricularising of knowledge (from the production field to the recontextualising field) and pedagogising of knowledge (from the recontextualising field to the reproduction field) is represented by left-to-right flow. However, as indicated by the arrows between fields in Figure 3.2, recontextualisation across fields occurs in both directions. In Maton's EPD model, activities across the arena are encompassed by distributive logics rather than it underpinning production fields, for which the term epistemic logics is now used. Literature on the EPD does not distinguish between the official and pedagogic recontextualising fields and so the results of the current study in Chapters Six and Seven will refer to the pedagogic device rather than the EPD.

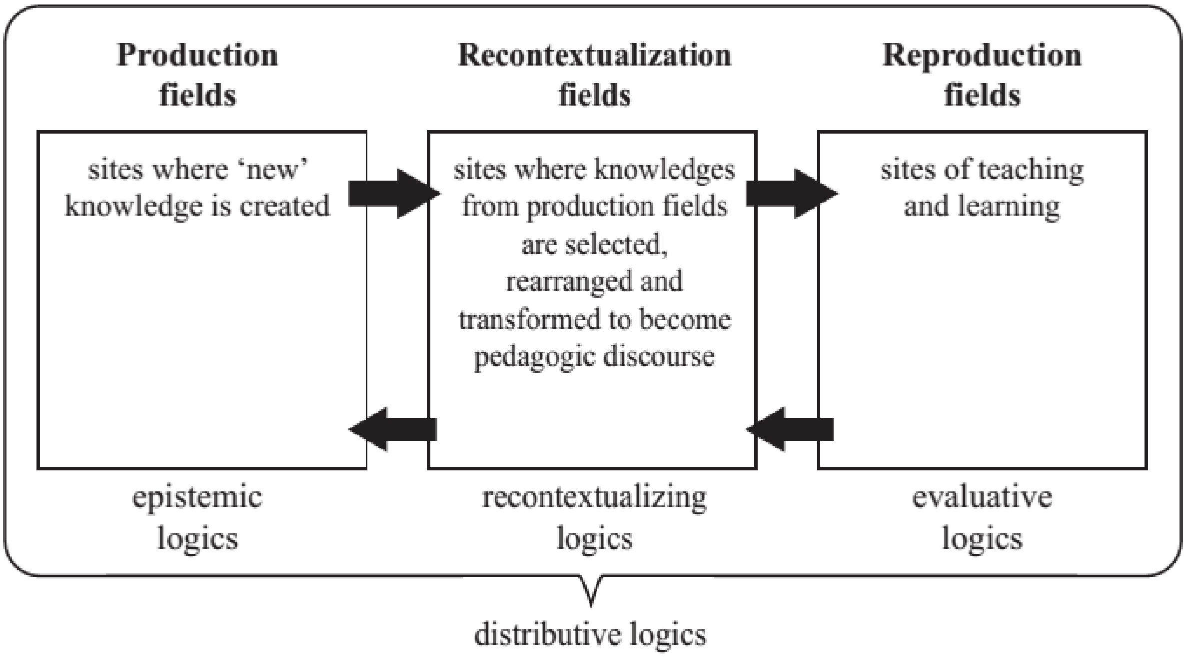


Figure 3.2: The arena created by the epistemic pedagogic device (Maton, 2014, p. 48)

3.6.3 LCT Semantics

Previous substantive studies employing the LCT dimension of specialisation highlighted condensation and context-dependence of meaning that the dimension of specialisation could not fully address (extension of the framework was needed). According to Maton (2013), these issues were also highlighted in Bernstein's models of elaborated and restricted codes and discourses and knowledge structures, but were conflated as dichotomous types with their organising principles yet to be conceptualised (development beyond the foundational framework was needed). Furthermore, collaborative studies with Systemic Functional Linguistics raised questions about features such as grammatical metaphor manifested in knowledge practices (new facets were highlighted by a complementary framework) (Maton, 2013). LCT Semantics views social fields of practice as semantic structures for which the organising principles are semantic codes that consist of varying strengths of SG and SD (Maton, 2013). In social practices such as education, SG relates to context-dependence of meaning while SD relates to condensation of meaning (Maton, 2014).

3.6.3.1 Semantic density and semantic gravity

Semantic density (SD) is defined as the degree to which meanings are condensed within sociocultural practices and is evident in such things as "symbols, terms, concepts, phrases, expressions, gestures, actions, clothing etc." (Maton, 2014, p. 129). SD is relatively stronger (SD+) when more meanings are condensed within practices, and relatively weaker (SD-) when fewer meanings are condensed within practices, along a continuum of strengths. The degree of SD of a practice/symbol is related to its position within relational systems of meaning in the semantic structure of the particular intellectual field (Maton, 2014). Due to the differing semantic structures of the fields of production, recontextualisation and reproduction, the SD of a particular practice/term may be stronger in one field and weaker in another. Additionally, for words with both everyday and scientific meanings, the pedagogic realisations in vertical discourse are likely to be SD+.

The process of strengthening SD (SD↑), known as condensation, involves moving from fewer constellations (or relational systems) of meaning towards more constellations of meaning – for example, relating concepts such as cell, protein, and pigment to describe photosynthesis in biology (Maton, 2014). On the other hand, the process of weakening SD (SD↓), known as rarefaction, involves de-location from the full range of constellational relations – for example, explaining a technical term from an academic source in simpler terms limits the full range of its meanings (Maton, 2014).

We now turn our attention to the particular legitimation code relevant to the notion of abstraction discussed in Chapters One and Two. Every meaning relates to some kind of context and SG conceptualises the extent of their dependence on the context in order for them to make sense (Maton, 2013). Bernstein's model provided a clue regarding the conceptualisation of contextual transfer of knowledge, through its focus on "relations between knowledge and its social and cultural contexts" (Maton, 2009, p. 46). Forms of knowledge can thus be described in terms of context-dependence of meaning – semantic gravity (SG) (Maton, 2009). Stronger semantic gravity (SG+) is more closely linked to social/symbolic context of acquisition/use (Maton, 2014) than weaker semantic gravity (SG-), which is less context-dependent. SG can also undergo processes of being strengthened (SG↑) – known as gravitation, or of being weakened (SG↓) – known as levitation. Maton (2013) provided the example of a specific plant name having stronger gravity than a species of plant which in turn has stronger gravity than processes such as photosynthesis. SG contributes to an integrated account of education through its applicability in all three fields of the epistemic pedagogic device. Recontextualisation can be viewed as realisations of varying degrees of SG.

Maton (2009) pointed out that discourses, knowledge structures, curriculum structures, and forms of learning can thus be recast as realisations of different degrees of SG. This is illustrated in Figure 3.3 (Maton, 2009, p. 46). As discussed later in this chapter, cumulative learning is afforded by weaker SG while segmented learning arises from stronger SG (since it constrains the transfer of meaning between contexts). Maton (2009, p. 46) highlighted that "a hierarchical curriculum structure does not by itself enable cumulative learning", implying that the practices from one field cannot simply be "read off" from the practices in another field (Maton, 2014, p. 110).

In the current study of SG of text and visuals in chemistry curriculum documents for example, it cannot be assumed that these are reflected in the related knowledge structures of the production field or teaching and learning structures of the reproduction field. The fact that chemistry discourse has a hierarchical knowledge structure does not mean that a particular chemistry curriculum will have a hierarchical curriculum structure, and if it does then this does not guarantee that cumulative learning will take place.

Semantic gravity	**Forms of:**		
	discourse	knowledge structures or curriculum structures	learning
weaker ↑	vertical	hierarchical	cumulative
		horizontal	segmented
stronger ↓	horizontal		

Figure 3.3: SG and structuring of knowledge (Maton, 2009, p. 46)

Maton (2015) pointed out that a range of semantic codes (SG+/-, SD+/-) are possible due to both SG and SD existing along continua of strengths. For example, at different times, science lecturers' talk or students' responses to assessment may have stronger or weaker SD depending on how many meanings are condensed in their language. References that are more contextualised have stronger SG compared to those which are more decontextualised and thus have weaker SG. The continua of strengths for each, generates a semantic plane where each can be varied in relation to the other as shown in Figure 3.4 (Maton, 2014, p. 16). The rarefied code for example, involves weaker SG and SD (SG- and SD-) while the rhizomatic code involves weaker SG (SG-) and higher SD (SD+).

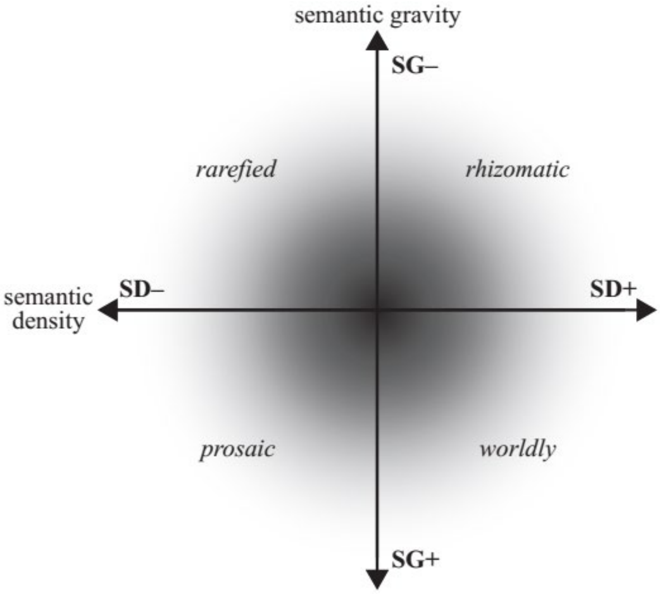


Figure 3.4: The semantic plane and associated codes (Maton, 2016, p. 16)

3.6.3.2 Semantic profiling

Due to the potential for semantic shifts between relatively stronger and weaker SG and SD over time, it is possible to plot semantic profiles (Macnaught et al., 2013) of lecturers' talk or students' written responses or reflections, for example. Semantic profiles of practices can be traced, and the related semantic range (difference between highest and lowest strengths) can be determined. A semantic profile represents a semantic scale of strengths of SG and SD of practices on the vertical axis against time (the unfolding of such things as classroom practice, curriculum, or text) (Maton, 2013). Three kinds of semantic profiles are illustrated in Figure 3.5 (Maton, 2015, p. 17).

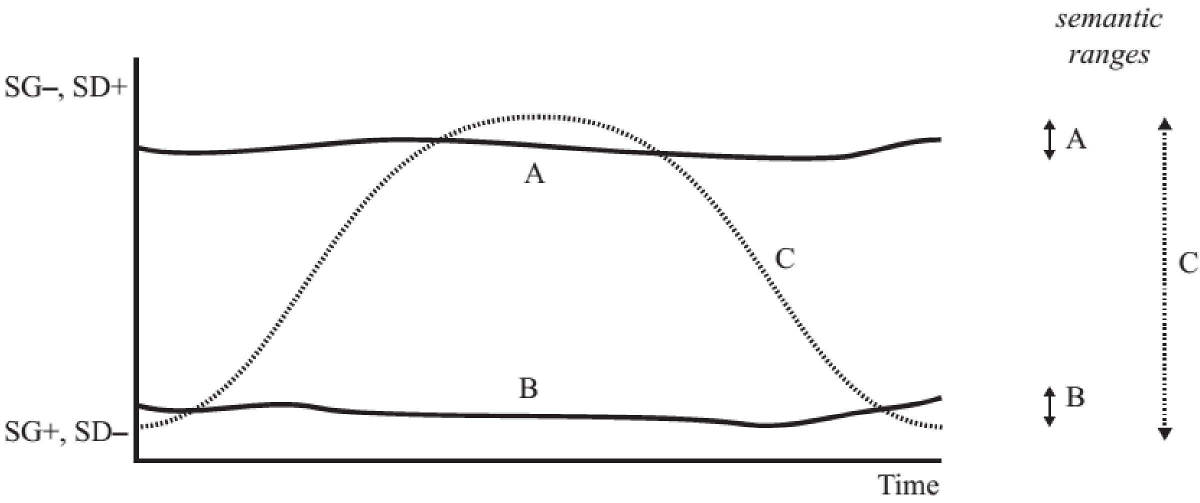


Figure 3.5: Three semantic profiles (Maton, 2015, p. 17)

In a semantic profile of talk or writing, the potential of upward and downward semantic shifts creating a semantic wave over time (C in the figure) is recognised as being powerful for cumulative knowledge-building. In Figure 3.5, A illustrates a high semantic flatline while B illustrates a low semantic flatline. Semantic flatlines (regions of minimal or no semantic shift) suggest the author/speaker is stuck in a limited semantic range (Macnaught et al., 2013) and they constrain knowledge-building. Uncovering mechanisms for extending semantic range is central both to learning and fostering a society that is more inclusive and far-sighted (Maton, 2014).

While SG and SD work together to frame the knowledge practices through semantic codes and profiles (Maton, 2009), the strengths of SG and SD can be independently varied. Analysis of student responses for example, can focus on SG as illustrated in the study by Bennet (2002). In the study, "reproductive description", such as students' direct quotation from cases, was coded as having the strongest SG since meanings were "locked into the context of the case from which the quote was taken" (Maton, 2009, p. 48). The other end of the SG spectrum (the weakest SG), involved abstraction where "meanings are decontextualized from the specific case to create abstract principles for use in other potential contexts" (ibid.). In between these (in order from lower to higher SG) were summarising description, interpretation, judgement, and generalisation.

Since SG can be explored independently of SD, it is also possible to plot a 'gravity wave' as illustrated in Figure 3.6 (Maton, 2014, p. A-45). This SG wave shows the profiles for two student essays based on three English readings/texts. As evident in the SG profile, the low-achieving essay exhibits a SG flatline (lower SG range) while the high-scoring essay involves a SG wave (higher SG range).

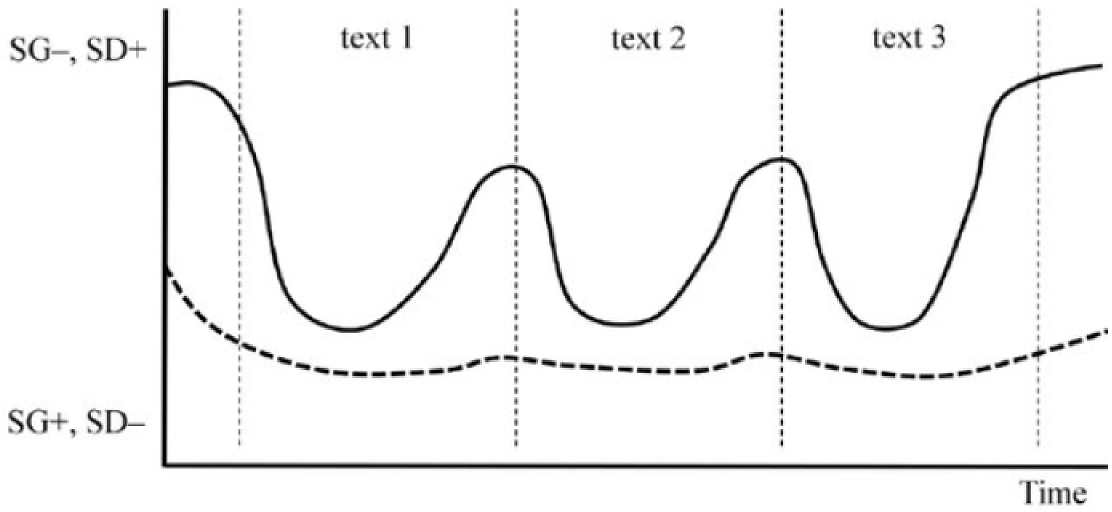


Figure 3.6: The SG profiles for two school English essays (Maton, 2014, p. A45)

Maton (2009, p. 54) revealed that education practices associated with a knower code can enable "low-road transfer, the automatic triggering of well-learned behaviour in a new context". Some curriculum structures aim for 'high-road transfer' which refers to mindful abstraction of meaning from a specific context for application in another context. High-road transfers require principles for knowledge recontextualisation in order for meaning to rise above the gravity of specific contexts. While knowledge codes enable high-road transfer, over time knower codes enable low-road transfer. In social realist perspectives on education, knowledge itself has causal powers and tendencies: "different structuring's of knowledge possess different affordances – they lend themselves more to certain forms of pedagogy, evaluation, identity, change over time, and so forth, than others" (Maton, 2009, p. 55). An advantage of LCT is that its concepts are not limited to particular contexts of application and thus allow for the integration of disparate foci such as curriculum guidelines, pedagogy, and student outputs.

3.6.3.3 Cumulative and segmented learning

Maton (2009) alerted us to the possibility of extending Bernstein's work on the development of hierarchical and horizontal knowledge structures in the knowledge production field, to the hierarchical and horizontal curriculum structures depending on whether a unit of study builds on previous knowledge via integration and subsumption or segmental aggregation. Furthermore, he pointed out that a distinction can be made between cumulative and segmented learning. He flagged segmental learning (learning isolated ideas/skills strongly tied to context of acquisition), as a pressing concern in educational debates (Maton, 2009). This kind of learning constrains students' knowledge-building by limiting transfer of ideas/skills to new contexts such as everyday life, future studies, or work (Maton, 2014). On a macro level, this is especially significant for economic and education policy in industrialised societies given the need for lifelong learning to meet the demands of a knowledge economy as described in section 1.2.1 of Chapter One.

While segmentalism is a "spectre" haunting education, "enabling cumulative learning is central to education" (Maton, 2014, p. 106). Cumulative learning, "where new knowledge builds and integrates past knowledge, is becoming increasingly salient" (Maton, 2009, p. 43). The structuring of knowledge itself is often invisible in research around cumulative and segmented knowledge-building (Moore, 2007; Young, 2008 in Maton, 2009). Legitimation Code Theory (LCT) responds to the question of how to enable cumulative learning at school and university. It declares that "mastering semantic gravity is a key to cumulative learning" (Maton, 2014, p. 106). This affirms the significance of SG, considering that "cumulative knowledge-building in research, teaching and learning are at the heart of education" (Martin et al., 2019, p. 59).

LCT serves as a useful theoretical framework in the current study for the following reasons:

- It points out the paradox of knowledge blindness in education as well as the related conflation between knowledge and knowing, and allows the pedagogic discourse of curriculum structures to be brought into focus separately from the pedagogic practices involved in teaching and learning.

- The Semantics dimension allows for exploring abstraction in chemistry separately from complexity (which it addresses via semantic density), accounting for both abstraction (in terms of decrease in SG, termed levitation) and contextualisation (in terms of increase in SG, termed gravitation).
- It explains the significance of levitation and gravitation (such as in the semiotic abstraction continua of studies discussed in Chapter Two) to education, in terms of them enabling semantic waving which contributes to cumulative learning as opposed to segmented learning.

The LCT approach to education, knowledge, and practice is rapidly growing (Maton, 2014). While various studies have demonstrated the utility of LCT Semantics, of particular significance to this study are those having employed it in biology, physics, and chemistry education. Some of these will now be discussed.

3.6.3.4 Some science studies employing LCT Semantics

Kelly-Laubscher and Luckett (2016) pointed out that some students who perform well in high school biology and gain formal access to university, subsequently struggle with the subject at university level (indicating they have not gained epistemological access). They highlighted the negative consequence of this for retention of students, graduation rates, and overall throughput, citing low figures for these in South Africa. For this reason, they explored the difference in curriculum structure between high school and university biology. Acknowledging that previous LCT studies focused on the semantic structure of biology lessons at secondary school level (pedagogic practice), the authors positioned their study in response to the gap around biology knowledge structure in the field of recontextualisation (pedagogic discourse). LCT Semantics was used to analyse sections of high school and university biology textbooks covering the same topic (sex determination and sex-linked genes). The authors focused solely on text that presented the content, omitting such things as figures, activities, and assessment tasks. More semantic waving (increases and decreases in SG and SD) was evident in the university textbook data than the high school textbook data. Their results indicated a mismatch between the semantic range demanded at university and high school levels, thus revealing a stumbling block to students' epistemological access to university biology knowledge.

Mouton and Archer (2019) reminded us of the challenge South Africa faces in terms of low higher education first-year success rates, and cite dropout rates of more than 50 per cent in previous years. They point to the curriculum problem of "the lack of effective articulation or educational continuity between consecutive educational levels" (Mouton & Archer, 2019, p. 2). The authors argue that LCT Semantics offers a tool for strategically reshaping first-year biology curricula towards a gradual transition for students moving from high school to university biology courses. This is significant considering that the transition from high school to higher education is one of the most challenging life experiences worldwide (Mouton & Archer, 2019). They revealed that teaching activities can be explicitly planned in a way that gradually increases the range between context-dependent meaning and decontextualised meanings in order to optimise the potential for cumulative learning. In this way, they demonstrate one way in which biology curriculum and lesson planning can be restructured in a manner that increases epistemological access to biology knowledge.

Georgiou (2016) affirmed that in physics education research, the focus has been on students' conceptions and characterising learning, or on *knowing* (as opposed to *knowledge*). Her study involved a SG analysis of first-year university students' responses to questions on thermodynamics. She explained on the basis of the Resources Framework (a cognitive science view of learning) that "one way physics knowledge works is by connecting the abstract to the concrete" (2016, p. 178). On this basis, Georgiou posited that the spectrum between abstractness and concreteness can be characterised as an alternative to them remaining "contestable, ambiguous and often morally charged" extremes (2016, pp. 178-179). Georgiou (2016) drew on the LCT dimension of Semantics, and specifically on the concept of SG for addressing the issue of context-dependence of knowledge. A 3-tiered translation device (translation devices are discussed in Chapter Four) was developed for enacting the SG analysis of student responses. Such a language of description for SG would define what is meant by 'context' as well as how relative strengths are realised for the specific data being analysed (Georgiou et al., 2014). The results indicated that most students attempted using general principles for explaining concrete physical phenomena.

Interestingly, some students were tempted to make more abstract principles work even when this was unnecessary. The significant conclusion from this is "that there is an appropriate semantic range for success" and "that learning physics includes learning how abstract and how concrete one needs to be" (Georgiou et al., pp. 191-192). Legitimate answers in other words, reside within a specific range of context-dependence (Georgiou et al., 2014). Stated differently, it is not a case of greater abstraction and generalisation always being better. The mistake of reaching for too high an abstraction/generalisation level too soon was termed the Icarus effect (Georgiou et al., 2014). Georgiou pointed out that enacting SG addresses limitations not just of physics but of science in general by its focus on knowledge as an object, as is emphasised by social realism arguments discussed earlier in Section 3.2.

Conana, Marshall and Case (2020), drew on LCT Semantics as a perspective for thinking about the hierarchical structure of physics knowledge and for examining the use of representations in physics teaching and learning. They focused on the physics topic of Mechanics, for which experts engage in various representations: verbal, pictorial, physical and mathematical. These were ranked in order of semantic strengths to form the translation device used to analyse video-recordings of lectures and of students solving Mechanics problems, as well as interviews with students. Semantic shifts were then profiled for the teaching approach and for students' approach to problem-solving. The authors found that teaching approaches influenced the approach used by students in solving Mechanics problems. The study supports others which report that environments which are rich in representations can support students in learning how representations can be used.

Blackie (2014, p. 462) reminded us that chemistry "is profoundly abstract" and went on to describe LCT semantic waves in chemistry education as illuminating. In her conceptual paper (Blackie, 2014), she highlighted the interplay between words, ideas, and facts as being central to the challenge of chemistry education. Blackie reminded us that chemistry is a hierarchical knowledge structure since any one aspect is built on the foundation of underpinning theory which needs to be assimilated before understanding can be reached. She illustrated the use of the semantic code from LCT for teaching chemistry, using the Grignard reaction as an example. One of the uses of LCT Semantics which Blackie (2014) revealed is in the setting or evaluation of examination papers to ensure for example, that SG shifts are included. The author shared that she finds questions involving transitions between low and high semantic density easier to set and quicker to mark, compared to those involving transitions between weaker and stronger SG. She also affirmed the notion of the backwash effect discussed in Chapters One and Two, in stating that "it is well established that the form of the assessment has a significant influence on the way in which students learn" (Blackie, 2014, p. 468).

3.7 Concluding Comments

The research design (Chapter Four) for the study reported on in this thesis study does not involve the Specialisation dimension of LCT. However, it is included in this chapter for the sake of completeness since the Semantics dimension, which is of relevance to the research design, evolved in response to the shortcomings of the Specialisation dimension. Similarly, the semantic density legitimation code was discussed in this chapter since it is an important component of the Semantics dimension and is often considered in tandem with SG, even though it is SG which lies at the heart of the research design for the current thesis. Semantic profiling was also discussed in this chapter in order to provide a more complete overview of the theory since the SG range (of relevance to the current study) has an influence on semantic profiles, even though answering the research questions do not require it. Chapter Four thus revolves around the use of SG codes to develop translation devices for the data, in order to characterise visual and textual chemistry curriculum literacy demands and describe the nature of the alignment of these between chemistry curriculum documents.

CHAPTER FOUR: RESEARCH DESIGN

4.1 Introduction

Since the manner in which the world is viewed determines the choices made around inquiry (such as what can be investigated, what kind of questions to ask, and how to collect data and interpret findings), worldviews shape the way in which the world is researched. In other words, the particular researcher's worldview or research paradigm defines what should be researched and how (Bertram & Christiansen, 2014). According to Mouton (1996), the notion of a paradigm arose from the field of language, in which it referred to an exemplar (model example) which typically presented a solution to some problem. A paradigm is comprised of, and so can be defined by, three basic beliefs – an ontology, the related epistemology, and associated methodology (Guba & Lincoln, 1994; Scotland, 2012). Scotland (2012) included methods as a fourth component of paradigms. Rather than these various components of a paradigm being a random assembly of choices, they are necessarily interrelated.

Ontological assumptions lay the foundations for epistemological assumptions, which themselves birth methodological considerations, that in turn shape data collection and analysis methods (Hitchcock et al., 1995). The converse reasoning – that research methods can be traced through methodology and epistemology to an ontological stance, highlights that it is impossible to conduct research without committing either explicitly or implicitly, to epistemological and ontological positions (Scotland, 2012). Maton (2014) explained that LCT and its social realist underpinning draws from the critical realist philosophy of Roy Bhaskar, in terms of ontological realism (see section 4.3), epistemological relativism and judgmental rationality (see section 4.4). The methodology and method appropriate for answering the research questions in this study, were case study (see section 4.5) and document analysis (see section 4.6), respectively. Since each of the four defining aspects of a paradigm need to work coherently towards the purpose of answering the research questions, they will be discussed after first stating the research questions in Section 4.2. The translation devices are presented in section 4.7 and coding of data is discussed in section 4.8. Trustworthiness and ethical considerations will then be presented in sections 4.9 and 4.10, respectively.

4.2 Research Questions

What is the nature of the alignment of school chemistry literacy demands between associated curriculum documents, in terms of:

1. visual abstraction? (answered via a SG translation device for visual abstraction)

2. textual abstraction? (answered via a SG translation device for textual abstraction)

4.3 Realist Ontology

Ontology is derived from the Greek "ontos" which translates to "being" or "reality", and so ontology in research refers to the study of being or reality (Mouton, 1996, pp. 8, 46). Ontological assumptions then, are concerned with "what is", and researchers have their own perceptions of how things are and how they work (Scotland, 2012, p. 9). In social science, ontological questions are associated with the nature of reality (Tuli, 2010). Researchers are required to take a position on what constitutes reality (Scotland, 2012). The ontological stance that "reality has no existence independently of the human mind that perceives it" is termed idealism (DeLanda, 2009, p. 25). Such an ontology involves mental entities being considered to be as transcendental concepts or social conventions. The ontological stance that some objects (those of everyday experience) have a mind-independent existence while others (such as unobservable relations and entities) may not, is taken by positivists, pragmatists, and instrumentalists. The stance that reality has full autonomy from the human mind is termed realism. The realist argument is that an ontology based on what is observable or unobservable "betrays a deep anthropocentricism" (DeLanda, 2009, p. 25). Realists display a range of beliefs around the content of mind-independent reality, giving rise to different forms of realism, such as social realism which is the ontological stance of the current thesis.

The seminal author of the theoretical framework employed in this study, Karl Maton (2014), elaborated that ontological realism recognises knowledge as being about something apart from itself – reality exists beyond the symbolic realm. The stance of ontological realism is that a reality exists independent of discourse, which contributes to our knowledge of the world. This does not mean that knowledge reflects reality in an unmediated way. It does imply that knowledge is more than power relations and that reality can speak back to knowledge (Maton, 2014). It is thus evident why Maton and Moore (2010) averred that both truth and truthfulness are recognised by social realism, which was explored in Chapter Three (see section 3.3).

4.4 Relativist Epistemology and Judgmental Rationality

Epistemology focuses on the nature and forms of knowledge, and epistemological assumptions focus on "what it means to know" (Scotland, 2012, p. 9). Epistemological relativism recognises that our knowledge of the world is not a standard, essential truth (Maton & Moore, 2010). The world is known through knowledges that are socially produced and thus change over time and vary across contexts. An understanding of our subjective knowledge and what we can claim to know about the world, is dependent upon "the nature of knowledge as an object, its forms and their modes of change" (Maton & Moore, 2010, p. 4). This does not, however, imply judgemental relativism – that it is impossible to make judgements across different knowledges (Maton, 2014). Judgmental relativism has negative consequences, such as being a threat to validity (Rich et al., 1988). Steinmetz (1998) elaborated on judgmental relativism as claiming that conventions rather than rational criteria, determine choice of theory.

In philosophy, rationality is associated with epistemology, together with other concepts (Schipper, 2009). Drawing on various authors, Schipper (2009, p. 162) posited that in its broad sense, rationality or reason can be viewed as wise/intelligent accounting for thinking and acting, with good warrants for both, towards promoting "the art of life". He distinguishes between two models of rationality – algorithmic and judgmental. Algorithmic rationality involves the use of strict rules (in the form of such things as logic, protocols, formal procedures, and decision trees). Judgmental rationality on the other hand, is based on general maxims (such as empirical adequacy related to a practice or field, simplicity, and fairness). In contrast to algorithmic rationality, judgmental rationality (which is the epistemological stance of the current thesis) is personal and allows for consideration of unique situations.

Maton (2014) explained that in contrast to judgmental relativism, judgmental rationality in social realism allows for acknowledging the existence of an intersubjective basis for ascertaining relative merits of competing knowledge claims. It is possible to propose that truth has not and may never be known, and also that there are means of evaluating different knowledge claims (Maton, 2014). The focus of the epistemological stance of judgmental rationality is not on the logical properties of knowledge claims but on collective procedures for judgements against background constraints (Maton & Moore, 2010).

4.5 Case Study Methodology and Grade 10 Chemistry Curriculum document Sampling

Case studies pay attention to one or a few instances of a phenomenon towards the purpose of "an in-depth account of events, relationships, experiences or processes occurring in that particular instance" (Denscombe, 2007, p. 35). The particular case being explored often already exists (is a natural setting) rather than being generated specifically for the research, as evident in the case of South African Grade 10 chemistry curriculum documents. Denscombe (2007) emphasised that a strength of case study approaches is their allowing for methods specific to the situation. Of particular relevance to this study, is that the case study approach lends itself to exploring processes and relationships within a particular setting and that it is possible to incorporate elements of both inductive and deductive logic (Denscombe, 2007). According to Denscombe (2007), the researcher is required to choose from various options such as possible events, people, and organisations. The case is selected based on particular attributes, and the criteria for its selection must be explicated.

Drawing on the literature review (Chapter Two), the case of South African Grade 10 chemistry curriculum documents in this study, can be framed in different ways. In the model provided by Van den Akker (2003), the case being explored in this study includes the formal and written components of the intended curriculum. In the model by Nakedi et al. (2012), the published curriculum (NCS-CAPS: Physical Sciences) embodies the ideal curriculum of the envisioned curriculum phase and illustrated curriculum (textbook and exemplar examination paper) serves as the bridge between the envisioned and enacted curriculum. This is consistent with the focus of this study being on curriculum discourse (in official and pedagogic texts) in the recontextualisation field of the Pedagogic Device, rather than on pedagogic practice (teaching and learning) of the reproduction field.

The focus on Grade 10 is purposeful, based on this being the first grade in which chemistry is examined independently of other science topics (such as physics or biology) in South Africa. The section of the syllabus of relevance to this study is thus the Grade 10 chemistry component of the CAPS: Physical Sciences (DBE, 2011). The 2012 Grade 10 chemistry exemplar examination paper was also selected purposefully – it was the only one developed by the South African DBE to model summative assessment of Grade 10 chemistry for the CAPS: Physical Sciences (DBE, 2011). There were three Grade 10 Physical Sciences textbooks listed on the DBE-approved catalogue as being aligned to the NCS-CAPS, when this study commenced. The selected textbook (Grayson et al., 2011) was chosen on the basis of it previously having been used by the researcher in his role as a Grade 10 Physical Sciences teacher in 2014. While such convenience sampling is sometimes criticised as difficult to reconcile with good research (Denscombe, 2007), the researcher's choice of the one textbook out of three that he was familiar with, contributes to trustworthiness of the study as discussed in section 4.9.

4.6 Document Analysis as a Research Method

Documents take a variety of forms but are "social facts" produced, used, and shared through socially organised means (Atkinson & Coffey, 1997 in Bowen, 2009, p. 27). According to Bowen (2009, p. 27), "Document analysis is a systematic procedure for reviewing or evaluating documents" for the purpose of producing empirical knowledge & developing understanding. In order to elicit meaning, document analysis involves the examination and interpretation of data. According to Labuschagne (2003 in Bowen, 2009, p. 28), "Document analysis yields data – excerpts, quotations or entire passages – that are then organised into major themes, categories and case examples specifically through content analysis". Document analysis is commonly employed together with other research methods (such as interviews and observation) for the purpose of triangulation, and mixed-method studies may also include document analysis as one component. While being used in conjunction with other methods allows for triangulation, document analysis is recognised as a stand-alone method in its own right in instances of specialised research (Bowen, 2009), such as the exploration of the nature of alignment of literacy demands between curriculum documents in this study.

According to Bowen (2009), document analysis is a systematic procedure for reviewing or evaluating documents existing prior to the study (as opposed to documents generated specifically for use in the study). The advantages of document analysis highlighted by Appleton and Cowley (1997) included the:

- data being readily available thus saving time that would otherwise be spent on data collection;
- documents being a relatively inexpensive and economic data form;

- documents being unbiased (since they existed before the research);
- researcher presence not being needed when the documents were developed; and
- method being unobtrusive and non-reactive.

The possible limitations of document analysis mentioned by Bowen (2009) include:

- details in the documents possibly being insufficient, since they were generated independently of the research agenda;
- the documents sometimes being impossible or difficult to retrieve (such as in instances where access is deliberately blocked); and
- biased selectivity resulting from an incomplete selection (such as when documents are drawn from only one particular organisational unit).

Bowen (2009) further pointed out that rather than being major disadvantages these are potential flaws, and so the advantages may still outweigh the limitations. This is indeed the case for the current study which recognises the significant role of the three curriculum documents in question, in recontextualising knowledge from the production field of the epistemic-pedagogic device, for teaching and learning in the knowledge reproduction field.

Document analysis is an iterative process involving superficial examination (skimming), thorough examination (reading) and interpretation in such a way that combines aspects of content and thematic analysis (Bowen, 2009). Content analysis is the process by which information is organised into categories of relevance to the research questions and involves a review through which meaningful passages of text are identified and separated from what is not pertinent (Corbin & Straus, 2008; Strauss & Corbin, 1998 in Bowen, 2009). Thematic analysis is a type of pattern recognition within data in which themes emerge from categories after coding, and it involves careful and focused re-reading and review of data. In the current study, these processes took place in the context of developing an external language of description, as will now be discussed.

4.7 Bridging the Discursive Gap Between Theory and Data

4.7.1 Internal and external languages of description

According to Bernstein (2000), where theoretical concepts are not able to engage with substantive problems, theoretical development is futile. This implies that the data and theoretical concepts within a study should engage each other (Maton, 2014). However, as Maton and Chen (2016) highlighted, many qualitative researchers experience a gap between their theory and data. This gap is related to the distinction between a theory's "internal language of description" referred to as L^1, and "external language of description" referred to as L^2 (Bernstein, 2000, p. 132). L^1 refers to the manner in which a theory's constituent concepts interrelate, while L^2 refers to the way in which those concepts are related to referents that exist beyond the theory. Bernstein (2000) argued for the bridging of the discursive gap through the use of external languages of description – a "means of translating between concepts and data" (Maton, 2014, p. 113).

Since external languages of description are data specific, it makes sense why, as Maton (2014) indicated, different objects of study necessitate different translation devices for translating between their specific data and theoretical concepts. Maton (2014) averred that developing an external language of description means extending the framework to a new problem situation. Furthermore, external languages as means of analysis for particular objects of study should be made "publicly visible to and reproducible by other researchers. … Anyone who understands the theory can see if the analysis is consistent with the data and conclusions borne out by evidence" (Maton, 2014, p. 137).

Maton (2014) revealed that existing models can be used as the basis for generating external languages of description in new studies. He provided the example of Bloom's taxonomy of educational objectives being adapted for the enactment of SG. While cautioning that their original purposes (such as being models of knowing rather than of knowledge) should be acknowledged, Maton (2014, p. 211) affirmed their value in "enabling more powerful analyses in terms of legitimation codes". He explained that the use of existing models as organising frameworks or external languages "not only utilizes ready-made and topic-sensitive guides to key issues but also enables new research to connect with and build on existing studies" (Maton, 2014, p. 211).

An external language of description or "translation device" acknowledges the discursive gap between theory and data while also enabling dialogue between them in such a way that neither is imposed on the other (Maton & Chen, 2016, p. 28). Since L^2 is not just an extension of L^1, developing an external language of description requires some distance from the internal language as well as a period of immersion in the data of a study (Maton & Chen, 2016). In the current study, this immersion is illustrated by Chapter Five, which presents detailed descriptions of each of the three curriculum documents that provided the data analysed in the study.

Answering the research questions entailed coding of textual and visual data from the curriculum documents. "A code in qualitative inquiry is most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data", and such data may be in the form of documents (Saldana, 2013, p. 3). Codes are refined through multiple layers of comparison – for example data are compared to other data, data are compared to codes, and codes are compared to other codes (alluding to the process being cyclic rather than simply linear) (Saldana, 2013). The particular codes of relevance for answering the research questions in this study are SG codes as discussed in section 3.6.3 of Chapter Three. Semantic gravity translation devices were developed for the purpose of characterising the nature of visual and textual chemistry curriculum literacy demands in terms of abstraction. This allowed the subsequent description of the nature of the alignment of visual and textual curriculum literacy demands between the three curriculum documents.

4.7.2 SG translation device for visual items in chemistry curriculum

In consideration of Maton's (2014) indication that translation devices of new studies which draw from existing models allow for more powerful analysis, the researcher looked to the literature pertaining to levels of visual and textual abstraction in science. For visual abstraction, the current study drew from Pozzer and Roth (2002) who developed an abstraction continuum for biology textbook representations, and Offerdahl et al. (2017) who presented a taxonomy of visual abstraction for biochemical and molecular biology representations (as discussed in Chapter Two). The visual abstraction levels in their respective framings are shown in Table 4.1, with a comparison included.

Table 4.1: Comparison of the levels of visual abstraction by Pozzer and Roth (2002) and Offerdahl et al. (2017)

Abstraction levels used by Pozzer and Roth (2002) for analysing representations in school biology textbooks	**Abstraction levels used by Offerdahl et al. (2017) for categorising representations in biochemistry and molecular biology**	**Comparison**
Equations (such as $E = mc^2$)	Symbolic (such as chemical formula and mathematical equations)	Both rank mathematical equations at the highest level of abstraction. Offerdahl et al. (2017) includes chemical formula which makes sense since their study focused on chemical and molecular aspects of biology.
(no equivalent to schematic diagrams)	Schematic (diagrams with symbols such as chemical reactions)	Since the data set in the study by Offerdahl et al. (2017) would have included more diagrammatic representations of chemical reactions, it makes sense they include this level while the school biology focus by Pozzer and Roth (2002) did not.
Graphs and Tables (their generic example of a graph provides no further detail)	Graphs (such as titration curves)	Both include graphs, and Pozzer and Roth (2002) include tables in this category as well.
Diagrams and Maps (such as a street map)	**(no equivalent to diagrams and maps)**	This level has more relevance for school biology than biochemistry.
(no equivalent to cartoons)	Cartoons (drawing or computer-generated representation highlighting particular aspects)	The type of cartoon referred to by Offerdahl et al. (2017) are exaggerated molecular models used in biochemistry.
Naturalistic Drawings (of a rose, for example)	Realistic (closely resemble original subject, possibly with "superfluous contextual information" (p. 6). Examples include micrographs and photographs)	The lowest level in the study by Offerdahl et al. (2017), subsumes the two lowest levels in the study by Pozzer and Roth (2002), since both naturalistic drawings and photographs are realistic.
Photographs (of a rose, for example)		

Offerdahl et al. (2017) did not include tables as a general category of visual representation, even though Pozzer and Roth (2002) ranked these generically at the same level of graphs. Considering that tables consist of columns and rows forming blocks or cells in which information is contained, it does not make sense to situate them on a visual abstraction continuum since it is the visual and/or textual information within them that is of relevance for coding. For the current study, tables did not feature as a general point on the visual abstraction continuum. Despite its name, the periodic table does not fall within the traditional definition of 'table' and was therefore considered as a visual item.

It is evident that while both framings for the relative abstraction of visuals are five-tiered and have some levels in common, there are also differences which reflective their respective discipline's discourses. The basis for characterising visual abstraction levels evident in the models by Pozzer and Roth (2002) and Offerdahl et al. (2017), are illustrated in Table 4.2. It is evident that the lower levels are two-dimensional representations closely resembling three-dimensional scenarios (Pozzer & Roth indicated 'world' on the lowest end of the abstraction scale, before photographs), with the intermediate levels involving two-dimensional portrayals with less resemblance to the three-dimensional world. At the highest abstraction level, are one-dimensional visuals (equations). Related to this, Offerdahl et al. (2017) situated macroscopic-level visuals at the lower end of the abstraction continuum and symbolic visuals at the higher end, with the submicroscopic level between the macroscopic and symbolic. Their inclusion of schematic diagrams such as chemical reactions makes sense considering their data is more related to chemistry than the school biology textbooks visuals explored by Pozzer and Roth (2002). The one-dimensional, symbolic end of the abstraction continuum involves little or no contextual detail while the other end of the abstraction continuum includes the most contextual detail.

Table 4.2: Basis for characterising visual abstraction levels evident in the models by Pozzer and Roth (2002) and Offerdahl et al. (2017)

Visual Abstraction	**Basis for characterising levels of abstraction**	
	Dimensionality	**Chemistry Representation levels**
Higher	One-Dimensional	Symbolic
	Two-Dimensional (some resemblance to Three Dimensional Object or space)	Submicroscopic
Lower	Two-Dimensional (strong resemblance to Three Dimensional object or space)	macroscopic

The dimensionality basis for distinguishing visual abstraction levels evident in the models by Pozzer and Roth (2002) and Offerdahl et al. (2017), overlap with abstraction as omission of detail and abstraction as decontextualisation perspectives by Williams et al. (2017), mentioned in Chapter One. Furthermore, it affirms the relationship between visual abstraction levels and Johnstone's (1982) chemistry triplet. Since these bases for exploring visual abstraction are aligned to the LCT definition of SG as context-dependence of meaning (Maton, 2009), they offered useful guidelines informing the development of the SG translation device shown in Table 4.3. Although external languages of description evolve iteratively during the data analysis stage and so can also be seen as products of a study (based on the full range of data), the translation devices employed in this study are presented here since data analysis tools are an aspect of research design.

Table 4.3: SG translation device for visual abstraction in chemistry curriculum documents

Semantic gravity code	Data analysis code	Brief description	Example (in words for the sake of brevity, the related visual examples from the data are shown in <u>Appendix A)</u>
SG - -	5	Symbolic (1-Dimentional)	Unknown chemical elements (represented by variables)
			Chemical equations and mathematical equations
			Spectroscopic electron configurations
			Chemical Formulae/symbols
SG -	4	Symbolic (with some 2-Dimensional meaning)	Periodic table (no visual atomic detail)
			Graphs
			Energy level/Afbau/ Lewis diagrams
SGϴ	3	Hybrid iconic/symbolic	Periodic table (with some visual atomic detail)
			Naturalistic drawing with symbols (e.g. electric circuit)
			Global cycles with processes represented by arrows
			Classification scheme
			Schematic chemical reaction
SG+	2	Iconic (2-Dimensional) resembling something at larger/smaller scale than human experience	Atomic and Molecular representations/models
			Photographs (objects smaller/larger than human scale) eg line spectra and telescope photographs
SG+ +	1	Iconic (2-Dimensional) closely resembles 3-Dimensional objects/phenomena at human scale	Naturalistic drawings of objects at human scale
			Comic strips
			Photographs (objects at human scale)

The above translation device is aligned to Maton's (2013; 2014) explanation that references which are more contextualised have stronger SG compared to those which are more decontextualised and thus have weaker SG. This translation device thus frames degree of (de)contextualisation specifically in terms of dimensionality and chemistry representation levels. It reflects a shift from meanings that are specific/concrete (such as meanings associated with objects or phenomena at human scale), to those which are more generalised and context-independent (such as highly symbolic meanings). This device was developed for characterisation of the visual literacy demands of the three curriculum documents in order to answer research question one.

4.7.3 SG translation device for focal textual items in chemistry curriculum

Fang (2005) reminds us about the two senses of scientific literacy presented by Norris and Phillips (2003): the fundamental sense (ability to read and write science texts) and the derived sense (knowing science content). He contends that the two senses are interrelated to the extent of being inseparable in modern western science. While acknowledging the multimodality of science genres and thus the important role of the visual mode in science meaning, he also focuses on science text more specifically in presenting a systemic functional linguistic perspective on science literacy.

Content carrying words include such classes as nouns, verbs, adjectives, and adverbs, while non-content words include pronouns, prepositions, conjunctions, and auxiliary verbs (Fang, 2005). Furthermore, nuances in the use of these categories (content and non-content) as well as classes (such as nouns) contribute to distinguishing features of science language such as high information density, technicality, authoritativeness, and abstraction (Fang, 2005). The discussion here will be limited to the feature of relevance to this study – abstraction.

In elaborating on abstraction as a feature of scientific writing, Fang (2005, p. 339) contrasted commonsense language used for the purpose of "construing everyday life experiences", with scientific language which "theorizes concrete life experiences into abstract entities". "Scientific writing has a particular preference for nouns" (Fang, 2005, p. 340). Furthermore, while "commonsense knowledge construes reality as a balanced tension between things and processes, the elaborated register of scientific knowledge construes it as an edifice of things … which is the mode of being a noun" (Halliday & Martin, 1993, p. 341).

Fang (2005) explained the theorising of concrete experiences as involving processes (expressed through such lexical categories as verbs and adjectives) being transformed into participants (expressed through nouns) – a process referred to as nominalisation. The process of nominalisation is evident for example, in the verb *react* which refers to the interaction between chemical substances during chemical change, being expressed as the noun *reaction*. Such nouns represent movement away from immediate lived experiences towards constructs such as abstractions and generalisations (Christie, 2001). As Halliday (1998) revealed, nominalisation goes beyond remodelling grammar (re-grammaticising) towards re-meaning (re-semanticising).

In elucidating a functional perspective on nouns, Fang (2008, p. 25) referred to them as "grammatical participants in a text that construct different semantic roles". Fang (2005, p. 341) described the privileging of nouns as unsurprising, given that they are "an especially powerful resource" for accomplishing core aspects of the discipline of science, such as "defining, comparing, characterizing, classifying and explaining". Since texts (such as textbooks and examination papers) are used in particular contexts and have particular purposes, nouns are used in different ways (Fang et al., 2006). For example, informal registers often employ simple nouns such as pronouns to establish exophoric references (relations of text to external objects) or endophoric references (relations between internal aspects of text) while in formal registers, abstract nouns are often used to construe abstraction (Fang, 2008).

Fang (2008) pointed out a range of noun types: pronouns such as *we* and *this*, proper nouns such as *Chicago* and *Prince Harry*, technical nouns such as *trachea* and *polygon*, abstract nouns or nominalisations such as *deforestation* and *frequency*, and those involving pre and post modifiers such as *the small table with a yellow cloth.* It is evident that the range of noun types as arranged in Table 4.4, reflect different levels of abstraction. Since nouns with pre and/or post modifiers are noun groupings which move away from the individual word level towards clause level and do not have a consistent nature in terms of level of abstraction relative to other noun types, they were analysed in terms of the individual nouns comprising them rather than as larger nominal groups in the current study. Furthermore, since not all abstract nouns are nominalisations, these are shown at separate levels with nominalisations at a higher abstraction level since they correspond less closely to material/physical constructs than abstract nouns.

Table 4.4: Noun types mentioned by Fang (2008)

Noun Type	Example from Fang (2008) [except for *]
Nominalisations	deforestation, frequency
Abstract nouns	* (these would include physical/material entities which are not observable by the senses, such as *atom* or *energy* as well as non-physical concepts which do not arise from the process of nominalisation, such as *pressure*)
Technical nouns	trachea, polygon
Pronouns	we, this
Proper nouns	Chicago, Prince Harry

These noun types being associated with different levels of abstraction (with concrete nouns such as proper nouns being at a lower level and nominalisations being at a higher level) informed the thinking around the analysis of nouns allowing characterisation of textual abstraction in documents. The use of abstractness of nouns to characterise the abstractness of text was previously also recognised by Mikk and Kukemelk (2010). Reference to 'category' rather than 'type' in this discussion, serves to distinguish between nouns types presented by Fang (2008) and the thinking around noun categories for developing a translation device in the current study.

The category of proper nouns is a useful example for illustrating concrete nouns referring to everyday material objects/people. Concrete nouns signify entities that can be perceived through the senses (Franzon & Zanini, 2019) and are thus strongly rooted in social contexts. Since the category of pronouns are non-content words and so do not contribute to such things as information density of a text, they were not included in this study. They did, however, alert the researcher to the issue of more general references to objects which involve less contextual detail than the names of objects themselves. Examples of more general references to concrete nouns, such as category names include 'city' in the case of the more specific, 'Chicago' from

Table 4.4, and ‘royalty’ in the case of the more specific ‘Prince Harry’ in Table 4.4.

Specialised or technical nouns refer to more specialised objects than those in everyday life, such as the chemicals and equipment encountered by chemists in their work. In addition to abstract nouns referring to such unobservable entities as ‘atom’, ‘energy’ or ‘temperature’, they would also include more general categories of, or correlations to technical or specialised nouns, such as ‘*respiratory system’* for the more specific object ‘*trachea’* in Table 4.4. Nominalisations such as deforestation or frequency in Table 4.4 are similar to the non-physical entities described as abstract nouns, but are reconstruals of actions or processes as entities through the process of grammatical metaphor. The categories of abstract nouns and nominalisations refer to nouns that have less relation to specific social contexts, making their meanings more universal.

The noun categories considered thus far exclude symbols for nouns such as phase symbols (for example, ‘s’ for solid), quantities (for example, n for number of moles of a substance), units (for example, g for grams) and abbreviated nouns (such as STP for standard temperature and pressure). Such symbols and abbreviations are commonplace in chemistry discourse and appeared frequently in the Grade 10 chemistry exemplar examination paper, Grade 10 chemistry sections of NCS-CAPS: Physical Sciences, and chemistry sections of the Grade 10 Physical Sciences textbook analysed in the current study. Since these symbols and abbreviations occurred frequently in the textual data, are references to nouns, and display further semiotic decontextualisation from the earlier noun categories, symbolic and abbreviated nouns were included as the noun category at the highest level of textual abstraction in this study. This contributed to a broader range of noun categories, which in turn provided a more nuanced basis for characterising the textual abstraction of chemistry curriculum documents, as illustrated in Table 4.5.

Table 4.5: Basis for characterising textual abstraction levels

Textual Abstraction	Reference Type	Noun Categories
Higher	Symbolic and metaphoric references	Symbolic and abbreviated nouns
↕ Intermediate levels	↕ Specialised/ technical references and categories	Nominalisations Categories of specialised/technical nouns, and related abstract concepts Specialised/technical nouns Categories of everyday nouns, and related abstract concepts
Lower	Everyday references and categories	Everyday nouns

In broad terms, the six noun categories reflect a continuum of textual abstraction. A higher proportion of more everyday nouns would contribute to decreasing the overall level of textual abstraction within a document while a higher proportion of symbolic nouns, abbreviations, and nominalisations would contribute to an increase the overall level of textual abstraction. Using noun categories as the basis for characterising textual abstraction was found to be useful for developing a SG translation device. This basis for exploring textual abstraction overlaps with the *abstraction as omission of detail* and *abstraction as decontextualisation* perspectives by Williams et al. (2017), mentioned in Chapter One. Furthermore, it is aligned to the LCT definition of SG as context-dependence of meaning (Maton, 2009). The six-tiered translation device is shown in Table 4.6.

Table 4.6: SG translation device for textual abstraction in chemistry curriculum documents

Semantic gravity code	**Data analysis code**	**Brief description**	**Example (from the exemplar examination question paper)**
SG - - -	6	Symbolic and abbreviated nouns	n (number of moles) STP (for standard temperature and pressure)
SG - -	5	Nominalisations	conductivity
SG -	4	Specialised or technical categories and concepts	compound
SG +	3	Specialised or technical objects	chromatogram
SG + +	2	Everyday categories and concepts	Diagram, drinks
SG + + +	1	Everyday objects	Coffee beans

This device was employed to characterise the textual literacy demands of the three curriculum documents in order to answer research question two. At this point, it is worthwhile to acknowledge that the range of SG codes within translation devices such as those shown in Table 4.3 and Table 4.6, allow researchers to avoid the false dichotomy between everyday and academic knowledge through them recognising SG as varying across a continuum of strengths (Maton, 2014). This is supported by the work of Halliday and Martin (1993), who highlighted that the progression of academic study involving knowledge becoming more specialised is mirrored in the associated language progressively increasing in abstraction. This also illustrates Bernstein's (2000) distinction between horizontal (or everyday) discourse and vertical (or academic) discourse. It situates the nouns related to everyday life or commonsense knowledge at a lower level on the SG continuum reflecting that their meaning is more related to social context. In contrast, the nouns related to scholarly knowledge appear at an intermediate to high level in the SG continuum, reflecting that their meaning is less dependent on social context and more related to other meanings. Symbols, at the highest level of abstraction in the SG continuum are independent of context.

4.8 Coding

Coding refers to the process in which qualitative data is organised and sorted so that related data segments can be clustered by the researcher (Stuckey, 2015). “A code in qualitative inquiry is most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data”, such as data in the form of documents (Saldana, 2013, p. 3). The data segments or units of analysis in the current study were visual items as exemplified in Table 4.3 and discussed in Section 4.8.1, and specific textual items as exemplified in Table 4.6. and discussed in Section 4.8.2. The term ‘focal textual’ items is used to refer to the symbols and noun categories focused on in this thesis.

4.8.1 Coding of visual data to answer research question one

The SG translation device for visuals in Table 4.3 illustrates the manner in which the SG codes were related to the visual data in this study. The coding involved individual visuals from the exemplar examination paper and textbook being assigned a data analysis code number corresponding to a particular SG code (for example, photographs were coded with the number 1 indicating the SG code SG+ +). Thereafter the percentage of visuals related to each SG category was calculated for reporting graphically in Chapter Six.

The following data were included in the coding of visuals:

- visuals alongside main text, interspersed with main text, within experiment boxes, within tables, within ‘Exam Practice Questions’ and ‘Summary of Topic’ sections of the textbook;
- visuals without captions
- mathematical formulae as per the translation device; and
- individual chemical symbols, formulae, and equations as per the translation device.

4.8.2 Coding of textual data to answer research question two

The SG translation device for textual abstraction in Table 4.6 illustrates the manner in which the SG codes were related to the textual data in this study. The coding involved focal lexical items from the exemplar examination paper, syllabus and textbook being assigned a data analysis code number corresponding to a particular SG code (for example, specific everyday concrete nouns were coded with the number 1 indicating the SG code SG+ + +). Thereafter the percentage of focal lexical items related to each SG category was calculated for reporting graphically in Chapter Six.

In addition to the main or paragraph text, the following data were included in the coding of text:

- nouns in question and activity instructions;
- nouns pertaining to and within visuals (such as captions, graph axes, and diagram labels);
- symbolic nouns within chemical equations such as phase symbols: (s), (l), (g), (aq); and
- label letters for nouns within visuals.

The following data were excluded in the coding of text:

- sections prior to and after the actual chemistry content. For example: the Exam Instructions and Information' section, and multiple choice answer sheet of the exemplar examination question paper; sections 1, 2 and 4 as well as the physics component of section 3 in the NCS-CAPS: Physical Sciences document; contents page and publication information at the beginning of the textbook, glossary and index at the back of the textbook;
- question numbers and labels;
- headers and footers; and
- count nouns and other numbers.

4.9 Trustworthiness

The literature points out that research such as in this study, cannot be judged using the same criteria as positivism. Criteria such as member checking and peer review are ineffective for this study since they are based on an objective reality that can be converged upon (Angen, 2000). Trustworthiness refers to the elements of good practice throughout the research process (Merrick, 1999). The emphasis on quality at all points in the research and not just in a post-hoc evaluation, is embodied in the term ‘verification’, which in qualitative research refers to “mechanisms used during the process of research to incrementally contribute to ensuring reliability and validity and, thus, the rigor of a study” (Morse et al., 2002, p. 9).

Drawing from the above-mentioned literature, the trustworthiness of the study was strengthened by transparency regarding the steps taken and choices made by the researcher so the research orientation is known to the reader and interpretations can be put into perspective whether or not the reader shares the researcher’s orientation. Chapter Four of this thesis contributes to transparency around the research design choices such as social realist ontology, relativist epistemology tempered by judgmental rationality, case study methodology, document analysis method, and translation devices for coding of data.

The initial (draft) translation devices for visual and textual abstraction were discussed with the research supervisors (education researchers) and an expert Physical Sciences teacher (a science education practitioner) prior to being ‘piloted’ on the shortest data document – the exemplar examination paper. These productive conversations allowed for adjustments so that the translation device meaningfully traversed the theory and data. For example, the initial SG translation device for textual abstraction focused purely on the word levels and so did not include the category of symbols and abbreviations, but consideration of the data and discussions with the research supervisors and expert teacher led to the inclusion of these at the highest level of abstraction in line with the definitions of abstraction presented in Chapters One, Two and Three.

The provision of detailed descriptions of the data is addressed through Chapter Five of the thesis, and grounding of interpretations through the use of examples from the data which support abstractions or high levels of theorising was addressed through the use of translation devices. The translation devices by their nature, show the relationship between theory and empirical data. Furthermore, prolonged engagement with data is one of the means of establishing trustworthiness towards identification of themes in data (Nowell et al., 2017). For the current study, the researcher had worked with the data sources (the syllabus document, textbook, and exemplar examination) as a Grade 10 Physical Sciences teacher during 2014. This contributed to prolonged engagement with the data, in addition to the researcher's immersion in the data for the purpose of completing this thesis, as reflected in the detailed description of data in Chapter Five. In-depth description of data is recognised as a procedure contributing to credibility of a study (Bowen, 2009; Cresswell & Miller, 2000).

4.10 Research Ethics

In social science research it is generally expected that informed consent will be obtained from the research participants (Sixsmith & Murray, 2001). Informed consent attempts to capture and communicate considerations around the appropriate relationship between research participants and the researcher (Miller & Boulton, 2007). This study, however, did not involve human participants since the research problem outlined in Chapter One was the knowledge gap around alignment of South African school chemistry official and pedagogic texts in terms of abstraction. Answering the research questions mentioned earlier in this chapter thus involved the analysis of data from pre-existing documents (the Grade 10 chemistry component of the South African NCS-CAPS and a related textbook, and the first Grade 10 chemistry exemplar examination for this curriculum). According to Felzmann (2013), researching data from documents in the public domain does not require consent.

There was thus little possibility of maleficence as the study did not involve human participants, and since the potential benefits of the study include improved curriculum documents, there is potential beneficence in terms of curriculum reform towards improved epistemological access. Honesty is also an important aspect of research ethics. In the Singapore Statement on Research Integrity, "Honesty in all aspects of research" is the first-mentioned fundamental principle of research integrity (Resnik et al., 2011, p. 73). The concept of translation devices contributes to honesty of this study since it necessitates transparency in terms of the data analysis tool being tailored to the range of data being analysed and open to critique by readers of the research. Plagiarism was avoided in this thesis by ongoing consideration of appropriate citation and referencing of the ideas sourced from other researchers, and the use of the Turnitin originality-checking and plagiarism prevention service. The Turnitin Report for this thesis (excluding direct quotations and references) shows a similarity index of 12 % (see Appendix B).

The formalised process for obtaining ethical clearance involved submitting an ethical clearance application to the College of Humanities at the University of Kwa-Zulu Natal. The related protocol reference number is HSS/1515/013D, and the letter confirming full approval by the Humanities and Social Sciences Research Ethics Committee is attached as Appendix C. It is worth noting that the initial project title mentioned on the ethical clearance letter: "A multiliteracies analysis of textual curriculum alignment – The case of South African Physical Sciences", was later changed as the study progression necessitated. The updated project title: "A Semantic Gravity perspective on South African school chemistry curriculum alignment", more adequately captures the current thesis.

4.11 Concluding Comments

This chapter explicated the overall paradigm of the study reported on in this thesis in terms of the distinct but interrelated research design choices pertaining to ontology, epistemology, methodology, and methods. An important consideration was the theoretical framing of the study – LCT. In terms of ontology and epistemology, LCT has social realist underpinnings and draws from the critical realist philosophy of Roy Bhaskar, subscribing to ontological realism (see section 4.3), and epistemological relativism tempered by judgmental rationality. The methodology of case study and method of document analysis are appropriate for answering the research questions.

The case that was explored in this study, is the South African Grade 10 chemistry curriculum documents that constitute the formal and written components of the intended curriculum as described by Van den Akker (2003), and which constitute the published curriculum and illustrated curriculum described in the model by Nakedi et al. (2012). The three documents are also consistent with the focus of this study being on curriculum discourse (in official and pedagogic texts) in the recontextualisation field of the pedagogic device, rather than on pedagogic practice (teaching and learning) of the reproduction field. The documents are the Grade 10 chemistry exemplar examination question paper, Grade 10 chemistry sections of the CAPS: Physical Sciences and chemistry sections of a Grade 10 Physical Sciences textbook. Strengths and weakness of document analysis as a method were also considered.

LCT theorises abstraction in terms of SG – the degree of decontextualisation of meaning, which it also relates to cumulative knowledge-building that is of relevance to hierarchical knowledge structures such as chemistry. The SG code was operationalised in this study through the use of two translation devices – one for the SG of visual items in the exemplar examination question paper and textbook, and the other for the SG of focal textual items in the relevant chemistry sections of all three documents. The bases for the choice of translation devices as well as the devices themselves were detailed in order to explain how the visual and focal lexical items would be coded. Furthermore, details were provided of which sections or aspects of the documents were not included in the analysis.

Trustworthiness considerations were outlined in terms of transparency, provision of detail, and prolonged engagement with data by the researcher. Consideration of research ethics was demonstrated in relation to risk of maleficence, likelihood of beneficence, honesty, avoidance of plagiarism, and formal ethical clearance approval from the institution at which the author of this thesis was registered as a PhD student.

CHAPTER FIVE: DESCRIPTION OF CURRICULUM DOCUMENT DATA SOURCES

5.1 Introduction

In consideration of this study employing document analysis, the purpose of this chapter is to acquaint the reader with the three document data sources: the chemistry component of the Grade 10 NCS-CAPS: Physical Sciences (DBE, 2011), the chemistry component of a Grade 10 Physical Sciences textbook (Grayson et al., 2011), and the Grade 10 chemistry exemplar examination paper developed for the NCS-CAPS (DBE, 2012). All three documents are situated in the recontextualisation field of the pedagogic device, but the NCS-CAPS lies within the official recontextualising field while both the textbook and exemplar examination paper lie within the pedagogic recontextualising field (see section 2.4.6 of Chapter Two).

A useful concept in achieving the descriptive purpose of this chapter, is 'genre' since the NCS-CAPS: Physical Sciences (DBE, 2011) is an example of syllabus genre, the Physical Sciences textbook (Grayson et al., 2011) is an example of textbook genre, and the Grade 10 chemistry exemplar examination question paper (DBE, 2012) is an example of test genre. Finn and Kushmerick (2006, p. 1506) used genre to "loosely mean the style of text in the document". Although relevant literature has been drawn upon for introducing the three documents in Chapter One and exploring them in more depth in terms of the broader notion of curriculum in Chapter Two, it is fitting to discuss some literature on curriculum genre at this point in the thesis as the discussion moves to a more fine-grained level of engagement with the documents that provided the data for this study.

5.2 Curriculum Genre

Although the term 'genre' appears regularly in popular culture, "genres are often vague concepts with no clear boundaries" (Finn & Kushmerick, 2006, p. 1507). Finn and Kushmerick (2006) acknowledged the lack of agreement regarding a universal definition of genre, but also consensus about genre relating to style. With regards to documents, a particular genre reflects a particular text style, rather than content (Finn & Kushmerick, 2006) – documents covering the same topic can belong to different genre (as is the case of the three curriculum documents explored in the current thesis all covering chemistry topics but not displaying the same text style), and documents of the same genre can cover different topics (as would be the case for either syllabi or textbooks or exemplar examination question papers of different school subjects, being comparable in terms of text style).

One indication of how style of text may vary is alluded to by Martin (2009) who referred to genre as social processes (communications acts involving more than one participant) which are goal-oriented (purposeful) and staged (occur through a sequence of steps). It makes sense that the specific stages contribute to the particular style of text that characterises a genre. As will be evident over the course of this chapter, the style of text in the three curriculum documents is indeed different in terms of the stages involved. However, all three documents being curriculum discourse artefacts of the knowledge recontextualisation field means that they inform the pedagogic activities of the knowledge reproduction field in general, and more specifically to this thesis – contain data of relevance to characterising curriculum literacy demands (not necessarily the same as those in enacted curriculum within the knowledge reproduction field).

The NCS-CAPS: Physical Sciences as a syllabus genre, will be discussed first, since "the syllabus is one of the most recognisable instantiations of academic genres" (Afros & Schryer, 2009, p. 225). Furthermore, it is situated in the official recontextualising field as the basis of further recontextualisation into documents such as textbooks and exemplar examination question papers which are situated in the pedagogic recontextualising field.

5.3 Description of the NCS-CAPS: Physical Sciences (DBE, 2011)

5.3.1 NCS-CAPS: Physical Sciences as an example of syllabus genre

Tron (2017) reminded us that the narrowest sense of science curriculum makes it synonymous with the term 'science syllabus' – a specification of content to be taught, and the order in which it is to be taught. From this perspective, a curriculum statement includes a summary of topics or lessons to be covered in the classroom over a specified period of time and serves as a useful record (Tron, 2017). Woods et al. (2010) argued that conflation of the concepts of curriculum and syllabus has resulted in curriculum debates overshadowing valuable insights from syllabus documents in terms of their technical form. In essence, ideological and cultural curriculum content debates have been foregrounded at the expense of such things as syllabus categories, shape, and structure (Woods et al., 2010). While syllabus design has been explored in the fields of English language teaching and higher education, there is still a paucity of knowledge about syllabus design at the school level (Woods et al., 2010). Woods et al. (2010) pointed out that the form of a syllabus influences the level of specification as well as locus of control and authority, making 'syllabus form' a contributing factor to quality and equity.

It is to be expected that the NCS-CAPS: Physical Sciences document details the physics and chemistry knowledge to be taught. De Vos et al. (1994, p. 743) highlighted that "Every chemistry syllabus contains a list of concepts – chemical reactions, element, compound, atom, molecule etc. There is a hard core in these course outlines that does not differ much from country to country and that has not changed essentially over a long period of time". In addition to this, "Curriculum documents present a rationale, general guidelines, and a plan about goals, values, learning objectives, skills, content, teaching methods, and assessment as envisioned by curriculum developers" (Elmas et al., 2020, p. 839). A discussion of syllabus form thus needs to consider content of the document in order for a discussion of the genre form to be more comprehensive. In this regard, Afros and Schryer (2009, p. 225) highlighted that the genre of syllabus "offers instructors a constellation of rhetorical strategies to describe the course, its goals and objectives, its structure and its correlation with other courses within the program, classroom and institutional policies as well as general logistical and procedural information". This is reflected in the NCS-CAPS: Physical Sciences where the explication of content and teaching is embedded within other genre stages, as will now be discussed.

The NCS-CAPS: Physical Sciences document consists of four pages that are unnumbered, and 164 numbered pages. An overall breakdown of the main components and subcomponents is provided in Table 5.1. In terms of genre stages, it is evident that the first stage serves the purpose of orientating the reader to the publication, the second stage situates the document in relation to the overall South African schooling system, the third stage frames Physical Sciences as a subject in relation to various curriculum considerations, the fourth stage details the physics and chemistry content and teaching strategies, the fifth stage explicates the assessment framework, and the sixth stage contains information (which supports earlier stages) in the form of appendices.

With regard to genre being goal-oriented, these stages work together towards the purpose of

"A single comprehensive Curriculum and Assessment Policy document ... to replace Subject Statements, Learning Programme Guidelines and Subject Assessment Guidelines" (DBE, 2011, p. 3). In terms of being a social process, the NCS-CAPS: Physical Sciences indicates what Physical Sciences teachers in South Africa are mandated by the DBE to teach and assess in their classrooms. It is important to note that the document is not intended for use directly by learners in the way that learners work with textbooks and exemplar exams. Rather, it informs the work of stakeholders such as teachers, textbook authors, and examiners.

Nonetheless, it is still a worthwhile data source for investigating curriculum literacy demands - although school science is a recontextualised version (for pedagogic purposes) of the science originally derived in the field of production, it inherits the core aspects of professional science such as abstraction (Fang, 2006). Since the representational systems and practices lie at the heart of success in schooling (Gee, 2005) and prominence must be given to the means and modes of representing scientific ideas and direct teaching of how to read, write, and talk science (Wellington & Osborne, 2001), it makes sense that literacy demands can be gleaned from the official recontextualisation field.

Table 5.1: Genre stages, components and subcomponents of the NCS-CAPS: Physical Sciences document (DBE, 2011)

Genre Stage	Page	Component	Subcomponent
1) Orientation	(unnumbered page 1)	Cover page	Logo/emblem Curriculum Name Phase Subject
	(unnumbered pages 2-3)	Publication details	Department of Basic Education contact details ISBN number Design, layout, and printing information
	(unnumbered page 4)	Foreword by the Minister	Role of education and curriculum in realising aims of the constitution

			SA school curriculum evolution since 1997 Three National Curriculum Statement components
	1-2	Contents Page	Section and subsection page numbers
2) Situation of the publication as curriculum policy in relation to other subjects in SA school system	3-7	Section 1: Introduction to the CAPS: Physical Sciences	1.1. Background 1.2. Overview 1.3. General Aims of the South African Curriculum 1.4. Time allocation per subject per grade, for each phase
3) Framing of Physical Sciences as a school subject in Grades 10-12, with time allocations	8-14	Section 2: Physical Sciences	2.1. What is Physical Sciences? 2.2. Specific aims of Physical Sciences 2.3. Time allocation for Physical Sciences 2.4. Overview of topics 2.5. Overview of practical work 2.6. Weighting of topics 2.7. Overview of formal assessment and recommended practical work 2.8. Developing language skills
4) Explication of content and teaching strategies	15-142	Section 3: Physical Sciences content	Column 1: Time Column 2: Topics Column 3: Content, concepts and skills Column 4: Practical activities Column 5: Resource materials Column 6: Guidelines for teachers
5) Assessment framework explication	143-151	Section 4: Assessment	4.1. Introduction 4.2. Informal or daily assessment 4.3. Formal assessment 4.4. Programme of assessment 4.5. Recording and reporting

			4.6. Moderation and assessment 4.7. General
6) Support	152-163	Appendices	Appendix 1: Physical Sciences Assessment Taxonomy Appendix 2: Skills for Grade 10 Physical Sciences learners Appendix 3: Periodic table Appendix 4: Cation and Anion tables Appendix 5: Solubility table

The data analysed in the current study was limited to the Grade 10 chemistry component of Section 3 of the document (genre stage 4). The discussion now thus zooms in on this section of the syllabus.

5.3.2 The content component of NCS-CAPS: Physical Sciences

Section 3 (Physical Sciences Content) provides information for Grades 10, 11, and 12 indicated per term per grade, as exemplified in Figure 5.1. The 19 pages of data which covers Grade 10 chemistry that were analysed in this study appears within this section. As Figure 5.1 illustrates, Section 3 of the syllabus appears in tabular form with six columns covering Time; Topics, Content, concepts, and skills; Practical activities; Resource materials; and Guidelines for teachers. A description of the data in each of these columns follows after Figure 5.1.

CAPS

SECTION 3

PHYSICAL SCIENCES CONTENT (GRADES 10 -12)

TERM 1 GRADE 10					
GRADE 10 CHEMISTRY *(MATTER & MATERIALS)* TERM 1					
Time	**Topics Grade 10**	**Content, Concepts & Skills**	**Practical Activities**	**Resource Material**	**Guidelines for Teachers**
2 HOURS	**Revise Matter & classification (from grade 9)**	Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity. See appendix 2 for skills that need to be infused with content in all grades.			Observing, describing, classifying and using materials - a macroscopic view (do this in detail in grade 9 if possible)
0.25 hour	The material(s) of which an object is composed	• Revise the properties of material, e.g. 1. Strength 2. Thermal and electrical conductivity 3. Brittle, malleable or ductile 4. Magnetic or non-magnetic 5. Density (lead / aluminium) 6. Melting points and boiling points	**Activity:** **What materials are products made of?** If you have a sand dune, the material out of which the dune is made is sand. Look at the labels on the containers of food or on medicine bottles, or the wrapper of chocolate. Note the ingredients of the material in the container. What do the different compounds tell you about the material in the container? Why do the manufacturers give the ingredients of the material? Use safety data to learn about the compounds contained in your food and medicines	An activity that classifies a range of materials and combines all these properties could be useful to revise the content	The introduction of the topic was moved to grade 9 and is **only revised in grade 10** Learners are encouraged to look at food additives and preservatives. This should be contrasted with indigenous ways of food preservation

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PHYSICAL SCIENCES GRADES 10-12

Figure 5.1: The first page of the Grade 10 chemistry section of the syllabus (DBE, 2011, p. 15)

5.3.2.1 Time (column one)

Time appears in the first column and this focus is consistent with time considerations appearing earlier in stages two and three of the syllabus. The shortest time allocated as evident for topics such as 'The materials of which an object is composed' (DBE, 2011, p. 15) is 0.25 hours. The longest time allocated as evident for topics such as 'Atoms and compounds' (DBE, 2011, p. 32) is eight hours. The fine-grained focus given to time per topic extends beyond typical syllabus format and illustrates why Sibanda and Hobden (2016) mentioned that the document provides an explicit work schedule.

5.3.2.2 Topics per grade (column two)

The second column lists the specific topics and subtopics of each chemistry knowledge area, for which the time allocations were indicated in column one. There are three chemistry knowledge areas which cover a total of 11 topics and 33 subtopics. These are summarised in Table 5.2.

Table 5.2: Grade 10 chemistry knowledge areas, topics, and subtopics in NCS-CAPS: Physical Sciences (DBE, 2011)

Knowledge Areas	Topics	Subtopics
1. Matter and materials	1.1. Revise Matter and Classification	1.1.1. The material(s) of which an object is composed 1.1.2. Mixtures: heterogenous and homogenous 1.1.3. Pure substances: elements and compounds 1.1.4. Names and formulae of substances 1.1.5. Metals, metalloids and non-metals 1.1.6. Electrical conductors, semiconductors and insulators 1.1.7. Thermal conductors and insulators 1.1.8. Magnetic and Non-magnetic materials
	1.2. States of Matter and the kinetic Molecular Theory	1. 2.1. Three states of matter 1.2.2. Kinetic Molecular Theory

	1.3. The atom: basic building block of all matter (Atomic structure)	1.3.1. Models of the atom 1.3.2. Atomic mass and diameter 1.3.3. Structure of the atom: protons, neutrons, electrons 1.3.4. Isotope 1.3.5. Electron Configuration
	1.4. Periodic Table	1.4.1. The position of the elements in the periodic table related to their electronic arrangements 1.4.2. Similarities in chemical properties among elements in Groups 1, 2, 17 and 18
	1.5. Chemical bonding	1.5.1. Covalent bonding, ionic bonding and metallic bonding
	1.6. Particles substances are made of	1.6.1. Atoms and compounds. • Molecules (molecular substances) are due to covalent bonding. • Ionic substances are due to ionic bonding. (The EFFECT of the different types of chemical bonding are emphasized here.)
2. Chemical change	2.1. Physical and Chemical Change	2.1.1. Separation of particles in physical change and chemical change 2.1.2. Conservation of atoms and mass 2.1.3. Law of constant composition
	2.2. Representing Chemical Change	2.2.1. Balanced chemical equations
	2.3. Reactions in aqueous solution	2.3.1. Ions in aqueous solution: their interaction and effects 2.3.2. Electrolytes and extent of ionisation as measured by conductivity 2.3.3. Precipitation reactions 2.3.4. Other chemical reaction types. In water solution
	2.4. Quantitative aspects of chemical change	2.4.1. Atomic mass and the MOLE CONCEPT 2.4.2. Molecular and formula masses 2.4.3. Determining the composition of substances

		2.4.4. Amount of substance (mole), molar volume of gases, concentration of solutions. 2.4.5. Basic stoichiometric calculations
3. Chemical systems	3.1. The hydrosphere	3.1.1 Its composition and interaction with other global systems

5.3.2.3 Content, concepts, and skills (column three)

The distinction between content, concepts, and skills are blurred due to them appearing in one column. Furthermore, many bullet points appearing in this column are not directly related to physics or chemistry content, concepts, or skills. An example of this is “Understand the meaning of prefixes di-, tri- etc” (p. 17). Compounding the possible confusion that may arise from this, is the fact that the majority of bullet points appear as instructions/questions due to them beginning with action verbs (such as: revise, give examples, devise, use, understand, identify, describe). Some of the action verbs are problematic due to them being intangible – for example, “Appreciate the PT as a systematic way to arrange elements” (p. 23), or conflating different actions – for example “showing” and “explaining” as evident in the statement: “Show that the atom is mainly an empty space with the nucleus occupying a very small space in any atom (*explain* the α–particle scattering experiment)” (p. 21).

Questions appear in this column, for example – “What is the influence of periodicity on electron-affinity and electronegativity?” (p. 23). Questions also appear in other columns of the tables in Section Three, perhaps highlighting this aspect of scientific inquiry that was mentioned under specific aims of physical science (p. 8). In some instances, statements are included which exemplify what the appropriate answer to certain questions would be – for example, “Define melting, evaporation, freezing, sublimation and condensation as changes in state” (p. 19). However, in other instances, this is not the case – for example, “State Hund’s rule and Pauli’s exclusion principle” (p. 22).

Statements of content (that are not framed as instructions or questions) also appear in this column – such as explanations for covalent, ionic, and metallic bonding (p. 25). However, this is not characteristic of the Content, concepts and skills column, since such statements also occur in other columns. For instance: “If you have a sand dune, the material out of which the dune is made is sand” appears under the Practical activities column (p. 15). Another example of a content statement appearing elsewhere, is the following excerpt from the Guidelines for teachers column:

> The Afbau principle (building-up principle) is the principle that the orbital that fills first is the orbital with the lowest energy. In atoms the order for filling of orbitals is 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p ... electronic structure. (Afbau is German for building-up). (p. 22)

Furthermore, each topic heading has a content statement alongside it, crossing columns three and four – for example, the topic heading ‘Physical and chemical change’ has alongside it: “The properties of matter determine how matter interacts with energy” (p. 35).

The mixing of different statement types or forms under the Content, concepts and skills column in Section Three of the NCS-CAPS: Physical Sciences, appears to be random and suggests an inconsistent or incomplete transfiguring of content, concepts, and skills into teaching and learning goals or objectives and then into questions and/or instructions. This supports the aforementioned idea that Section Three extends beyond typical syllabus form towards work schedule format, albeit in an inconsistent manner. A specific example of this is whether the instruction to “Give examples of” which appears on multiple occasions (for example pp. 16, 18, 19, 39) means that teachers are meant to provide the examples to learners or that learners should be able to provide examples, or both.

Overall, this column includes instructions, questions, and content statements, all of which also appear in other columns. For this reason, the analysis of the Grade 10 chemistry component of the NCS-CAPS: Physical Sciences in this study, focused on data across columns two-six rather than just on the Content, concepts and skills column. Due to inconsistency in form or type of statements as well as the elusive nature of some action verbs, the analysis of textual abstraction was conducted at the lexical item level, as discussed in Chapter Four (see sections 4.7.3 and 4.8.2). It is important to note that visuals do not appear in the syllabus data (apart from some chemical symbols, formulae and equations), and a few direct references to visuals (for example, “labels on the containers of food” on page 15, “heating and cooling curve for water” on page 19, and “periodic table” on page 23). This means that the syllabus document cannot be analysed for curriculum literacy demands in terms of visual abstraction - only textual abstraction was explored in this data.

5.3.2.4 Practical activities (column four)

This is the first column in which there are blank spaces (no information/statement) for some of the subtopics (for example pp. 37 and 39). As expected from Stage 3 indicating that "Practical activities … will refer to practical demonstrations, experiments or projects used to strengthen the concepts being taught" (p. 9), this column includes Activities as well as Prescribed experiments for formal assessment and Recommended experiments for informal assessment. Examples include:

- "Activity: Do experiment with paper chromatography to show that water soluble ink-pens or 'Smarties' are not pure colours, but are mixtures of colours". (p. 16)
- "Prescribed experiment for formal assessment: Draw the heating and cooling curve for water. Start with ice in a glass beaker and use a thermometer to read the temperature every 1 minute when you determine the heating curve of water. Do the same with the cooling curve of water starting at the boiling point. Give your results on a graph". (p. 19)
- "Recommended experiment for informal assessment: … Do flame tests to identify some metal cations and metals". (p. 22)

In addition to these, some activities also appeared without any of the abovementioned types of headings. Furthermore, some appeared with the heading being a question, or: Experiment, Practical Experiment, Demonstration, Practical Demonstration, and Practical Work, with the distinction between these categories and the earlier-mentioned Activities heading being unclear. Examples include:

- (no heading) "Use molecular models to build pure substances, elements and compounds". (p. 16)
- "Which mixtures are heterogeneous and which mixtures are homogenous? Make mixtures of sand and water, potassium dichromate and water, iodine and ethanol, iodine and water". (p. 16)

- “Experiment: … (2) Determine the products of the electrolysis of water (sodium sulphate added)”. (p. 32)

- “Practical Experiments: … (2) Use apparatus for hydrogen combustion to burn hydrogen in oxygen. Is this a physical change or a chemical change? Explain”. (p. 36)

- “Demonstration: … (2) Demonstrate chemical bonding. Use atomic model kits to demonstrate chemical bonding in elements and compounds”. (p. 32)

- “Practical Demonstration: … (4) Mix iron and sulphur and separate with a magnet”. (p. 35)

- “Practical Work: Investigate different types of solutions (table salt in water…) and write balanced equations for each” (Subtopic p. 46)

In the above examples it is evident that the practical activities appear as instructions without a heading, or with a range of different headings. As apparent in the second and fourth examples above, questions also appeared in this column as an activity heading or for answering after carrying out the activity. Furthermore, questions sometimes appeared as the actual activity, either with the answer provided or not, as illustrated in the following examples:

- “Activity: Why do we have scientific names?” (p. 17)

- “Recommended experiment for informal assessment: … (2) What is the driving force of each reaction type? (The formation of an insoluble salt; the formation of a gas; the transfer of protons; the transfer of electrons)”. (p. 49)

The first example above also highlights that many items listed under this heading are not hands-on ‘practical’ activities. Other examples of this include semiotic activities such as:

- “Activities: (1) Describe and draw the formation of a covalent bond”. (p. 25)

“Activity: Find in literature the different definitions of chemical change and physical change. Discuss the definitions and come to a conclusion about the most correct definition” (p. 47). Another interesting finding was a guideline for teachers appearing under this column even though column six is a dedicated to such statements:

- "Visual representations, preferably 3D, is important here to ensure conceptual understanding of the formation of the different types of compounds". (p. 32).

It is evident that the inconsistency with the items included under column three continues in column four. Overall, column four includes content statements, questions, guidelines for teachers, and spoken or written tasks in addition to practical activities either without a heading or under a range of heading options, with many types not being distinguishable from others. This would raise significant challenges for applying frameworks such as Bloom's taxonomy of educational objectives, or revisions of Bloom's taxonomy (which require statements to be framed in a consistent manner) in analysing intellectual demands of the NCS-CAPS: Physical Sciences. However, it was possible to devise a word and symbol level translation device for exploring the textual curriculum literacy demand as illustrated in Table 4.6 (Chapter Four).

5.3.2.5 Resource materials (column five)

As with the Practical activities column, the Resource materials column is also blank for some subtopics (for example pp. 16-18). Although this makes sense when no practical activity is mentioned (for example p. 24), there are instances where practical activities requiring specific resources are included in the Practical activities column but associated resources are not mentioned alongside in the Resource materials column. An example of this is evident for the practical activity in which learners are required to make mixtures of sand and water, potassium dichromate and water, iodine and ethanol, and iodine and water (p. 16), where none of the substances or relevant glassware such as beakers and stirring rods are listed as resource materials. Also, there are instances where resource materials are listed in other columns, such as marbles, Prestik, jelly-tots, and toothpicks being listed for use in illustrating conservation of mass in chemical equations, in column six (Guidelines for teachers) (p. 36).

Further inconsistencies exist in terms of the Periodic Table as a resource material. This is evident from it being mentioned as a resource material for the activity in which learners are required to make a science puzzle (p. 21), but not being mentioned as a resource material for the activity of identifying metals, non-metals, and metalloids on the periodic table (p. 17). Additionally, information for the periodic table activity (p. 23) appears under Resource materials (column five) rather than under Practical activities (column four) or Guidelines for teachers (column six). Further cause for confusion arises from the instruction: "Use the periodic table to identify the elements" being listed under Resource materials rather than as a Practical activity (p. 16) and a knowledge statement about the periodic table being mentioned under Resource material (p. 22). A class activity (with that as the heading), appears in the Resource Material column (p. 32). It was considered possible that the basis for only some materials being listed was their being specialised items such as the apparatus, and chemicals required for the flame tests practical activity (p. 22). However, everyday items are also listed, such as polystyrene balls and wooden sticks for representing ionic crystal lattices (p. 25). This is also an example in which there is no Materials heading appearing above the items, while in other instances the items are listed in that way (for example p. 19).

It is clear that the Resource Materials column includes many inconsistencies, as is the case for the Content, Concepts and Skills (column three) and Practical Activities (column four) columns. Some items required for listed practical activities are included (sometimes under the heading of Materials) while others are not; some physical objects listed are not related to practical activities mentioned; resource materials are sometimes mentioned in other columns; items relevant to other columns sometimes appear in this column; and some items (such as the periodic table) are referred to inconsistently. This calls into question what actually counts as resource material in Physical Sciences education, and what the purpose of this column is in the syllabus document.

5.3.2.6 Guidelines for teachers (column six)

Together with the Practical activities and Resource material columns, the Guidelines for teacher's column does not include any information for some topics (for example p. 16). As was the case for some of the other columns, some items appearing in this column also appear out of place. For example, "Learners are encouraged to look at food additives and preservatives. This should be contrasted with indigenous ways of food preservation" (p. 15) might be more suitably placed in the Practical activities column. In addition, some information appearing in this column might be better situated in the Content, concepts and skills column – for example, "Z=atomic number and A=mass number" (p. 22). Furthermore, the way in which the symbol meanings are expressed (using =) is problematic irrespective which column this information is placed in. Despite these problems and of relevance to the current thesis, statements appear here that acknowledge curriculum literacy demands albeit in a less structured and comprehensive way. Examples of such acknowledgement are shown in Table 5.3.

Table 5.3: Examples of statements acknowledging textual and visual literacy demands from Guidelines for teachers column, in the NCS-CAPS: Physical Sciences (DBE, 2011)

Curriculum Literacy Demands	**Examples of related statements**
Textual	• Pay attention to the names of covalent compounds and the names of ionic compounds. • Ensure that the correct terminology is used here, e.g. ionic substances do not form *molecules.* • Under Chemical Bonding here only the definitions of covalent bonding, ionic bonding, and metallic bonding are done. • Describe matter from the concepts: atoms, elements, compounds, chemical reactions. The terms simple molecules and giant molecules are confusing (sugar being anything but a simple molecule if water is seen as a simple molecule!) The terms covalent molecular structures and covalent network structures can be used instead. • The use of the terminology single displacement reactions and double displacement reactions leads to misconceptions with redox reactions where displacement reactions take place due to electron transfer.
Visual	• Visualisation is very important in chemistry to demystify the subject and make it easier to understand. • Remember these concepts are very abstract to learners. The more visual you can make the concepts, even by using models, the more logical the concepts will become to the learners. • The use of models to demonstrate is crucial in this section. This helps learners to 'see' into the submicroscopic world of matter: 'a macroscopic view'. • Always move between macroscopic and submicroscopic and use symbols effectively. • Reaction types are done to create awareness of the types of reactions and to make it easier for learners to write balanced chemical equations.

5.3.3 Summary and discussion of the information appearing in section three of the NCS-CAPS: Physical Sciences

As evident from the earlier discussions in this chapter, the tabular format with specific column headings is misleading since many items appearing in columns three to six are unrelated to the column headings under which they appear. It is for this reason that the analysis in the current thesis could not only focus on any one particular column such as Content, concepts and skills. All the textual data in Section Three pertaining to Grade 10 Chemistry was thus analysed in this study since the arrangement of specific information into particular columns is not consistent. The issue of teaching details such as time, activities, resource materials, and teacher guidelines being specified for each subtopic indicates a shift beyond syllabus towards a work schedule format, and at times down to the level of lesson planning.

This reminds us that in terms of Thijs and Van den Akker's (2009) description of curriculum levels, the NCS-CAPS raises a micro/meso level curriculum to macro (national) level. Also, problematic issues are cemented into the curriculum document (Grussendorff et al., 2014), such as confusion arising from column headings not always being directly relevant to their content. Ramatlapana and Makonye (2012, p. S7) argued that "the prescriptive nature of the curriculum as espoused by CAPS at times compromised educator autonomy in effecting quality teaching". Teacher autonomy in ensuring quality teaching thus also requires them addressing shortcomings of the syllabus document, which is only possible if the curriculum demands are made explicit. Chapter Six contributes to shedding light on something that was previously implicit and cemented into the syllabus – the nature of textual curriculum literacy demands. The textbooks to be used with the NCS-CAPS: Physical Sciences are also prescribed by government (appearing on a catalogue of government-approved school textbooks) and for Grade 10 include the *Platinum physical sciences learners' book* (Grayson et al., 2011) that we now turn our attention to.

5.4 Description of Grade 10 Physical Sciences Textbook (Grayson et al., 2011)

5.4.1 Physical sciences grade 10 learner's book as an example of textbook genre

There are a wide range of definitions available for 'textbook', contributing to it being a polysemic term since it applies simultaneously to the academic textbooks employed at university, instruction booklets, technical manuals, as well as school textbooks (Parodi, 2010,

p. 196). This is perhaps related to the paucity of research on textbook genre mentioned by Parodi (2010). This is affirmed by Friesen (2013, pp. 498-499), who described textbooks as "a popular but often ignored pedagogical genre" and as an "unusual and difficult genre". From the perspective of genre as a social process, textbooks are pedagogic recontextualisations of the syllabus, that is, they are artefacts of the pedagogic recontextualising field, employed by both teachers and learners in the knowledge reproduction field.

In terms of genre as goal oriented, textbooks are framed by Hyland (1999 in Parodi, 2010, p. 212) as "a repository of knowledge that opens paths to beginning learners in the discipline and allows them to construct preliminary access to this specialised knowledge". Parodi (2010, p. 195) acknowledged that textbooks are "employed as fundamental means of constructing specialised knowledge in a variety of disciplines". It is worthy of noting for the context of this thesis, Paxton's (2007) acknowledgement that the genre of textbooks provide an exemplar in terms of disciplinary literacy practices. Specifically, regarding the discipline of chemistry, Cheung (2000) remarked that the predominant function of this genre is regulation of learners' entry into the knowledge area, and he affirmed the significance of this genre as a gatekeeper to chemical literacy. The stages of the genre, as evident from the chemistry components of the Grade 10 *Platinum physical sciences* textbook (Grayson et al., 2011) will now be considered.

The Grade 10 *Platinum physical sciences* textbook (Grayson et al., 2011) for which the chemistry components were analysed in this study, consists of a total of eight unnumbered pages and 274 numbered pages. The chemistry component of the textbook covers a total of 143 pages, and these constitute the textbook data analysed in this study. An overall breakdown of the main components and subcomponents of the textbook genre is provided in Table 5.4 (with a focus on the chemistry sections for genre stage 2). In terms of genre involving stages, it is evident that the first stage serves the purpose of orientating the reader to the publication, the second stage explicates content and learning, as well as exam practice questions. The third stage includes information (that supports earlier sections) in the form of appendices.

Table 5.4: An overview of the chemistry topics, chapters, and units in the textbook

Genre Stage	**Page**	**Genre Component**	**Genre Subcomponent**
1. Orientation	(Unnumbered) 1	Cover Page	Series Name, Subject, Publisher, Authors, Logo/emblem, Curriculum Name, Grade
	(Unnumbered) 3	Repeat of Cover Page Info	As above (includes copyright statement)
	(Unnumbered) 4	Publication Details	Publisher name, Publisher contact details, offices and website, Copyright information, ISBN number, Editor Name, Book designer, Cover design, Typesetting , Printer credits
	(Unnumbered) 5-7	Contents Page	List of Topics, Chapters, Units, and their page numbers
2. Content, learning and assessment explication		**Topic**	**Chapters**
	1-56	1. Matter and Materials	1. Revision of Matter and Classification
			2. States of Matter and the kinetic Molecular Theory
			3. The atom
			4. The Periodic Table
			5. Chemical bonding
			Exam Practice Questions
			Summary of Topic 1
	94-104	3. Matter and Materials	11. Particles substances are made of
			Exam Practice Questions
			Summary of Topic 3

	105-127	4. Chemical Change	12. Physical and chemical change.
			13. Representing chemical change
			Exam Practice Questions
			Summary of Topic 4
	162-200	6. Chemical Change	17. Reactions in aqueous solution
			18. Quantitative aspects of chemical change
			Exam Practice Questions
			Summary of Topic 6
	253-266	8. The Hydrosphere	23. The hydrosphere
			Exam Practice Questions
			Summary of Topic 8
3. Support	267-270	Glossary	Scientific terms and definitions
	271-273	Index	Topics and page numbers
	274	Periodic Table	Information regarding chemical elements

Source: Grayson et al. (2011)

The textbook chemistry topics are based on the three chemistry knowledge areas of the NCS-CAPS, the textbook chapters are based on the NCS-CAPS topics and the textbook units are based on the NCS-CAPS subtopics. This is evidence of the textbook having been written specifically for use with the NCS-CAPS: Physical Sciences and suggests strong alignment in terms of disciplinary content. As evident in Table 5.5, each topic is followed by a set of related exam practice questions and a summary of the topic. The textbook ends with a glossary, index and periodic table. Genre stage 2 in the table, covers the data analysed in this study.

5.4.2 Forms of information in the chemistry component of the textbook

Each unit of the textbook (Grayson et al., 2011) consists of an assortment of information forms, as shown in Figures 5.2 to 5.10:

1. Paragraph or main text (Figure 5.2);
2. Examples (Figure 5.3, 5.4 and 5.5);
3. Keyword boxes (Figure 5.6);
4. Figures (Figure 5.7);
5. Activity, practical demonstrations, and experiment boxes (Figure 5.8);
6. Tables (Figure 5.9); and
7. 'Did you know?' Boxes (Figure 5.10).

These information forms will now be described.

5.4.2.1 Paragraph or main text

An excerpt of paragraph text is shown in Figure 5.2.

> The properties of materials are the characteristics that identify materials and make them different from one another. We choose materials for the properties they contain that suit our particular needs. For example, if we are allergic to a particular substance, we will make sure that we do not eat it. Materials for clothing are also chosen for their particular properties. For example, rubberised or plastic materials are used for rainwear because they are waterproof.
>
> Some of the important properties of materials are given below. Most of these are discussed in detail later in this chapter:
>
> - strength and hardness – does the material break easily?
> - thermal and electrical conductivity – does the material allow heat energy or electrical current to pass through it?
> - brittle, malleable or ductile – what happens when you hammer the material?
> - magnetic or non-magnetic – is it attracted by a magnetic field?
> - density – does the object float or sink?
> - melting and boiling points – what is the state of the substance at room temperature? It it a solid, liquid or gas?

Figure 5.2: An example of paragraph text from the textbook (Grayson et al., 2011, p. 1)

Paragraph text appears to be the central type of information form, linking to all the other forms. It:

- includes words that also appear in the keyword boxes;
- is sometimes accompanied by an illustration of what it refers to (by figure number) in the text;
- provides explanations and examples before activity, practical, and demonstration boxes;
- is sometimes accompanied by a table which summarises or exemplifies what it refers to (by table number) in the text; and
- is contextualised by (for example on p. 4), or provides the basis for (on p. 9) Did you know boxes.

5.4.2.2 Examples

'Examples' occur regularly throughout the textbook units, either within the paragraph text as evident from Figure 5.1, within Activity boxes (for example on p. 26 as will be illustrated when Activity boxes are discussed), as illustrated by some figures or tables (for example on p. 6 as illustrated in Figure 5.3, and p. 33 as illustrated in Figure 5.4), or followed by the text and labelled with example numbers (for example on p. 22, as illustrated in Figure 5.5).

Name	Formula
Hydrogen fluoride	HF
Nitrogen dioxide	NO_2
Phosphorus pentachloride	PO_5
Dinitrogen tetrafluoride	N_2F_4
Nitrogen trihydride	NH_3

Figure 5.3: An instance of examples shown within a table in the textbook (Grayson et al., 2011, p. 6)

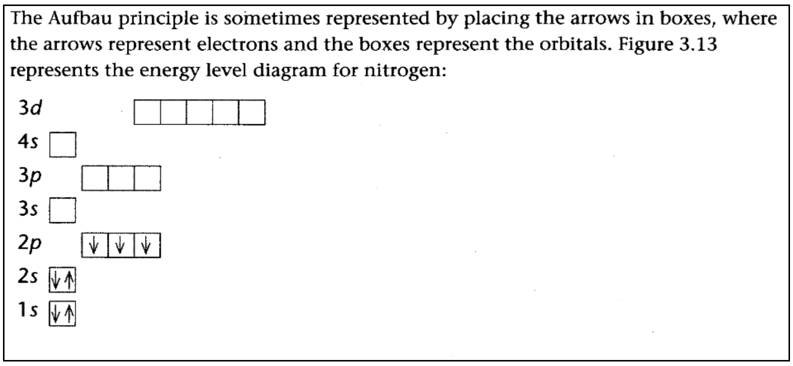


Figure 5.4: An instance of examples shown in the form of figures in the textbook (Grayson et al., 2011, p. 33)

Example 1

If hydrogen, with a mass of 1,673 55 × 10^{-27} kg, has a mass equal to 1 on the **hydrogen scale**, what is the relative mass of oxygen, with mass 2,656 59 × 10^{-26} kg, on the hydrogen scale?

Answer:

1,673 55 × 10^{-27} kg of hydrogen = 1 on the hydrogen scale

Therefore 2,656 59 × 10^{-26} kg of oxygen = $\frac{1 \times 2{,}656\ 59 \times 10^{-26}\ \text{kg}}{1{,}673\ 55 \times 10^{-27}\ \text{kg}}$

= 15,87 on the hydrogen scale

Figure 5.5: An instance of examples labelled as such, in between paragraph text (Grayson et al., 2011, p. 22)

An instance of examples appearing within the textbook units with the heading 'Example' followed by the example number is shown in Figure 5.5. They take the form of questions or instructions followed by the answers. Answering the question requires sequences of reasoning such as those required for calculation or symbolic representation.

5.4.2.3 Key words boxes

Keywords and their definitions appear in Key words boxes on the left or right margins of the paragraph text of the textbook (Grayson et al., 2011). An example is shown in Figure 5.6.

> **KEY WORDS**
>
> **malleable** – able to be shaped by hammering or rolling
> **ductile** – can be stretched and made, for example, into wires
> **metalloid** – element that has metallic and non-metallic properties

Figure 5.6: An instance of a key words box from the textbook (Grayson et al., 2011, p. 9)

There are a total of 47 Key words boxes in the chemistry section of the textbook. They appear in the left or right margin alongside paragraph text that's including the particular words or terms. Each box contains a maximum number of six key words. Accompanying each key word is a definition or explanation, which also appears in the glossary section of the textbook.

5.4.2.4 Figures

Figures in the textbook (Grayson et al., 2011) appear either in margins or in line with the paragraph text. An example in shown in Figure 5.7.

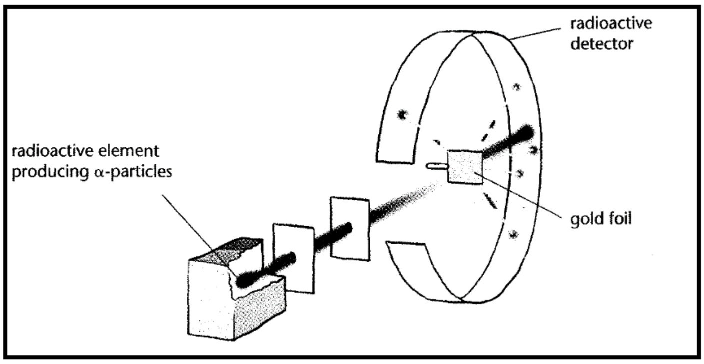


Figure 5.7: An instance of a figure from the textbook (Grayson et al., 2011, p. 19)

There is a total of 85 figures in the chemistry section of the textbook. They occur in the left or right margin alongside paragraph text, in between paragraphs, or in Activity boxes.

5.4.2.5 Activities, practical demonstrations and experiment boxes

Activities, practical demonstrations and experiment boxes also appear regularly in the textbook (Grayson et al., 2011). An example is shown in Figure 5.8.

ACTIVITY 6: MAKE UP A GAME OR A QUIZ

Pairs

1. Make up a list of ten questions about the Periodic Table. People should be able to answer your questions if they have a copy of the Periodic Table open in front of them. Write down the answers to your questions.
2. Suggest a fun way to use your questions in a game. For example, you could play 'Hangman.'

Figure 5.8: An example of an activity box from the textbook (Grayson et al., 2011, p. 26)

There are five practical demonstration, 26 experiment and 58 Activity boxes in the chemistry section of the textbook. Each of these activities, experiments, and practical demonstrations has a title which is followed by an indication of whether the task is to be done by 'individual' learners, is a 'group' task, or is to be done in 'pairs'.

The activities, experiments, and practical demonstrations usually include the following:

- Questions or instructions;
- Information related to the questions/instructions; and
- ‘You will need’ followed by ‘method’, and sometimes ‘results and conclusions’.

The only exceptions to this typical format, are:

- Activity 1: The Atom (p. 21). This involves students choosing between listing key experiments and how they influenced description of the atom or making a flowchart/timeline showing discoveries about atomic structure. The activity instructs students to note they will use information provided in the textbook unit but also need to do additional research using a library or the internet.
- Activity 6: Make up a Game or a Quiz (p. 26). This activity requires learners making a list of 10 questions that people could answer using a copy of the periodic table, and to write answers to the questions as well. Learners are required to suggest a fun way to use their questions in a game such as ‘hangman’.
- Activity 2: Water Purification (p. 264). This activity requires learners to research how water is purified and the expected quality of water, and to present their project as a poster and/or presentation.

5.4.2.6 Tables

An example of a table appearing in the textbook (Grayson et al., 2011) is shown in Figure 5.9.

Energy levels of principal quantum number	**Number and type of subshell**	**Number and type of orbitals in subshells**	**Number and type of electrons in an energy level**
n = 1	One 1*s* subshell	One 1*s* orbital	Two 1*s* electrons
n = 2	One 2*s* subshell One 2*p* subshell	One 2*s* orbital Three 2*p* orbitals	Two 2*s* electrons Six 2*p* electrons
n = 3	One 3*s* subshell One 3*p* subshell One 3*d* subshell	One 3*s* orbital Three 3*p* orbitals Five 3*d* orbitals	Two 3*s* electrons Six 3*p* electrons Ten 3*d* electrons

Figure 5.9: An example of a table from the textbook (Grayson et al., 2011, p. 31)

There is a total of 12 tables in the chemistry section of the textbook. Some of these are not labelled as such but include the normal column and row arrangement of tables, and so were counted as tables. Additionally, eight activity/practical demonstration/experiment boxes include tables for learners to copy and complete. Interestingly, all 12 tables appear in the first knowledge area (matter and materials). Furthermore, four activity/practical/experiment boxes in this knowledge area require students to copy and complete a table, with this being required twice for the chemical change knowledge area and twice for the chemical systems knowledge area.

5.4.2.7 'Did you know?' boxes

'Did you know?' boxes containing interesting facts also appear in the textbook, as illustrated by Figure 5.10.

DID YOU KNOW?

Photovoltaic modules contain semiconductors such as silicon. The modules convert solar radiation to electrical current. They provide an eco-friendly and energy-efficient way to charge cellphones and provide lighting. Numerous government housing projects in South Africa make use of this technology.

Figure 5.10: An example of a 'Did you know?' box (p. 9)

There is a total of 12 ‘Did you know?’ boxes across the chemistry sections of the textbook. Interestingly, three of these are about water and span all three chemistry knowledge areas. This is probably due to water providing a familiar, everyday context for relating theoretical concepts to.

5.4.3 Summary and discussion of the Grade 10 Physical Sciences textbook chemistry components

While learning is usually facilitated by the teacher, the visual identification of textbook elements allows learners to use textbooks more independently (Gavora, 2014). There are usually a wide array of navigation elements in textbooks such as pagination, and in addition to being navigation tools, page numbers are also signs of progression. Additional navigation elements include chapter names, units, and activities – with consistent formatting in terms of such things as font and colour making themes easily recognisable (Gavora, 2014). This range of navigation elements was also evidenced in the *Platinum physical sciences* textbook (Grayson et al., 2011).

Although describing the rhetorical organisation of textbook genre is not straightforward, it is acknowledged in the study by Parodi (2010) that it includes sequences of content that are supported by didactic resources. The sequences of content referred to, are commonly in the paragraph or main text described earlier in this chapter. Language is an important feature of textbook genre, and while other modes (such as visuals) can be used for conveying academic content, “language is the most important means of communication both in classroom interaction and individual learning from textbook by the pupil. Language is a gate through which the pupil enters the textbook content” (Gavora, 2014, p. 291). Of particular relevance to this thesis, Gavora (2014) recognised that content area terminology characteristically contains more abstract terms.

Different from other types of children’s literature, structure is an especially strong feature of textbooks in order to make the content accessible (Gavora, 2014). This is evident in the *Platinum physical sciences* textbook (Grayson et al., 2011) using a range of standard information formats: paragraph or main text, visuals, examples, keyword boxes, activity/practical demonstrations/experiment boxes, tables, and ‘Did you know?’ boxes. Textbooks also contain tasks (problems or assignments) in each unit, which serve as learning instruments and Gavora (2014) included questions under the category of tasks. This association of tasks with questions also helps make sense of why questions appear regularly in the Practical activities column of the NCS-CAPS: Physical Sciences, as highlighted earlier in this chapter. An important research question pertains to the relative difficulty of knowledge and skill acquisition for textbook learning by pupils (Gavora, 2014).

Gavora (2014) emphasised textbooks as the dominant textual material which children encounter at school as an aspect of moving from a predominantly oral culture, to one that is predominantly textual. In addition to containing text, some content forms contain visual (including symbolic) content and both serve the purpose of supporting learning in the knowledge reproduction field. Kanto et al. (1983 in Parodi, 2010, p. 208) used the term "considerate texts" for texts which are articulated in a special way in order to be more accessible to readers. This is of significance for the current thesis in distinguishing textbooks as pedagogic recontextualising texts that learners work with directly, from syllabi which are official recontextualising texts that influence what learners learn but which learners themselves do not read.

Despite textbooks being pedagogic recontextualisations of the official pedagogising text within the recontextualisation field of the pedagogic device, there is sometimes little alignment between textbooks and curriculum policy according to a UNESCO study (UNESCO Institute for Statistics, 2012). Some South African Physical Sciences teachers described prescribed textbooks as advantageous to those teachers unable to interpret the syllabus directly, since such teachers could more easily follow textbooks aligned to the curriculum (Ramatlapana & Makonye, 2012). Drawing from the work of Bernstein, however, the authors alerted us to the fact that "in mathematical literacy for example, some of the tasks were set in language too difficult and that distracts access to mathematics concepts particularly to disadvantaged learners when classifying experience and creating meaning" (Ramatlapana & Makonye, 2012, p. S23). As pointed out by Kearsey and Turner (1999) more generally, "Textbooks need to address the literacy needs of specific pupils if they are to be useful as teaching and learning materials". As is the case with textbooks, exemplar examination papers to which we now turn our attention, are examples of curriculum support materials used by teachers and learners.

5.5 Description of the Grade 10 Exemplar Exam (DBE, 2012)

5.5.1 The Grade 10 chemistry exemplar examination paper as an example of test genre

Although tests are one of the genres developed and employed in the knowledge reproduction field, exemplars are located in the recontextualisation field. In terms of genre being a social process, tests (like textbook genre and unlike school syllabi) are worked with by learners directly. Tests are developed by education authorities such as schoolteachers or examiners appointed by government ministries. As is the case for textbook genre, the literature on test genre is thin. What is recognised however, is that the passages of a test are different from most other texts that children read since they serve the function of testing rather than being appealing, and are sparsely illustrated (Fuhrken & Roser, 2009). The challenge of staying focused when reading tests is compounded for a student who lacks experience in navigating them. The manner in which learners read other texts on a daily basis, is different from the reading of test items on a specific test day, and so learners need opportunities to learn how to navigate tests successfully (Fuhrken & Roser, 2009). This highlights the goal aspect of genre, for exemplar assessment such as the Grade 10 chemistry exemplar chemistry examination explored in this thesis. A scanned page from the exemplar exam is shown in Figure 5.11.

Physical Sciences/P2 11 DBE/2012
NSC – Grade 10 Exemplar

QUESTION 6 (Start on a new page.)

The unbalanced equation **(i)** and the word equation **(ii)** for two chemical reactions are shown below.

(i) $SO_2(g) + O_2(g) \rightarrow SO_3(g)$

(ii) Calcium carbonate → calcium oxide + carbon dioxide

6.1 Which ONE of the above equations (**i** or **ii**) represents a:

6.1.1 Decomposition reaction (1)

6.1.2 Synthesis reaction (1)

6.2 What does (g) represent in equation **(i)** above? (1)

6.3 Write down a balanced chemical equation for the word equation **(ii)**. Show the phases of ALL reactants and products. (4)

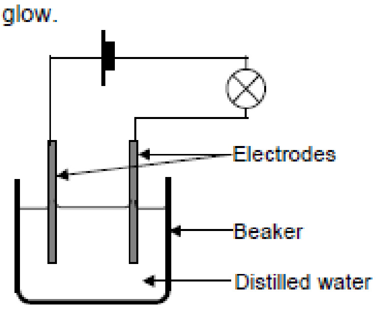
6.4 Rewrite equation **(i)** in the ANSWER BOOK and balance the equation. (1)

6.5 Name the chemical law that a balanced equation illustrates. (1)

6.6 Using equation **(i)** above, show that mass is conserved during the reaction. (3)
[12]

QUESTION 7 (Start on a new page.)

7.1 The arrangement below is used in a class to investigate the conductivity of a solution. The beaker is initially filled with 250 mℓ distilled water. It is observed that the bulb does not glow.



7.1.1 Give a reason why the bulb does NOT glow. (1)

A 15 g sample of ammonium nitrate is now dissolved in the distilled water. It is observed that the bulb glows brightly.

7.1.2 Write down the general name given to an aqueous solution that conducts electricity. (1)

Figure 5.11: A page from the Grade 10 Chemistry exemplar examination paper (DBE, 2012, p. 11)

When using exemplar assessments for the purpose of learning, mastering the test genre requires that students inhabit it – "Students are introduced to well-chosen models of a text form. They learn to recognise its distinguishing features and traits through close inspection. … Students need time to study the form, to read within the genre, to explore it, to notice its particularities as a text form …, and to identify its patterns and constants. Without exposure, texts will seem more foreign, mysterious and bewildering than they currently do" (Fuhrken & Roser, 2009, p. 186). The stages of test genre are evident from the structure of the Grade 10 chemistry exemplar examination paper, shown in Table 5.5.

Table 5.5: Overall structure of the Grade 10 chemistry exemplar exam (DBE, 2012)

Genre Stage	Page	Genre Component	Genre Subcomponent
Orientation	1	Cover page	Examining authority
			Examination name
			Grade
			Subject
			Component
			Year
			Marks
			Time
			Number of pages
	2-3	Instructions/guidelines	General
			Question-specific
Questions and related information	4-15	Questions and mark allocations	Question 1 (compulsory)
			Question 2 (compulsory)
			Question 3 (compulsory)
			Question 4 (compulsory)
			Question 5 (compulsory)
			Question 6 (compulsory)
			Question 7 (compulsory)

			Question 8 (compulsory)
			Question 9 (compulsory)
Support	16-17	Reference sheets	Data sheet
			Periodic table
	18	Answer sheet	NA

5.5.2. Types of subquestions

Upon closer inspection of the exemplar examination questions, eight broad subquestion themes became evident inductively:

1) Definition;
2) Counting;
3) State/name;
4) Explanation/Justification;
5) Interpreting;
6) Comparison;
7) Representation; and
8) Calculation.

The subquestions for each of these categories, as well as subquestion marks, total marks, and percentage of total marks are summarised in Appendix D. In some instances, a particular subquestion involved elements of more than one category, and was then included in both categories with the marks being divided accordingly. For example, subquestion 3.2 asks to state with a reason, whether the substance for which the heating curve was shown in question 3, is water – this involved both the comparison and justification categories and so the subquestion appears in both categories with the relevant mark component for each. Another example is when a balanced chemical equation was needed – this was included in both the representation and counting categories (the latter category involved counting the number of atoms of each element present in reactants and products, towards balancing the equation).

5.5.3 Summary and discussion of the Grade 10 chemistry exemplar exam

In comparison to the Grade 12 NSC examination papers which are described in annual examiner reports after the marking of Grade 12 scripts has been completed, exemplar examinations such as the Grade 10 chemistry exemplar exam have received scant attention. This could be due to Grade 10 Physical Sciences learner performance not being reported on to the same extent as the Grade 12 Physical Sciences learner performance in the NSC examinations, or Grade 8/9 Natural Sciences learner performance in TIMSS. Furthermore, it suggests a relative lack of appreciation for feed-forward approaches as opposed to feedback.

The exemplar examination appears to have comparable mark allocations for the themes of definition, counting, naming/stating, and explanation/justification. The mark allocations for the themes of interpretation and comparison are also comparable, but relatively higher than the aforementioned themes. The marks allocated to the representation and calculation themes are also comparable, but substantially higher than the other themes. These broad themes are the kinds of patterns in the text form mentioned earlier, which learners need to acquaint themselves with ahead of formal examinations that will be used for the purpose of actual assessment towards promotion/certification. The themes also highlight the textual and visual nature of chemistry discourse that learners are expected to navigate. As Myhill (2005, p. 290) alluded to, the demands of examinations and assessments are particular examples of "school literacy demands". While themes for subquestion types do emerge inductively, the visual and textual literacy demands do not, and the results presented in Chapter Six shed light on these.

5.6 Concluding Comments

This chapter has provided an in-depth description of the curriculum documents which served as data sources for the study. It has shed some light on the broad genre stages for each document inductively, and presented the goal as well as individuals involved in each genre. Noteworthy of emphasis here is that all three documents contain textual data which can be explored for characterising textual abstraction. However, while the textbook and exemplar exam also contain a range of visuals, the syllabus does not. It was thus not meaningful to explore all three curriculum texts in terms of visual abstraction, and so only the exemplar examination and textbook were analysed using the visual SG translation device.

The researcher has had first-hand experience in using all three of the curriculum documents in teaching Physical Sciences at high school level (Grades 10, 11, and 12) during 2014. In addition, the researcher subsequently lectured university education students enrolled for the "Physical Sciences Teaching Method" course in the Post Graduate Certificate in Education programme, during 2016 and 2017. This ongoing engagement with the data analysed in this study contributed to the researcher achieving immersion in the data, which is regarded as the first step in the analysis process by Green et al. (2007) and as the space which allows the researcher to "'incubate' ideas about the possibilities of analysis'' (p. 547). As Maton and Chen (2016, p. 32) pointed out, "Evolving an external language thus requires a measure of distance from the internal language and immersion in the data of the study".

CHAPTER SIX: RESULTS AND DISCUSSION

6.1 Introduction

The first research question in this thesis pertains to the nature of the alignment of school chemistry literacy demands between the chemistry sections of a Grade 10 textbook (Grayson et al., 2011) and related chemistry exemplar examination paper (DBE, 2012) in terms of visual abstraction. The second research question pertains to the nature of the alignment of school chemistry literacy demands between the NCS-CAPS: Physical Sciences (DBE, 2011), the related Grade 10 textbook (Grayson et al., 2011), and exemplar examination paper (DBE, 2012) in terms of textual abstraction. The results for the analysis of abstraction of visual items and focal textual items employing the respective SG translation devices are presented first in this chapter, followed by a discussion of these results. Section 6.2. presents the results for the SG of visual items, and thus provides the basis for answering the first research question. Section 6.3. presents the results for the SG of focal lexical items, and thus provides the basis for answering the second research question. The discussion of the results, including answers to the research questions, is then presented in section 6.4. Concluding comments are included in section 6.5.

6.2 Results for SG of Visual Items

In this study, the LCT SG code was employed for characterising the abstraction of visual items from two of the three curriculum documents – the Grade 10 chemistry exemplar examination question paper (DoE, 2012) and Grade 10 chemistry sections of the textbook (Grayson et al., 2011). The visual SG coding was not applied to the Grade 10 chemistry sections of the NCS-CAPS since it is textual in nature and did not contain a range of actual visual items for analysis (as mentioned in Chapters Four and Five). The results presented in this section are based on the five-tiered SG translation device for visuals presented in Table 4.3 (Chapter Four) and included again here in Table 6.1. for ease of reference.

Table 6.1: SG translation device for visual abstraction in chemistry curriculum documents

Semantic gravity code	Data analysis code	Brief description	Example (in words for the sake of brevity, the related visual examples from the data are shown in Appendix A)
SG- -	5	Symbolic (1-Dimensional)	Unknown chemical elements (represented by variables)
			Chemical equations/formulae/symbols
			Symbolic mathematical equations
			Spectroscopic electron configurations
			orbital diagrams
SG-	4	Symbolic (with some 2-Dimensional meaning)	Periodic table (no visual atomic detail)
			Graphs and pie charts
			Energy level/Afbau/ Lewis diagrams
			Atomic notation
			Chemical equations with dot diagrams/structures
SGϴ	3	Hybrid iconic/symbolic	Periodic table (with some visual atomic detail)
			Electric circuit (naturalistic drawing with symbols)
			Global cycles with processes represented by arrows
			Classification scheme of matter
			Schematic chemical reaction
SG+	2	Iconic (2-Dimensional) resembling something at larger/smaller scale than human experience	Atomic and Molecular representations/models
			Diagrams of global cycles
			Photographs (objects smaller/larger than human scale) eg line spectra and telescope photographs
SG+ +	1	Iconic (2-Dimensional) closely resembles 3-Dimensional objects/phenomena at human scale	Naturalistic drawings of objects at human scale
			Comic strips
			Photographs (objects at human scale)

6.2.1 Visual abstraction in the chemistry exemplar examination question paper

LaDue et al. (2015) pointed out that the high value of visual representations in science explains their occurrence across all levels of assessment. It was thus not surprising that even an exemplar assessment such as the South African Grade 10 chemistry exemplar exam question paper (DoE, 2012), contained numerous visual items. However, what remained unclear prior to this study, was the characterisation of the visual literacy demand in the current exemplar examination paper in terms of abstraction. This section presents the results for the analysis of visual abstraction in the chemistry exemplar examination question paper.

Of the three documents analysed in this study, the examination paper contained the fewest pages – 18 in total, of which the 15 pages containing chemistry content were analysed (the cover page, instructions and information pages, and multiple-choice answering sheet were omitted). The examination paper data contained a total of 54 visual items. It is interesting to note that one question (question 4) which focuses on the reaction between sodium and chlorine to form sodium chloride, and is worth a total of 19 marks (12.7% of the total 150 marks), includes no visuals at all despite focusing on the submicroscopic level. It does, however, include sub questions requiring that students draw an Afbau diagram, write spectroscopic electron configurations ('sp' notation), and represent a chlorine molecule and the formation of sodium chloride with the aid of Lewis diagrams. However, the focus of this study was on what Maton (2013) terms high-stakes reading, and not on what he describes as high-stakes writing, as will be mentioned in the limitations of the study (see section 7.5 of Chapter Seven). Table 6.2 shows the results from the SG analysis of visual items in the exemplar examination paper.

Table 6.2: SG of visual items in the exemplar examination paper (DBE, 2012)

Result	SG+ +	SG+	SGΘ	SG-	SG- -
Example from data	(Not applicable)	Drawing representing sample of element with two isotopes (Figure 6.1)	Drawing of an electrochemical cell using symbols for some circuit components (Figure 6.2)	Graph showing heating curve Figure 6.3)	Sp notation: '$1s^2 2s^2 2p^6 3s^2 3p^4$' (p. 10)
Total number across 15 pages analysed	0	1	6	3	44
% of total of 54 visuals	0	1.9	11.1	5.6	81.5

The examination paper did not contain any visual items from the strongest SG category (SG+ +) which includes iconic (2-dimensional) visuals closely resembling 3-dimensional objects/phenomena at human scale such photographs, comic strips and naturalistic drawings. The weakest SG category (SG - -) which includes symbolic visuals (1-dimensional), had the highest proportion of the total number of visuals. An example from the exemplar examination paper is the spectroscopic electron configuration for an unknown element 'P': '$1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^4$' (DBE, 2012, p. 10). Visual items in the other three categories (SG+, SGΘ, and SG-) constitute relatively smaller fractions of the total number of visuals. An example of a visual in the SG+ category is the drawing of a sample of an element containing two isotopes (DBE, 2012, p. 10) shown in Figure 6.1.

Figure 6.1: An example of visuals in the SG+ category from the exemplar examination paper (DBE, 2012, p. 10)

Figure 6.2 shows an example of a visual item from the examination paper, in the SGϴ category, which includes hybrid iconic-symbolic visuals. The visual is a drawing of an electrochemical cell which employs symbols for some circuit components (cell and bulb).

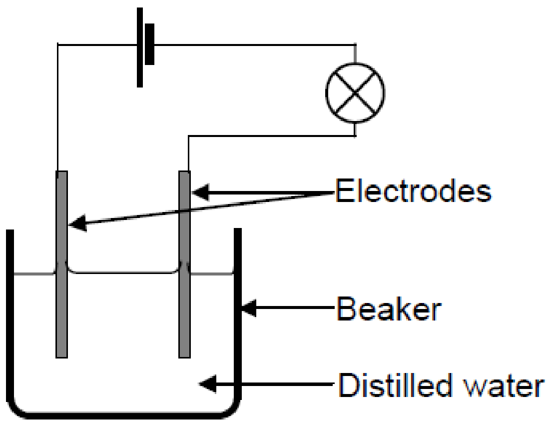


Figure 6.2: An example of visuals in the SGϴ category from the exemplar examination paper (DBE, 2012, p. 11)

An example of a visual item from the examination paper, in the SG- category is the heating curve for a pure substance (DBE, 2012, p. 10) shown in Figure 6.3.

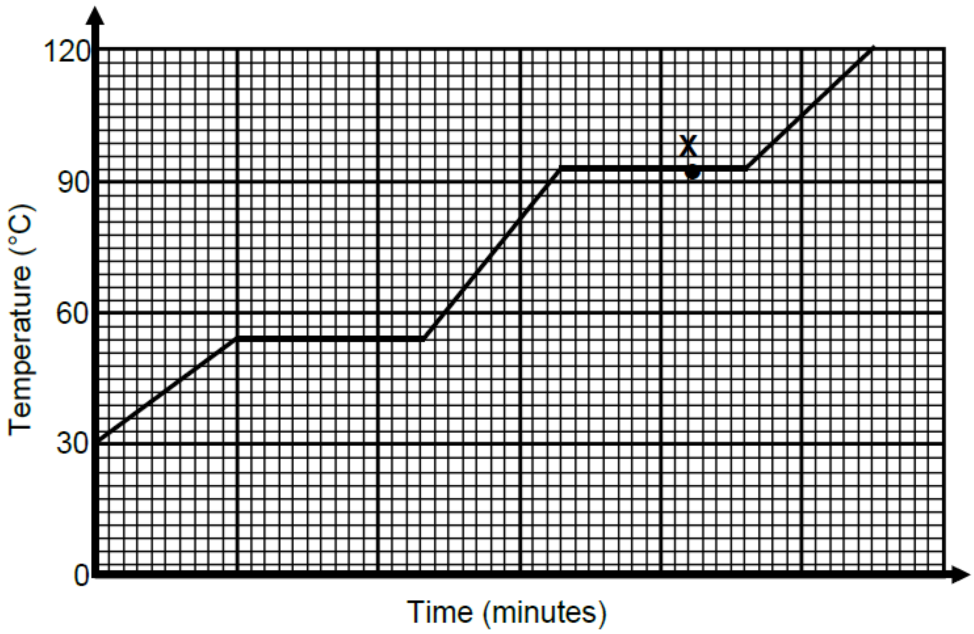


Figure 6.3: An example of visuals in the SG- category from the exemplar examination paper (DBE, 2012, p. 8)

The results in Table 6.2 reflect that the exemplar examination question paper is highly abstract in terms of the visuals it contains. Figure 6.4 illustrates the percentage of visuals coded in each category of the SG translation device.

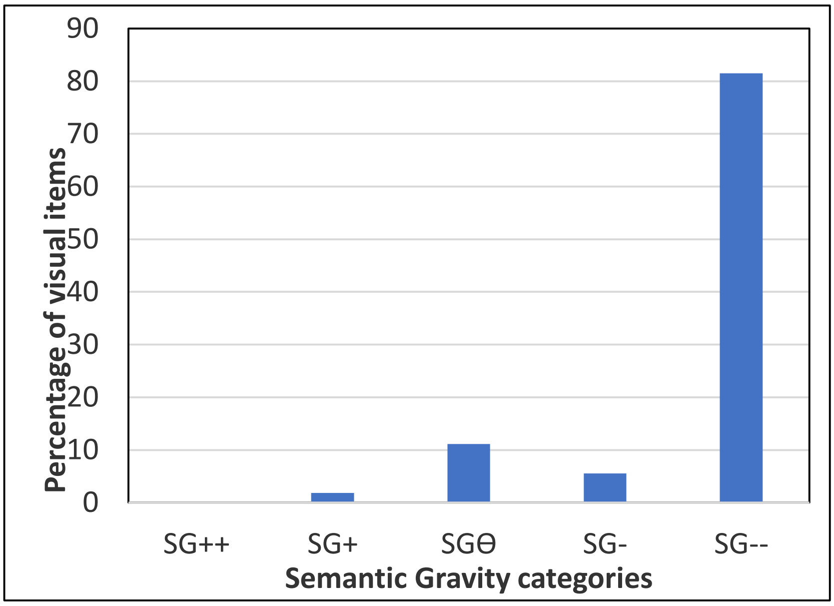


Figure 6.4: Percentage of visuals in each SG category for the Grade 10 chemistry exemplar examination paper

As evident from Figure 6.4, the distribution of visuals is more comparable between the SG+ and SG- range. The SG- - category covering symbolic 1-dimensional visual items such as chemical symbols, contains the vast majority of coded visuals. Additional examples include the chemical symbols for the two isotopes of Nitrogen "^{14}N'' and "^{15}N'' (DoE, 2012, p. 4). Other SG categories contained 11.1 % of the total visuals items (SGΘ), or lower. As an exemplar, the examination paper that was analysed in this study is representative of the demands of the assessed chemistry curriculum. Despite Grade 10 being the first year in which South African learners have a dedicated chemistry examination, South African Physical Sciences learners are expected to manage very high visual literacy demands when it comes to their end of year chemistry examination. This is discussed further in Section 6.4.1.

6.2.2 Visual abstraction in the chemistry sections of textbook

Prior to this study, there has been no characterisation of the abstraction of visuals in the current South African Grade 10 physical sciences textbooks. This section presents the results for the analysis of visual abstraction in the chemistry sections of one of these textbooks. The chemistry sections of the Physical Sciences textbook (Grayson et al., 2011) contained the highest number of pages out of the three documents analysed in this study – a total of 280 pages, of which the chemistry sections constituted 143 pages. A total of 1277 visual items appeared in the chemistry sections of the textbook, and were analysed in this study. This large number of visuals was unsurprising given the pervasive use of visuals in curriculum documents such as textbooks (LaDue et al., 2015). Table 6.3 shows the results from the SG analysis of visual items in the chemistry sections of the textbook which provided data for this study (Grayson et al., 2011).

Table 6.3: SG of visual items in chemistry sections of the textbook (Grayson et al., 2011)

Result	**SG+ +**	**SG+**	**SGϴ**	**SG-**	**SG- -**
Example from data	Photograph of Marie Curie (Figure 6.5)	Drawing showing the crystal structure of diamond (p. 97)	Submicroscopic representation of chemical reaction (Figure 6.8)	Graph showing density of elements in different groups (p. 37)	Chemical equations (Figure 6.6)
Total number across 143 pages analysed	43	33	19	30	1152
% of total of 1277 visuals	3.4	2.6	1.5	2.4	90.2

As mentioned in section 6.2.1, the Grade 10 chemistry exemplar examination question paper did not include any items in the SG+ + category and thus only contained visual items across four of the five SG categories. The chemistry sections of the textbook, however, included visual items across all five SG categories. An example of visuals in the SG+ + category present in the textbook, is the photograph of Marie Curie (Grayson et al., 2011, p. 21) shown in Figure 6.5.

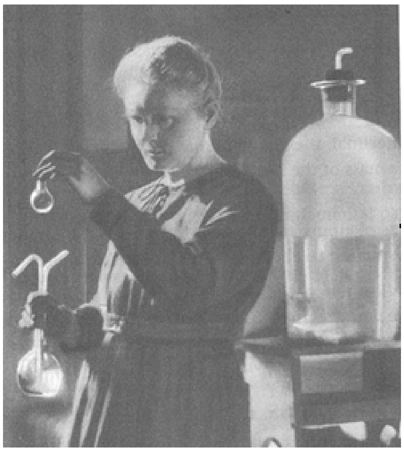


Figure 6.5: An example of visuals in the SG+ + category from the chemistry section of the textbook (Grayson et al., 2011, p. 21)

As was the case for the exemplar examination question paper, the predominant proportion of visuals in the chemistry sections of the textbook belong to the SG- - category which includes symbolic (1-D) visual items such as chemical symbols and equations. An example of the proliferation of visuals in the SG- - category, is the list of chemical equations shown in Figure 6.6, for which learners are asked to identify the reaction type.

(i) $Na_2SO_4(aq) + Ca(NO_3)_2(aq) \rightarrow 2NaNO_3(aq) + CaSO_4(s)$
(ii) $NaOH(aq) + HNO_3(aq) \rightarrow NaNO_3(aq) + H_2O(l)$
(iii) $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$
(iv) $MgCl_2(aq) + 2NaOH(aq) \rightarrow Mg(OH)_2(s) + 2NaCl(aq)$
(v) $HCl(aq) + KOH(aq) \rightarrow KCl(aq) + H_2O(l)$
(vi) $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$
(vii) $Na_2S(s) + 2HCl(aq) \rightarrow 2NaCl + H_2S(g)$
(viii) $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
(ix) $FeS(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + H_2S(g)$
(x) $AgNO_3(aq) + NaBr(aq) \rightarrow AgBr(s) + NaNO_3(aq)$

Figure 6.6: Excerpt from chemistry textbook illustrating the proliferation of visuals in the SG- - category (Grayson et al., 2011, p. 180)

Figures 6.5 and 6.6 illustrate the stark contrast between the strongest SG and weakest SG categories (lowest and highest levels of visual abstraction, respectively). Figure 6.7 illustrates the percentage of total visuals in each SG category of the visual abstraction translation device for the chemistry sections of the textbook (Grayson et al., 2011).

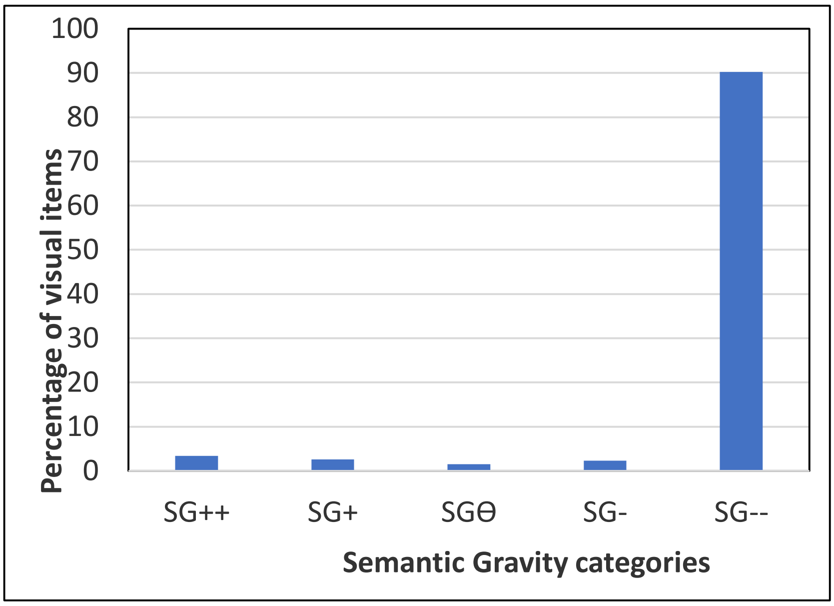


Figure 6.7: Percentage of visual items in each SG category for the Grade 10 chemistry sections of the textbook (Grayson et al., 2011)

As evident from Figure 6.7, the majority of visual items, 92.6%, are in the categories of weaker SG (SG- and SG- -) compared to only 6.0% being in the stronger SG categories (SG + + and SG+). In comparison to visuals in the SG- - category (symbolic 1-D visual representations), visual items in the SG+ + (iconic 2-D visual representations which closely resemble 3-D objects/phenomena at human scale), SG+ (iconic 2-D visual representations resembling something at larger/smaller scale than human experience), SGΘ (hybrid 2-D iconic-symbolic visuals) and SG- (symbolic visual items with spatial/2D meaning) categories occur much less frequently.

Dominance of visuals in the SG- - category (symbolic 1-D visual representations) indicates that visual items with no associated spatial meaning are emphasised in the textbook. This strong legitimation of symbolic 1-D visual representations coupled with weak legitimation of visual items that are a hybrid of 2-D iconic visuals and symbolic visuals is cause for concern, given that the hybrid nature of the latter enables it to play a bridging role between iconic and symbolic representations. For example, the hybrid iconic-symbolic visual from the textbook (Grayson et al., 2011, p. 113) shown in Figure 6.8, plays a valuable role in bridging the divide between:

1. Submicroscopic representation of the chemical reaction between diatomic hydrogen molecules and diatomic oxygen molecules, both in gaseous form (as evident from there being no container), to form water in liquid form (evident from the water molecules being in a container).
2. Symbolic representation of the chemical reaction between hydrogen gas and oxygen gas to form water via a chemical equation, that is balanced (evident from equal numbers of oxygen and hydrogen atoms on either side of the arrow). The arrow symbolises chemical rearrangement of the reactant molecules on the left of the arrow, to form the product on the right of the arrow.

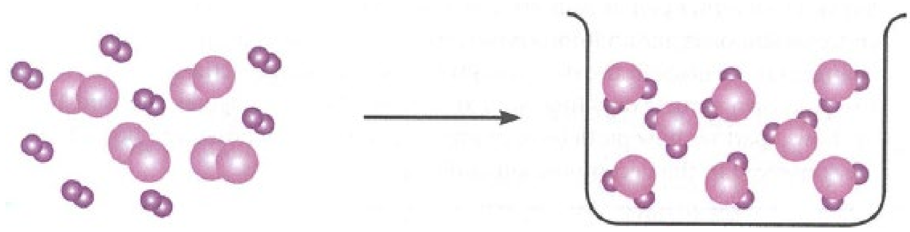


Figure 6.8: An example of a hybrid iconic-symbolic visual from the textbook (Grayson et al., 2011, p. 113)

Other SG categories contained 3.4% of the total visual items (SG+ +), or lower. There is thus a stark contrast between the percentage of visuals in the SG- - category, and the percentage of visuals in the other SG categories. Grade 10 Physical Sciences learners thus also face very high visual literacy demands when it comes to the chemistry components of the textbook, as will be discussed in Section 6.4.1.

6.3 Results for SG Analysis of Focal Textual Items

In this study, the LCT SG code was employed for characterising the abstraction of focal lexical items (nouns, abbreviations, and textual symbols) in all three of the curriculum documents. The results presented here are thus based on the six-tiered SG translation device for text shown in Table 4.6 (Chapter Four) and repeated in Table 6.4 for ease of reference.

Table 6.4: SG translation device for textual abstraction in chemistry curriculum documents

Semantic gravity code	**Data analysis code**	**Brief description**	**Example from exemplar exam question paper (DBE, 2012)**	**Example from chemistry sections of textbook (Grayson *et al.*, 2011)**	**Example from chemistry sections of NCS-CAPS: Physical Sciences (DBE, 2011)**
SG- - -	6	Abbreviated nouns, and textual symbols	N_A - the symbol for Avogadro's constant (p. 15); STP (p. 5) – for standard temperature and pressure	n (p. 195) – for number of moles	s (p. 46) - for solid
SG- -	5	Nominalisations	conductivity (p. 11)	precipitation (p. 172)	sublimation (p. 19)
SG-	4	Specialised/ technical categories and concepts	compound (p. 13)	isotope (p. 26)	anion (p. 17)
SG+	3	Specialised/ technical objects	chromatogram (p. 4)	sulphur (p. 103)	propette (p. 22)
SG+ +	2	Everyday categories and concepts	drinks (p. 4), diagram (p. 14),	example (p. 6), method (p. 176)	topic (p. 20), material (p. 15)
SG+ + +	1	Everyday objects	coffee (p. 4)	water (p. 4)	vinegar (p. 51)

6.3.1 Textual abstraction in chemistry exemplar examination question paper

The exemplar examination paper contained a total of 795 focal lexical items. Table 6.5 shows the results from the SG analysis of these lexical items.

Table 6.5: SG of focal lexical items in the exemplar examination paper (DoE, 2012)

Result	**SG+ + +**	**SG+ +**	**SG+**	**SG-**	**SG- -**	**SG- - -**
Example from data	'coffee' (p. 4)	'drinks' (p. 4), 'diagram' (p. 14)	'chromatogram' (p. 4)	'compound' (p. 13)	'conductivity' (p. 11)	'N_A' (p. 15), 'STP' (p. 5)
Total number across 15 pages	104	158	114	198	67	154
% of total (795 lexical items)	13.1	19.9	14.3	24.9	8.4	19.4

Unlike for the visual items, the focal lexical items in the Grade 10 chemistry exemplar examination paper covered all the SG categories of the related translation device. Also, the lexical items are more evenly distributed across the SG categories than was the case for visual items (see Figure 6.4). Figure 6.9 illustrates the percentage of the total number of focal lexical items in each SG category of the textual abstraction translation device.

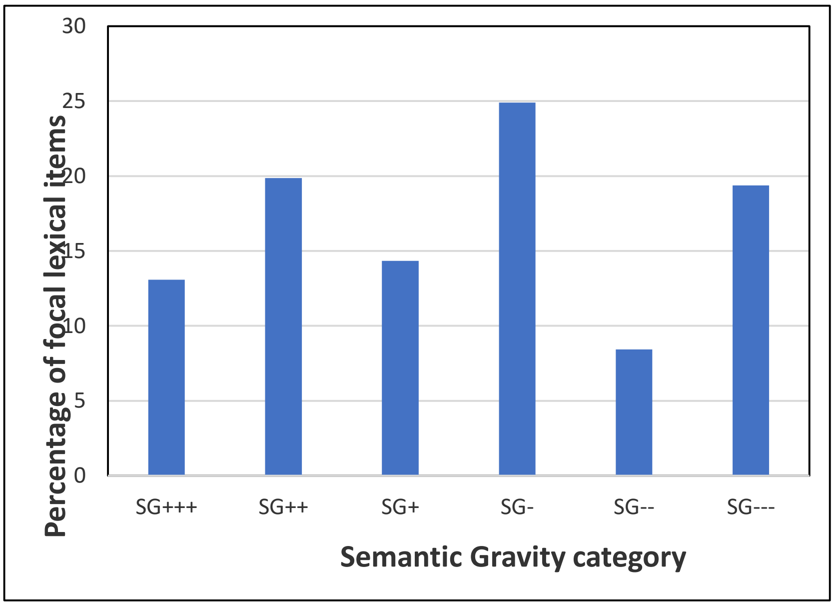


Figure 6.9: Percentage of focal lexical items from the Grade 10 chemistry exemplar examination paper, in each SG category

Overall, the more decontextualised lexical items were dominant for both everyday nouns and specialised nouns as evident from SG+ + having a higher value that SG+ + +, and SG- having a higher value that SG+. In simpler terms:

- There were more instances of everyday categories and concepts (SG+) such as ‘drinks’ (DoE, 2012, p. 4) and ‘diagram’ (DoE, 2012, p. 14), than of everyday objects (SG + +) such as coffee (DoE, 2012, p. 4).

- There were more instances of specialised/technical categories and concepts (SG-) such as ‘compound’ (DoE, 2012, p. 13) than of specialised/technical objects or substances (SG+), such as ‘chromatogram’ (DoE, 2012, p. 4).

This reveals that abstraction away from more specific, concrete items towards more conceptual and categorical ones for both the everyday and specialised visuals is more prominent than abstraction from the stronger SG categories (everyday lexical items, everyday categories and concepts, and specialised objects) to the weaker SG categories (specialised categories and concepts, nominalisations, and symbols). SG- - - had the third highest value, having a higher percentage of total lexical items than everyday objects (SG+ + +), specialised/technical objects (SG+ +), and nominalisations (SG- -). This indicates higher prominence of symbolic visuals compared to symbolic lexical items in the exemplar examination paper. Similarly, there were more instances of the SG- - - category which includes textual symbols such as for Avogadro's constant, 'N_A' (DoE, 2012, p. 13) and abbreviations such as for standard temperature and pressure, 'STP' (p. 5), than of nominalisations (SG- -) such as 'conductivity' (DoE, 2012, p. 11).

6.3.2 Textual abstraction in chemistry sections of NCS-CAPS: Physical Sciences

The chemistry component of the NCS-CAPS: Physical Sciences (DoE, 2011) contained a total of 1798 focal lexical items. Table 6.6. shows the results from the SG analysis of these lexical items.

Table 6.6: Results for the SG analysis of focal lexical items in the Grade 10 NCS-CAPS (DoE, 2011) chemistry sections

Result	SG+ + +	SG+ +	SG+	SG-	SG- -	SG- - -
Example from data	'vinegar' (p. 51)	'topic' (p. 20), 'material' (p. 15)	'propette' (p. 22)	'anion' (p. 17)	'sublimation' (p. 19)	'(s)' (p. 46)
Total number across 19 pages	216	321	200	694	309	58
% of total (1798 lexical items)	12.0	17.9	11.1	38.6	17.2	3.2

It is evident from Table 6.6 that the Grade 10 chemistry curriculum included focal lexical items across all six SG categories. In stark contrast to all the results presented thus far, the lowest proportion of items analysed were in the weakest SG category (SG- - -). The results are illustrated in Figure 6.10.

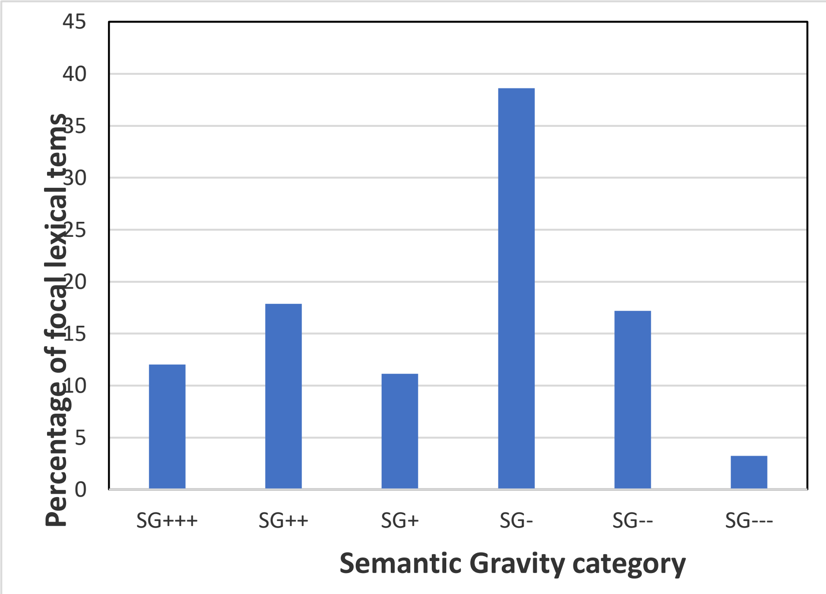


Figure 6.10: Percentage of focal lexical items from NCS-CAPS (DoE, 2011) Grade 10 chemistry sections, in each SG category

The results in Figure 6.10 indicate a higher percentage of more abstract lexical items (SG-, SG- - and SG- - -), a total of 59.0%, and a lower percentage of less abstract lexical items (SG+ + +, SG+ +, and SG+), a total of 41.0%. The proportions of focal lexical items in each SG category show a similar pattern to those of the exemplar examination paper in terms of more instances of abstraction within 'everyday' levels (SG+ + + and SG+ +) and within 'specialised/technical' levels (SG+ and SG-) of the translation device. However, while the exemplar examination question paper data had a higher proportion of symbolic text than nominalisations, the NCS-CAPS data included a higher proportion of nominalisations than symbolic text. This may be due to the fact that teachers, and not students, read the syllabus document, which lies in the official recontextualising field. Students only work directly with documents like exemplar examination papers and textbooks, which lie in the pedagogic recontextualising field. These results are discussed in section 6.4.2.

6.3.3 Textual abstraction in chemistry sections of textbook

The chemistry sections of the Grade 10 textbook spanned 143 pages, and included a total of 15 649 focal lexical items. Table 6.7 shows the results for the SG analysis of these lexical items.

Table 6.7: Results from the SG analysis of focal items from the textbook chemistry sections (Grayson et al., 2011)

Result	SG+ + +	SG+ +	SG+	SG-	SG- -	SG- - -
Example from data	‘balloons’ (p. 45)	‘medicine’ (p. 2)	‘heptane’ (p. 122)	‘hydrocarbon’ (p. 123)	‘neutralisation’ (p. 166)	‘$CaCl_2$’ (p. 197)
Total number across 143 pages	1848	3058	2271	6041	1392	1039
% of total (15649 lexical items)	11.8	19.5	14.5	38.6	8.9	6.6

These results indicate that the Grade 10 chemistry curriculum included relevant lexical items across all six SG categories. The lowest proportion of lexical items appeared for the SG- - - category as was the case for the NCS-CAPS, and the highest proportion of lexical items appeared for SG- as was the case for both the exemplar examination question paper and NCS-CAPS analysis. These results are illustrated in Figure 6.11.

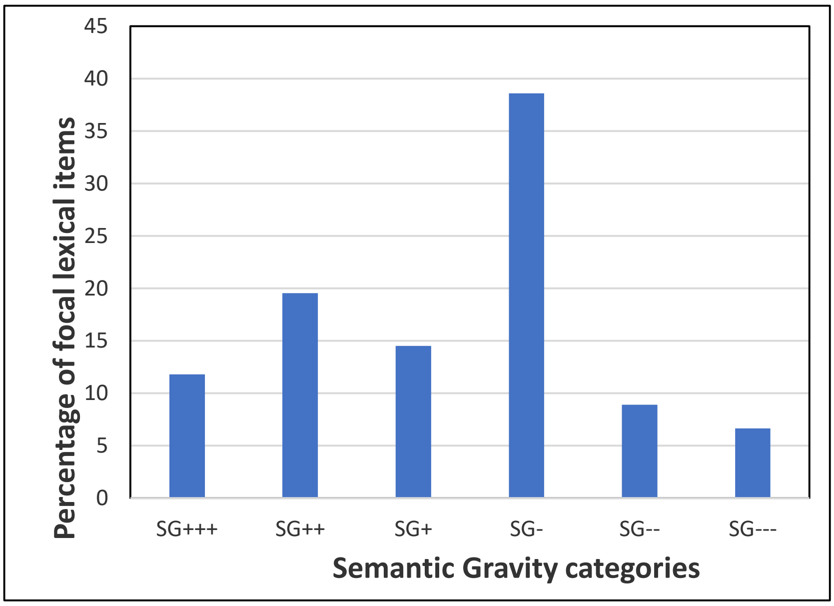


Figure 6.11: Percentage of focal lexical items in each SG category, for the Grade 10 chemistry sections of the textbook (Grayson et al., 2011)

It is evident that lexical items in the SG- category were dominant. As is the case for the Grade 10 chemistry sections of the NCS-CAPS and the Grade 10 exemplar examination question paper, this category plays a significant role in increasing the overall textual abstraction. The results are discussed in section 6.4.2.

6.4 Discussion of Results

The results presented in section 6.2. for the visual literacy demands in terms of abstraction afforded by the visual SG translation device in Table 6.1, are discussed in section 6.4.1. This discussion includes implications of the findings related to research question one. Thereafter, the results presented in section 6.3 for the textual literacy demands in terms of abstraction afforded by the textual SG translation device in Table 6.4, are discussed in section 6.4.2. Included in this discussion are the implications of the findings related to research question two.

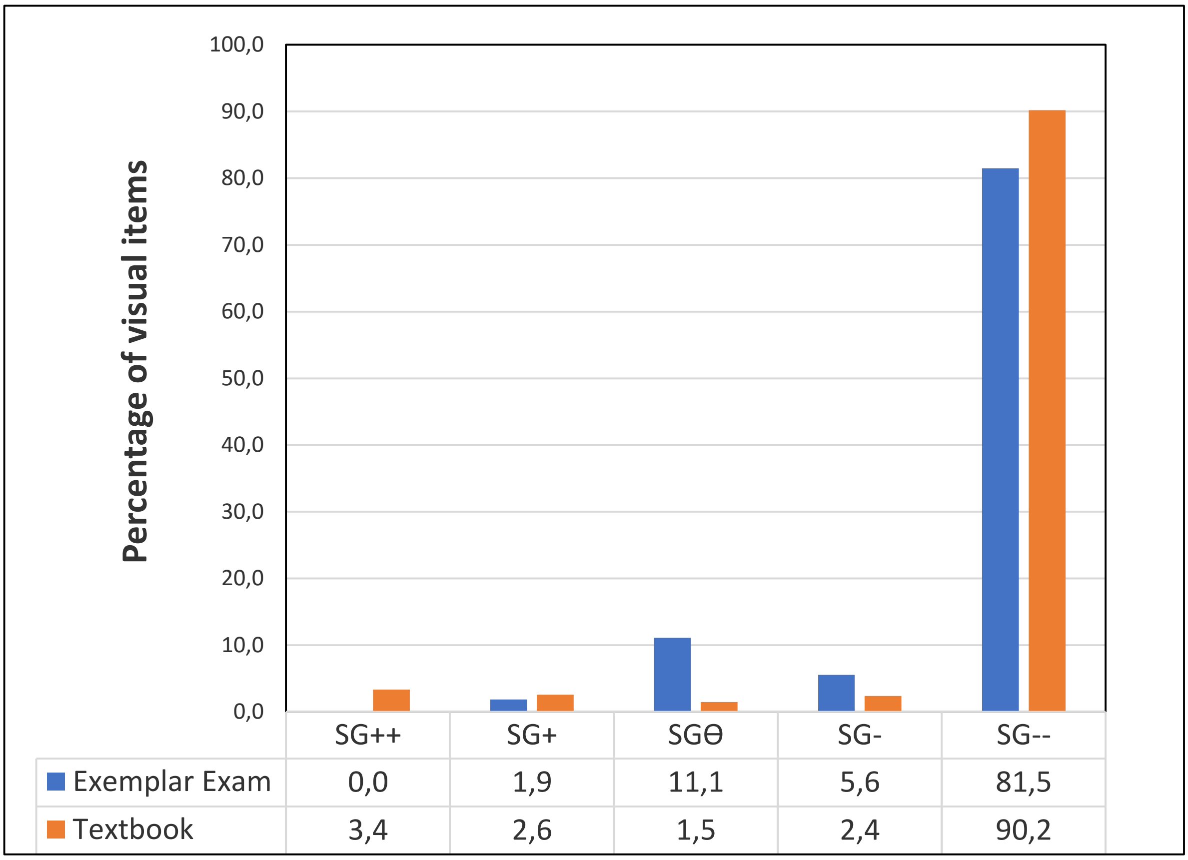
6.4.1 Nature of alignment of visual literacy demands between Grade 10 chemistry exemplar examination paper and textbook

The nature of alignment of visual literacy demands between the exemplar examination question paper and chemistry sections of the textbook from the perspective of SG is evident from the differences in percentages of visual items across the five SG categories. These are shown in Table 6.8.

Table 6.8: Differences in percentages of visual items across the SG categories for chemistry exemplar examination paper and textbook chemistry sections

Curriculum Document	**% of visual items**				
	SG+ +	**SG+**	**SGϴ**	**SG-**	**SG- -**
Grade 10 Chemistry textbook sections (total of 54 visual items)	3.4	2.6	1.5	2.4	90.2
Grade 10 chemistry exemplar examination paper (total of 1277 visual items)	0	1.9	11.1	5.6	81.5
Difference	**3.4**	**0.7**	**9.6**	**3.2**	**8.7**

The only two categories for which the exemplar examination paper has a higher percentage of visual items compared with the textbook, are SGϴ (hybrid iconic-symbolic visuals) and SG- (symbolic visuals with some 2-D meaning). All the differences in percentages of visual items across the SG categories are below 10% with three of the five categories having differences below 5%. This suggests strong overall alignment between the two curriculum documents in terms of visual abstraction and thus visual literacy demands, as illustrated by Figure 6.10. The dominance of visual items on the lower end of the SG continuum is more strongly evident than differences between the SG values for the two documents. The exception to the otherwise high degree of alignment, is that the exemplar examination paper did not include any visuals belonging to the SG+ + category such as photographs, comic strips, or naturalistic drawings and thus entailed a lower visual SG range.



	SG++	SG+	SGΘ	SG-	SG--
Exemplar Exam	0,0	1,9	11,1	5,6	81,5
Textbook	3,4	2,6	1,5	2,4	90,2

Figure 6.12: A comparison of percentages of visual items in each SG category, for Grade 10 chemistry exemplar examination paper and textbook sections

De Jong and Van Driel (2004) reminded us that students experience difficulty when it comes to understanding symbolic representations and Liu (2009) elaborated that because chemical symbolism is decontextualised from learners' sensory experience, it might be the most challenging category of representation in chemistry education. The highly decontextualised nature of chemical symbolism was reflected in the visual translation device employed in the current study including visuals such as chemical symbols, formulae, and equations at the lowest end of the SG continuum. Visual items at the highest level of abstraction – the symbolic, were the most common type of visual in both the Grade 10 chemistry textbook sections, as well as exemplar examination question paper. South African Grade 10 chemistry learners thus face very high visual literacy demands when it comes to the Grade 10 sections of the textbook as well as summative assessments, if summative examination papers follow the exemplar examination paper closely in this regard.

In terms of Johnstone's (1982) chemistry triplet as representational systems/levels for describing and explaining chemical phenomena (Johnstone, 1993; Talanquer, 2011) discussed in Chapter Two (see section 2.8.2), the lower SGΘ value compared to the SG + + and SG + values, suggests that the textbook visuals pay more attention to the movement between the macroscopic and submicroscopic levels than to the movement between the submicroscopic and symbolic levels. This is not necessarily problematic given that Grade 10 is the introductory year to Physical Sciences in South African schools. Furthermore, focusing along one side of the chemistry triplet triangle would be more manageable to Grade 10 learners as chemistry novices, than their working across all three levels at once (as discussed in section 2.8.2 of Chapter Two).

However, it is problematic given the prominence of the symbolic level (SG- -) and more attention being afforded to the SGΘ in the Grade 10 chemistry exemplar examination question paper. In other words, it is problematic that the textbook does not focus more on bridging the submicroscopic and symbolic levels considering the strong emphasis which the exemplar examination paper places on the hybrid and symbolic levels. These higher visual literacy demands at the hybrid and symbolic levels may extend to the intended and assessed levels of curriculum, given that the exemplar examination question paper (as an aspect of illustrated curriculum in the model by Nakedi et al. (2012) influences the foci of formal summative assessments (referred to as examined curriculum in the same model) (Nakedi et al., 2012). The findings from the current study, regarding the very high proportion of symbolic visual items in the exemplar examination paper and textbook resonate with Gabel's statement (1999, p. 549) that "The primary barrier to understanding chemistry, however, is not the existence of the three levels of representing matter. It is that chemistry instruction occurs predominantly on the most abstract level, the symbolic level".

In addition, similar results were reported by Upahi and Ramnarain (2019) for their analysis of Nigerian school chemistry textbooks. The chemistry textbooks employed in Nigerian schools are not grade specific, but used across the senior school phase (equivalent to Grades 10, 11, and 12 in South Africa). The chemistry textbooks analysed by Upahi and Ramnarain (2019) were approved by the Federal Ministry of Education, in the same way that the textbook explored in the current thesis was approved by the South African DoE. One focus of their study was the levels of chemistry as outlined by Johnstone (1991).

While their study did not focus on abstraction, it did categorise visuals according to the chemistry levels, and also acknowledged combinations such as hybrid representations. They reported that the vast majority of representations in the chemistry textbooks (87.9%) were in the category of symbolic representations – similar to the current study result of 92.56% of total visuals belonging to the SG- and SG- - categories. Also noteworthy from their results, was that only 0.2% of the representations were hybrid representations (Upahi & Ramnarain, 2019), compared to 1.5% in the study reported on in this thesis. Upahi and Ramnarain (2019) shared the concerns raised from the results of the analysis of textbook visuals in the current thesis, regarding the dominance of the symbolic and relatively few instances of hybrid representations.

Apart from the results having cognitive implications, there are also affective implications. Treagust et al. (2000) alerted us to the fact that such things as relevance and applicability of chemistry to everyday life could influence learners' attitudes towards learning chemistry. This relates to the inclusion of visual items at higher levels of SG (SG + + and SG +). Despite the value of this, many chemistry courses failed to make such relevance/applicability to everyday life clear necessitating that from the very beginning of many chemistry courses, learners have blind faith regarding the regarding the relevance and applicability of knowledge when learning such things as the chemical symbols and balancing of chemical equations before the (Treagust et al., 2000). Due to scientific nomenclature (such as the chemical symbols involved at the SG- - level) being akin to a foreign language to science students, learners may experience frustration in making sense of the symbolic categories of chemistry visuals (SG- and SG- -). The very high proportion of visuals at the lower end of the SG continuum for the exemplar examination and textbook sections explored in the current study, does not bode well for South African Grade 10 Physical Sciences learners' attitudes towards learning chemistry.

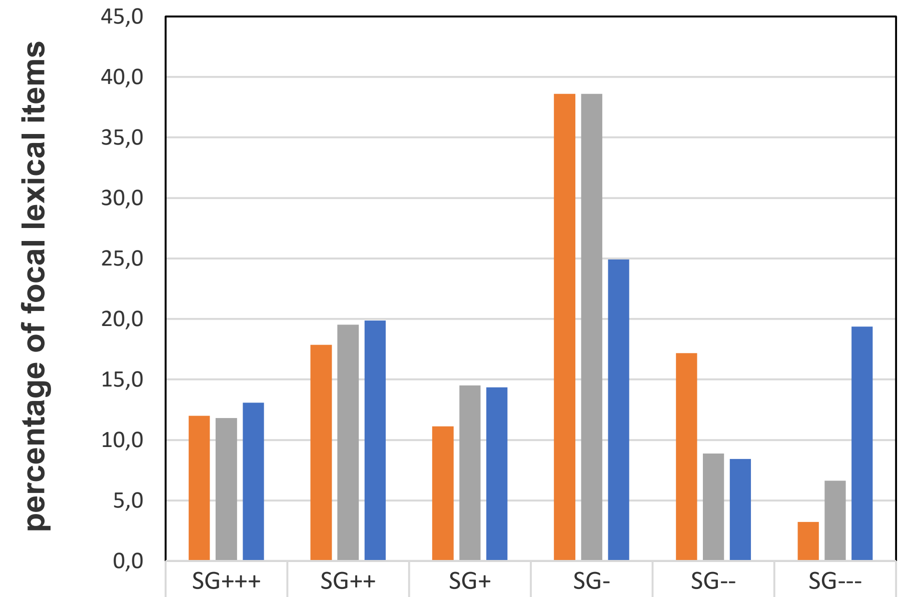
An area of weak alignment between the chemistry exemplar examination paper and textbook sections is that the examination paper does not include macro level representations (SG+ +) while the textbook does include some. Mbajiorgu and Reid argued that strong experience in macro level chemistry is needed before the submicroscopic and symbolic levels are introduced (2006). They explain that a strong foundation can be built at the macro level by relating content to students' previous knowledge and experience. This alludes to decreasing conceptual abstraction via expanding on previous learning and forging links to real-life contexts. However, this may be less problematic given the pedagogic focus of the textbook and the assessment focus of the exemplar examination paper. The disparity between the stronger and weaker levels of SG in both the chemistry exemplar examination paper and chemistry textbook sections does suggest a bias in favour of preparedness towards further chemistry studies over real-world applications which would have involved visuals at the higher end of the SG continuum.

This affirms the nature of the current curriculum reflecting a “science for government” rather than “science for life” perspective as argued by Koopman (2017, p. 25). It also supports Hofstein and Yagers’ (1982) argument from decades back, that contemporary science privileges the advancement of knowledge over the improvement of society. The need for preparing the minority – future scientists for the science workforce (canonical science) currently has stronger legitimacy than the needs of the majority – a scientifically literate society (humanistic science) (Umalusi, 2015). This disadvantages South African Grade 10 Physical Sciences learners who do not intend on pursuing science study and related careers.

Pun (2019) pointed out widespread consensus that science students who succeed in mastering scientific language are more successful academically due to the power code of fluent scientific English affording students a ‘privileged’ status not only at school but also in society more generally. Given the major role of textbooks being the provision of accessible linguistic resources for use by learners in developing scientific literacy (Pun, 2019), it is problematic when chemistry textbooks do not adequately span the levels of the chemistry triplet. A possible consequence is that learners with access to alternate resources (including devices such as laptops and internet access for online chemistry education videos and simulations) that support them bridging the divide between the submicroscopic and symbolic levels in ways that the textbook does not, may also be advantaged compared to their counterparts without such access to alternate resources to the textbook.

6.4.2 Nature of alignment of textual literacy demands of Grade 10 chemistry curriculum, exemplar exam paper and textbook

Knowledge is realised largely through language, and so it is problematic that language awareness is a commonly neglected area when it comes to pedagogy (Schleppegrell, 2019). This may be due to the fact that many science teachers do not believe it is their responsibility to teach the language of science (Pun, 2019) and place greater emphasis on curriculum texts which directly support student learning such as textbooks and exemplar examination papers. The nature of alignment of textual literacy demands between the Grade 10 chemistry syllabus, sections of the Grade 10 chemistry textbook, and chemistry exemplar examination question paper from the perspective of SG is evident from the differences in percentages of focal textual items across the six SG categories. A comparison of the distributions is illustrated in Figure 6.13.



	SG+++	SG++	SG+	SG-	SG--	SG---
CAPS Grade 10 chemistry sections	12,0	17,9	11,1	38,6	17,2	3,2
Chemistry sections of Grade 10 textbook	11,8	19,5	14,5	38,6	8,9	6,6
Grade 10 Chemistry Exemplar Examination	13,1	19,9	14,3	24,9	8,4	19,4

Figure 6.13: A comparison of the SG results of focal lexical items across the three curriculum documents

The differences between each of the SG categories for the three documents is shown in Table 6.9, in order to highlight areas of stronger and weaker alignment.

Table 6.9: Differences in percentages of focal lexical items for the SG categories, across the curriculum documents

Curriculum Document	% of focal lexical items					
	SG+ + +	SG+ +	SG+	SG-	SG- -	SG- - -
Grade 10 chemistry sections of NCS-CAPS (n=1798)	12.0	17.9	11.1	38.6	17.2	3.2
Grade 10 chemistry textbook sections (n=15649)	11.8	19.5	14.5	38.6	8.9	6.6
Difference between syllabus and textbook	**0.2**	**1.6**	**3.4**	**0**	**8.3**	**3.4**
Grade 10 chemistry sections of NCS-CAPS (n=1798)	12.0	17.9	11.1	38.6	17.2	3.2
Grade 10 chemistry exemplar examination paper (n=795)	13.1	19.9	14.3	24.9	8.4	19.4
Difference between syllabus and exemplar examination paper	**1.1**	**2.0**	**3.2**	**13.7**	**8.8**	**16.2**
Grade 10 chemistry textbook sections (n=15649)	11.8	19.5	14.5	38.6	8.9	6.6
Grade 10 chemistry exemplar examination paper (n=795)	13.1	19.9	14.3	24.9	8.4	19.4
Difference between textbook and exemplar examination paper	**1.3**	**0.4**	**0.2**	**13.7**	**0.5**	**12.8**

The comparison in Figure 6.13 and Table 6.9 reveals differences between the three curriculum documents in terms of the proportions of focal lexical items in the SG+ + +, SG+ + and SG+ categories of less than 5%. Overall, there is thus a higher level of alignment between the three curriculum documents in terms of textual curriculum literacy demands at the lower levels of abstraction. This means that the curriculum literacy demands between the three documents are more strongly aligned at the lower levels of abstraction – for everyday items, everyday categories and concepts, and for specialised or technical items. In terms of Bernstein's pedagogic device (discussed in section 2.4.6 of Chapter Two), the strongest alignment between the official recontextualising field (syllabus) and pedagogic recontextualising field (textbook and exemplar examination) components of this study, thus occur at the stronger end of the SG continuum (lower abstraction).

Differences greater than 5% occur between the proportions of focal lexical items in the SG-, SG- - and SG- - - categories, indicating that greater misalignment is evident between the three curriculum documents in terms of textual curriculum literacy demands at the higher levels of abstraction. The NCS-CAPS and textbook chemistry sections had exactly the same proportion of lexical items for the SG- category (38.6%), having 13.7% more lexical items related to specialised/technical categories and concepts than the exemplar examination paper did. The textbook and exemplar examination paper had almost the same proportions of nominalisations (SG- -), with the NCS-CAPS having between 8 and 9% more nominalisations compared to the data from the other two documents. The SG- - - category (abbreviated nouns and textual symbols) was most prevalent in the exemplar exam and occurred the least in the NCS-CAPS data (a difference of 16.2%) with the difference between the exemplar exam and the textbook data being 12.8%.

In terms of Bernstein's pedagogic device, the weakest alignment between the official recontextualising field (syllabus) and pedagogic recontextualising fields (textbook and exemplar examination) components in this thesis, occur on the lower side of the SG continuum (higher abstraction). The difference in alignment of textual literacy demands at the lower and higher levels of abstraction suggests that recontextualisation rules between the official and pedagogic recontextualisation fields of the pedagogic device work in different ways, at lower and higher levels of textual abstraction. Further research is needed to gauge the consistency of this finding across similar and different contexts, and if consistent then to explore the nature of the interaction.

Sadoski et al. (2000, p. 93) highlighted that the use of "more concrete language and content should have positive effects in making sentences and paragraphs of texts more comprehensible, interesting and memorable". Additionally, Sadoski (2001, p. 275) argued that "general principles need to be fleshed out with clearly connected concrete examples".

This emphasis on concrete language and examples for improved learner comprehension, interest, and acquisition of general principles relates to the inclusion of lexical items of stronger SG and portrays the SG+ + +, SG+ + and SG+ results in Figure 6.5 in a favourable light. However, the content of science texts also presupposes the use of such things as more abstract nouns (Mikk & Kukemelk, 2010), the results of which will now be considered.

The NCS-CAPS data and textbook data have higher values than the exemplar examination paper data for the SG- category indicating that specialised or technical items are less prominent in the exemplar examination paper. In contrast to this, the exemplar examination question paper data has a much higher proportion of symbolic text and abbreviations (SG- - -) compared to the NCS-CAPS data and textbook data indicating that it makes higher textual curriculum literacy demands at the most abstract level. There is a very long history of abbreviations being used in chemical literature, evident in their proliferation being pointed out decades back by Lide (1980). While their use has advantages for communication among scientists working in the same field, the fact that they can contribute to undesirable education difficulties is also recognised (Lide, 1980).

Mikk and Kukemelk (2010) reported on two studies of Estonian school students' ratings of interest in biology and physics texts. Symbolic text and abbreviations were found to result in low student interest in the texts (Mikk & Kukemelk, 2010), and from this perspective the lower proportions of lexical items in the SG- - - category in the NCS-CAPS and textbook data is favourable for learner interest in chemistry. However, the stronger SG- - - value for the exemplar examination question paper compared to the weaker SG- - - values for the NCS-CAPS data and textbook data, suggests that the latter may not be adequately orientating or preparing learners for the higher textual curriculum literacy demands of assessed curriculum. It appears that the exemplar examination reflects the gatekeeper role of assessment to further levels of study with the highest degree of semiotic abstraction (the power code of symbolic language) being the key, while the syllabus and textbook reflect a weaker focus on semiotic abstraction and stronger focus more practical aspects of chemistry (involving specialised or technical resources).

In terms of nominalisations (SG- -), the Grade 10 chemistry exemplar examination question paper and chemistry sections of the Grade 10 textbook are much more strongly aligned with each other than with the Grade 10 chemistry sections of NCS-CAPS, which demonstrates the highest frequency of occurrence for focal lexical items at this level. Fang (2006) included abstract nouns and technical vocabulary (such as lexical items included in the category SG- of the current study) and grammatical metaphor (such as lexical items included in category SG- - in the current study) among the language features of senior secondary science classrooms that were problematic for science students' reading comprehension. From this perspective, the exemplar examination paper and textbook are likely easier for learners to understand, but are not preparing them for facing the broader challenges of chemistry discourse in the way that the syllabus emphasises.

6.5 Concluding Comments

From a linguistic stance, academic disciplines and the manner in which they are reflected in school curricula consist of textual formations that allow, amongst other things, the building of knowledge (Freebody et al., 2013). Abstraction, for example, is a characteristic feature of science discourse (Fang, 2005) due to it serving the development of scientific knowledge through affordances such as the creation of relationships and categories (Schleppegrell, 2019). However, literacy demands associated with the characteristic expression of particular curriculum domains (such as chemistry), challenge the work of both teachers and learners (Freebody et al., 2013). This chapter presented the results and related discussion pertaining to a SG perspective on the alignment of chemistry curriculum.

It was found that there is an overall high degree of alignment between visual literacy demands of the Grade 10 chemistry exemplar examination question paper (DoE, 2012) and chemistry sections of the Grade 10 textbook (Grayson et al. 2011). This is evident from both data sources privileging highly abstract symbolic visuals (SG- - -) very strongly in terms of frequency of occurrence, compared to more contextualised visual items such as photographs and naturalistic drawings (SG+ + +). The positive consequence is that the assessed curriculum (assuming that actual summative examination question papers closely resemble the exemplar examination question paper) largely mirrors the very high visual literacy demands of the textbook.

An aspect of weaker alignment is that the exemplar examination covered a smaller SG range in comparison to the textbook, since it did not have any visuals coded in the SG+ + + category. Furthermore, the greater focus afforded by the textbook visuals to the interface of the macroscopic and submicroscopic levels than to the submicroscopic-symbolic interface is problematic considering the high value attached to hybrid and symbolic representations in the exemplar examination question paper. In addition to this, there are negative consequences in terms of symbolic representations being associated with negative learner attitudes towards learning chemistry.

For textual literacy demands, a higher degree of alignment between the exemplar examination, syllabus, and textbook was evident at the three stronger SG levels. The occurrence of focal lexical items at the stronger SG end of the continuum is aligned to the use of concrete language and examples for improved learner comprehension, interest, and acquisition of general principles. For the three weaker SG categories, the syllabus and textbook had the highest occurrence of specialised/technical categories and concepts (SG), the syllabus had the greatest proportion of nominalisations (SG- -), and the exemplar examination contained the highest percentage of symbolic text and abbreviations (SG- - -).

The higher proportion of symbolic text and abbreviations in the exemplar examination paper compared to the textbook and syllabus, suggests that the latter two documents do not adequately prepare and/or orientate learners to the textual literacy demands at the highest (symbolic) level of abstraction. Stronger alignment of textual chemistry curriculum literacy demands was evident between the official and pedagogic recontextualising fields at higher degrees of SG (lower abstraction) than at lower degrees of SG (higher abstraction) suggesting that the recontextualisation rules operate differently, at lower and higher levels of textual abstraction. One reason for areas of misalignment that emerge from the analysis, relates to the ORF and PRF consisting of stakeholders with different interests. Su (2012) points out that there are varied perceptions of curriculum by different stakeholders having their own agendas. As highlighted in section 3.6.2, the fields of the pedagogic device constitute an arena of struggle (Bernstein, 1990). The results from this study thus provide empirical evidence that visual and textual curriculum literacy demands is one avenue through which the struggle for power by stakeholders holding different interests and agendas, contributes to curriculum misalignment.

CHAPTER SEVEN: CONCLUSION

7.1 Introduction

Chemistry is recognised as a very important discipline in the overall schooling system (Ejidike & Oyelana, 2015) and so it is problematic that the abstract nature of chemistry poses challenges to students (Ware, 2001). In South Africa, this is evident in poor overall results for Physical Sciences, the subject which covers physics and chemistry, at the school exit level (as discussed in section 1.2.2 of Chapter One). The abstract nature of chemistry content is interrelated with the semiotic resources such as words and visuals that are the basis of literacy practices in chemistry (see section 1.1 of Chapter One). This makes sense considering that "a critical engagement with science texts is fundamental to the social practices that make science possible" (Sorvik et al., 2014, p. 40). The discipline-specific use of semiotic modes necessitates awareness of curriculum-specific literacies, which Wyatt-Smith and Cumming (1999) pointed out as contributing to the curriculum demands imposed on students. Chemistry curriculum literacy demands from the perspective of abstraction of visuals and text in chemistry curriculum documents are related to the fundamental sense of scientific literacy – the ability to read science texts, which is a pre-requisite for the derived sense of scientific literacy – knowledgeability about science (Norris & Phillips, 2003).

Various authors concurred that "a critical engagement with science texts is fundamental to the social practices that make science possible" (Sorvik et al., 2014, p. 40). However, while there is clear justification for promoting literacy practices in classrooms which address science communication and representation, the reading and writing involved in school science has received less attention compared to the focus on practical science activities (Sorvik et al., 2014). The result is that the central role of written language has been neglected (Wellington & Osborne, 2001). Subsequently, researchers have proposed the explicit integration of literacy into science education as evident from the recommendation by Hand et al. (2003) to identify the implicit literacy practices of academic disciplines. This also contributes to the addressing of knowledge blindness in education as argued for by theorists such as Maton (2014). Furthermore, a systematic analysis of curriculum literacy demand, and the alignment of such demand across different aspects of the pedagogic device in the key

STEM field of chemistry, was warranted for the purpose of enabling particular forms (such as visual and textual semiotic modes) of epistemological access needed for empowering chemistry students to progress in this field.

This thesis acknowledges the role of different curriculum documents – syllabi, textbooks, and exemplar examination papers, in the knowledge recontextualisation field of Bernstein's pedagogic device as will now be distilled from Chapter Five. Tron (2017) reminded us that, in a narrower sense, syllabus refers to a specification of content to be taught, and the order in which it is to be taught. Afros and Schryer (2009, p. 225) provided more detail on the broader role of syllabus by explaining that it "offers instructors a constellation of rhetorical strategies to describe the course, its goals and objectives, its structure and its correlation with other courses within the program, classroom and institutional policies as well as general logistical and procedural information".

Hyland (1999 in Parodi, 2010, p. 212) defined a textbook as "a repository of knowledge that opens paths to beginning learners in the discipline and allows them to construct preliminary access to this specialised knowledge". Parodi (2010, p. 195) expanded on their role as "fundamental means of constructing specialised knowledge in a variety of disciplines". Of particular relevance to this thesis, Paxton (2007) framed their role as providing an exemplar in terms of disciplinary literacy practices and Cheung (2000) argued that their main role is as a gatekeeper to chemical literacy and thus to the knowledge area. The role of exemplar examinations is to provide learners with opportunities to learn how to navigate tests successfully (Fuhrken & Roser, 2009). Fuhrken and Roser (2009) elaborated by adding that its exemplifies distinguishing features and traits of assessment in order for learners to notice its particularities, and identify patterns and constants.

These documents frame the chemistry discourse experienced in the knowledge reproduction field – for example by Physical Sciences learners at South African schools – and inform classroom pedagogy. Despite this, the alignment of visual and textual chemistry curriculum literacy demands through the lens of abstraction was unexplored prior to this thesis, providing strong support for the current study.

7.2 Summary of Findings

At the core of this study, were the following research questions:

What is the nature of the alignment of school chemistry literacy demands between associated curriculum documents, in terms of:

1. visual abstraction? (answered via a SG translation device for visual abstraction)

2. textual abstraction? (answered via a SG translation device for textual abstraction)

This section provides a summary of the findings related to the above research questions. The first research question is addressed in section 7.2.1 and the second research question is addressed in section 7.2.2. The implications of the findings are summarised in section 7.3.

7.2.1 Nature of alignment of the visual curriculum literacy demands between the exemplar examination paper and chemistry sections of the textbook

The results reveal strong overall alignment of visual literacy demands between the Grade 10 chemistry exemplar examination paper (DoE, 2012) and chemistry sections of the textbook (Grayson et al., 2011) in terms of abstraction. The strong emphasis on the weakest level of SG in the exemplar examination question paper largely mirrors the emphasis that the textbook places on the most abstract visuals – symbolic 1-D visuals such as chemical symbols, and chemical and mathematical equations. These curriculum documents lie in the pedagogic recontextualisation field of Bernstein's pedagogic device, and both were found to impose very high visual literacy demands on South African Physical Sciences learners in terms of abstraction. However, it was found that the textbook covers a broader semantic range since it included visuals across all five levels of visual SG while the exemplar exam did not include any visuals at the strongest level of SG (SG+ +) - iconic (2-D) visuals which closely resemble 3-D objects or phenomena at human scale, such as photographs.

For both documents, the most abstract types of visuals (symbolic visuals) are favoured over the other more contextualised types. The very low SG of the vast majority of visuals in the exemplar examination paper is surprising when one considers that Grade 10 is the first time that South African Physical Sciences students (around 16 years of age) write a dedicated chemistry examination. In terms of the earlier-mentioned role of exemplar examinations providing learners with opportunities to learn how to navigate tests successfully and exemplifying distinguishing features and traits of assessment (Fuhrken & Roser, 2009), the very low SG of most visuals in the exemplar examination paper suggests that South African Grade 10 Physical Sciences learners can expect very high visual literacy demands in the summative chemistry examinations.

Similarly, the emphasis on visuals at higher levels of abstraction at the expense of the number of visuals at lower levels of abstraction in the textbook is less surprising given the role of the textbook in:

- providing an exemplar of disciplinary literacy practices as suggested by Paxton (2007),
- being a gatekeeper to chemical literacy as suggested by Cheung (2000), and
- facilitating construction of specialised disciplinary knowledge as suggested by Parodi (2010).

However, the results are surprising given that textbooks usually open pathways for "beginning" learners for constructing "preliminary" access to specialised knowledge (Hyland, 1999 in Parodi, 2010, p. 212). This is significant in the South Africa context, where the same curriculum, textbook, and assessment apply to both Physical Sciences students who intend to study science at tertiary level as well as to those who do not.

The high degree of alignment of the two curriculum documents in terms of high visual literacy demands is problematic in terms of Johnstone's chemistry triplet (Johnstone, 1982; Johnstone, 1993; Talanquer, 2011). Strong alignment may be more productive were it related to a more even distribution of visual items across SG levels given the affordances of visuals at different levels of abstraction. The focus afforded by the textbook visuals to the interface of the macroscopic and submicroscopic representation levels is useful for illustrating the links between chemistry and everyday or real-life applications, but the relatively low attention it gives to the submicroscopic-symbolic interface is problematic considering the higher value attached to hybrid and symbolic representations in the exemplar examination question paper.

Similar results and concerns pertaining to greater focus on the symbolic representation level than on representations that were hybrids of two levels, were recently reported by Upahi and Ramnarain (2019) for Nigerian school chemistry textbooks. The relatively low proportion of visuals at the higher end of the SG continuum may have negative affective implications, due to learners needing blind faith in relevance and applicability to everyday life when learning such things as chemical symbols and balancing of chemical equations (Treagust et al., 2000). This may contribute to learners developing negative dispositions towards chemistry.

The general disparity between the proportions of visuals of stronger and weaker SG in both the chemistry exemplar examination paper and chemistry textbook sections points to the nature of the textbook and exemplar examination reflecting a "science for government" rather than "science for life" perspective as outlined by Koopman (2017, p. 25) and discussed in Chapter Two (see section 2.3). The focus on symbolic discourse required for epistemological access to higher levels of chemistry study (the needs of the few) at the cost of relevance or application of chemistry knowledge to everyday life (the needs of the many), and the paucity of visuals bridging the submicroscopic and symbolic levels of chemistry may result in learners already experiencing socioeconomic disadvantage, being further disadvantaged when it comes to their chemistry education. This is because learners with little or no access to alternate resources which alleviate the shortcomings of the textbook visuals may be doomed to alienation by the abstract way in which the textbook visuals depict chemistry, and may not learn to integrate the macroscopic, submicroscopic, and symbolic levels of chemistry adequately for accessing chemistry knowledge.

7.2.2 Nature of alignment of textual curriculum literacy demands between the three curriculum documents

The strongest alignment of textual literacy demands between the data from the official recontextualising field (syllabus) and pedagogic recontextualising fields (textbook and exemplar examination), occurs at the stronger end of the SG continuum (lower abstraction). This is apparent from the differences in the proportions of focal lexical items in the SG+ + +, SG+ +, and SG+ categories between the three curriculum documents all being less than 5% (as shown in Table 6.9 in Chapter Six). The alignment of textual literacy demands between the syllabus, textbook, and exemplar exam data was comparable for everyday items (SG+ + +), everyday categories and concepts (SG+ +), and for specialised/technical items (SG+) with each of these categories containing between 10 and 20% of all the focal lexical items for each of the curriculum documents.

The weakest alignment between the official recontextualising field (syllabus) and pedagogic recontextualising fields (textbook and exemplar examination) occur on the weaker end of the SG continuum (higher abstraction). For the three weaker SG categories, the syllabus and textbook had the highest proportion of specialised/technical categories and concepts (SG-), the syllabus had the greatest proportion of nominalisations (SG- -), and the exemplar examination contained the highest percentage of symbolic text and abbreviations (SG- - -). This suggests stronger agreement between recontextualisers - the writers of the textbook, the curriculum and the exemplar examination, regarding literacy demands at lower levels of abstraction, and contestation between recontextualisers arising from competing claims to legitimacy when it comes to more abstract textual forms.

The weaker alignment between the exemplar examination paper on one hand, and syllabus and textbook on the other hand, in terms of the proportion of symbolic text and abbreviations, suggests that the latter two documents may not be adequately gearing Physical Sciences teachers and learners to the textual literacy demands at the highest (symbolic) level of abstraction privileged in the exemplar examination. This may contribute to students performing poorly in summative assessments that follow the model of the exemplar examination closely. Alternatively, it may suggest that the exemplar examination paper is unnecessarily demanding when it comes to visual literacy at Grade 10 level of study. This is supported by Lide's (1980) recognition of abbreviations having advantages for communication among scientists but contributing to undesirable education difficulties.

On the other hand, the lower proportions of symbolic text in the syllabus and textbook may be favourable in terms of portraying chemistry as more accessible and thus in a way that is less likely to impact negatively on learners' attitudes towards learning chemistry. As Sadoski et al. (2000) pointed out, more concrete language has the positive effect of making text easier to comprehend, and this is consistent with Mikk and Kukemelk (2010) who found that symbolic and abbreviated text reduces learners' interest in science. In terms of nominalisations (SG- -), the Grade 10 chemistry sections of the NCS-CAPS demonstrates the highest frequency of occurrence for focal lexical items at this level. The lower proportions of nominalisations in the textbook and exemplar examination data, which are the pedagogic texts in this study, has positive and negative implications. Since this contributes to lower information density (Fang, 2005), the pedagogic recontextualising field makes lower literacy demands but may not be empowering learners to manage grammatical metaphor in the way the official recontextualising field intends.

7.3 Practical Implications of the Findings

The importance of language in chemistry education is well-documented but its particular relevance in research and in education varies as will now be explained drawing from Markic and Childs (2016). Historically, school learners and university students were more homogenous in terms of language and culture, and a high degree of foundational literacy in the language of instruction could be expected. The main linguistic focus in chemistry education was on nomenclature and new technical terms (Fang, 2006). However, the language of chemistry is not the only language of relevance in chemistry classrooms: to teach the language of chemistry, teachers use a particular language of learning and teaching which not all learners are mother-tongue speakers of. Pluddemann (2015) revealed that while 80% of African language speakers in South Africa begin their schooling in their home language, this drops to 10% by Grade 4 due to many parents opting for English or Afrikaans as the language of learning and teaching.

The role of language in chemistry education is thus more diverse and challenging in light of the evolving nature and diversity of the student population in terms of such things as English language ability (Markic & Childs, 2016). While the focus of the current thesis is not on literacy pertaining to language of learning and teaching, it is important to note that the diversity of home-languages spoken by the student population in South Africa – with there being nine African languages in addition to English and Afrikaans as official languages in the country (Pluddemann, 2015), makes the issue of chemistry literacy demands even more complex. The focus on subject-specific curriculum literacy demands in the current study, nonetheless, contributes to a more nuanced understanding of the broader phenomenon of literacy demands.

The literature clearly shows that abstraction is a key feature of scientific writing. It is thus necessary for curriculum documents such as chemistry syllabi, textbooks, and exemplar examination papers to include abstract visuals and text which supports learners' epistemological access to the power code (Pun, 2019) of chemistry discourse mentioned in Chapter Six (see section 6.4). This is needed for access into related courses in higher education and subsequent entry into chemistry careers. However, the abstract nature of chemistry discourse is also a barrier to chemistry learning, since it makes chemistry texts less comprehensible (De Jong & Van Driel, 2004; Liu, 2009) and less interesting to students

(Mikk & Kukemelk, 2010). In other words, the science discourse feature of abstraction is both necessary and challenging in chemistry education. Mikk and Kukemelk (2010, p. 65) recognise this when explicitly stating that, “Scientific terms, formulae, abstract words, and even long sentences are needed to properly deliver new and complicated content, but all these features usually make the text less interesting. Text authors have to find the optimal way between the two important but different goals”.

In South Africa, this tension is particularly problematic given that the same chemistry syllabus, textbooks, and exemplar examinations frame the education of two groups of Physical Sciences students. One group includes those Physical Sciences learners who intend to study chemistry further and thus need access to more symbolic forms of chemistry knowledge needed to succeed in higher levels of study. The other group includes those who do not intend to study chemistry further, and who thus benefit more from access to more contextualised forms of chemistry relevant to everyday life. Chemistry curriculum that frames chemistry in more symbolic and less contextualised forms would advantage the former – a minority, while a chemistry curriculum that frames the discipline in less symbolic and more contextualised forms would more strongly benefit the latter – the majority.

Meeting the needs of both categories of South African Physical Sciences students would entail a chemistry curriculum that balances more symbolic and contextualised framings of chemistry content. The results from the current study indicate that this ideal is more evident in the textual chemistry curriculum demands than visual chemistry curriculum demands. The current emphasis in the textbook and exemplar examination visual data on the symbolic level of chemistry imposes very high visual literacy demands and privileges the needs of Physical Sciences students intending to pursue chemistry careers. However, the dearth of visuals in the textbook that bridge the submicroscopic and symbolic levels of chemistry is even problematic for these future chemists’ understanding of symbolic chemical representations. Exacerbating this, is the fact that the exemplar exam which models summative chemistry assessment, includes a higher proportion of hybrid visuals bridging the submicroscopic and symbolic levels of chemistry than the textbook does.

The practical implication for the design of chemistry curriculum in the pedagogic recontextualising field then, is for the textbook writers and exemplar examinations developers to include a higher proportion of visual items at the lower and intermediate levels of abstraction (for example photographs, diagrams of submicroscopic chemical phenomena, and hybrids of macroscopic, submicroscopic, and symbolic chemical representations). The implication also applies to Physical Sciences teachers, who have the opportunity to buffer for these shortcomings of the pedagogic recontextualising field by including an abundance of visual items at the lower and intermediate levels of abstraction in their teaching activities. This would strengthen the cognitive and affective learning affordances of more contextualised chemistry visuals in the first year of Physical Sciences (Grade 10) without losing the affordances of symbolic chemical representations for access to higher levels of chemistry study.

While the textual chemistry curriculum literacy demands are more aligned at the lower levels of abstraction, there are disparities at the higher levels. Most notable, is the weak alignment between the official recontextualising field and pedagogic recontextualising field in terms of proportions of nominalisation, and symbolic and abbreviated text. While the syllabus seems to place greater emphasis on nominalisation compared to the textbook and exemplar exam, the textbook and exemplar exam seem to place greater emphasis on symbolic and abbreviated text. For similar reasons in the case of visual abstraction, the practical implication for textbooks developers and physical Science teachers is to ensure adequate focus is afforded to nominalisation in light of the challenges it poses to chemistry learners (Espinoza et al., 2013; Gabel, 1999) without it being excessive to the point of overwhelming learners and negatively impacting on their understanding. A practical implication for further exemplar examination development is to reduce the proportion of symbolic and abbreviated text in order to afford a more even distribution of lexical items across the SG continuum.

7.4 Methodological Contribution and Recommendations for Future Research

In addition to the practical implications for curriculum design as described above, this thesis makes a novel methodological contribution to curriculum alignment studies. The translation devices in the current study were developed through the iterative engagement with theory and literature on one hand, and the document data sources on the other hand. This allowed for a bridging of the discursive gap between theory and data (in order to avoid the constraints to building knowledge) that is epistemologically powerful (Maton & Chen, 2016). For example, the taxonomy of science words presented by Wellington and Osborne (2001, p. 20), and framed in terms of an abstraction continuum by Marais and Jordaan (2000) had the potential for informing the textual SG translation device of the current study. However, problems in operationalising this framing for the raw data in a meaningful way coupled with judgemental rationality of the researcher led to the alternate avenue sparked by the preference that scientific writing exhibits for nouns (Fang, 2005).

Similarly, the models of visual abstraction in biochemistry and biology by Offerdahl et al. (2017), and Pozzer and Roth (2002) had potential for adapting to the data in the current study. However, judgemental rationality led the researcher to establishing their representational basis and then considering how that basis related to the chemistry triplet in order for their models to be meaningfully adapted to the current study, for school chemistry visuals. The initial (draft) translation devices for visual and textual abstraction were discussed with the research supervisors (education researchers) and an expert Physical Sciences teacher (a science education practitioner) prior to being 'piloted' on the shortest data document – the exemplar examination paper. These conversations allowed for adjustments so that the translation device meaningfully bridged the theory and data, without either being imposed on the other. However, the translation devices were only finalised by the end of the data analysis since it is only at that point which the researcher could be sure that it extended to the full range of data in the current study. Maton and Chen (2016, p. 47) pointed out that "languages of description represent a crucial catalyst to development'' in providing an opportunity for translating between theory and data, which further studies can either adopt or adapt.

Furthermore, this thesis compliments the study by Clarence (2017), in which she used a case study on political science to illustrate how the LCT dimension of Specialisation provides a mode of analysing curriculum alignment for subjects that are not aggregative. It achieved this through a case study of chemistry curriculum to illustrates how the LCT SG code provided a mode of analysing curriculum alignment for subjects with hierarchical knowledge structures. This thesis thus adds to the growing range of scholarship employing LCT. Herein lies the methodological contribution of the current thesis, towards dialogue between studies for the purpose of cumulative knowledge-building.

Similar studies to the one reported in this thesis could be carried out which broaden the scope for comparison, and/or provide a more complete picture for the phenomenon of science curriculum literacy demands. For instance, the visual and textual curriculum demands for Grade 10 physics and life sciences could be explored, to compare and contrast results between curriculum literacy demands of different science disciplines towards reducing knowledge blindness in science education pertaining to subject-specific literacies. In the case where physics is taught together with chemistry in one school subject (as is the case for South African Physical Sciences) this would also provide a more complete picture for the school subject.

Another possibility is for future studies to explore the usefulness of the visual and textual SG translation devices developed in this study, for adaptation to other contexts. Examples of different contexts would include other chemistry curricula offered within South Africa (such as the International Baccalaureate, Advanced Subsidiary and Advanced level Cambridge curricula), or between school chemistry curricula as framed in other countries. Since many curriculum alignment studies focus on the alignment between the knowledge recontextualisation fields and knowledge reproduction fields, it would also be possible to compare the results from this study to those of a study exploring the literacy demands of enacted chemistry curriculum (the knowledge reproduction field).

Furthermore, similar studies could be conducted for chemistry curriculum of other grades (11 and 12), to explore curriculum literacy demands across school grades within the discipline of chemistry. This would provide insight into what chemistry progression between grades entails in terms of curriculum literacy demands. Such a study would be useful towards addressing articulation gaps between levels of study. Related curriculum alignment studies could be conducted from the perspective of other features of scientific language (such as technicality, for which semantic density translation devices would need to be developed).

7.5 Limitations of the Study

One limitation of the study is that it focused on visual and textual modes in isolation (as evident from the use of separate SG translation devices for chemistry visuals and text), rather than on intersemiosis between the visual and textual modes but such an intersemiotic focus would be a useful next step. An implication of this limitation is that semantic waves (which could be intersemiotic) were not considered. Furthermore, the current study focuses only on curriculum literacy demands in terms of what Maton (2013) termed high-stakes or academic reading, and not on high-stakes or academic writing, so visuals and text in the examination paper memorandum as well as expected answers to the textbook activities and practice questions were not included in the analysis. Another limitation, and one associated with the context-specificity of case studies such as the one reported on in this thesis, is that the results are not readily generalisable beyond the documents analysed in this study (Bertram & Christiansen, 2014). However, the aim of the study was not to generalize the findings but to contribute to the field of scholarship of chemistry education through generation of recommendations for agents in the recontextualisation field of the pedagogic device, and translation devices for chemistry visuals and text that might be of use to other scholars undertaking similar research.

7.6 Concluding Comments

The study makes both a methodological and an empirical contribution to the field of chemistry education. The methodological contribution is evident in the visual and textual SG translation devices which bridge the discursive gap between theory and data in a transparent way, thus being open to adoption or adaptation by researchers undertaking similar research. This affords opportunities for dialogue between studies towards the goal of cumulative knowledge-building. The centrality of translation devices is evident by the declaration that "No theoretical framework should be without translation devices'' (Maton & Chen, 2016, p. 48).

The empirical findings from this study reveal an overall high level of alignment for visual chemistry curriculum literacy demands, and for textual chemistry curriculum literacy demands at the lower levels of abstraction. The visual literacy demands were found to be higher than the textual literacy demands due to the emphasis on visuals at the highest level of abstraction, while the text displayed a more even distribution of focal lexical items across levels of abstraction. There are negative cognitive and affective implications of the emphasis placed by the textbook and exemplar examination on visuals at the symbolic level coupled with the textbook placing little emphasis on visuals that bridge the submicroscopic and symbolic levels of chemistry. Furthermore, the exemplar examination's emphasis on the symbolic text suggests that assessment privileges higher visual and textual literacy.

The results regarding areas of weaker and stronger alignment of visual and textual chemistry curriculum literacy demands have potential implications for the life chances of South African Physical Sciences students. The Physical Sciences learners who do not intend on pursuing further science study and related science careers are likely being disadvantaged compared to those studying the subject for the purpose of further study towards science careers. Additionally, learners with access to alternate resources to the textbook (including devices such as laptops and internet access for online chemistry resources) which bridge the divide between the submicroscopic and symbolic levels, are likely being advantaged when it comes to their chemistry learning compared to their counterparts without such access.

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APPENDICES

Appendix A: Examples from data for visual SG translation device

Table A1: SG translation device for visuals, with accompanying examples of visuals from data

Semantic Gravity code	Data analysis code	Brief description	Type (in words for the sake of brevity, with the related visual examples from the data shown in the figures following this table corresponding to the column alongside this one)	Examples from data (actual Figures shown after this table)
SG- -	5	Symbolic (1D)	Unknown chemical elements (represented by variables)	Figure A17
			Chemical and mathematical equations	Figure A16
			Spectroscopic electron configurations	Figure A15
			Chemical Formulae/symbols	Figure A14
SG-	4	Symbolic (with some 2D meaning)	Periodic table (minimal detail)	Figure A13
			Graphs	Figure A12
			Energy level/Afbau/ Lewis diagrams	Figure A11

SGϴ	3	Hybrid iconic/symbolic	PT (with some atomic detail)	Figure A10
			Naturalistic drawing with symbols (eg electric circuit)	Figure A9
			Global cycles with processes represented by arrows	Figure A8
			Classification scheme	Figure A7
			Schematic chemical reaction	Figure A6
SG+	2	Iconic (2D) resembling something at larger/smaller scale than human experience	Atomic and Molecular representations/models	Figure A5
			Photographs (objects smaller/larger than human scale) eg line spectra and telescope photographs	Figure A4
SG+ +	1	Iconic (2D) closely resembles 3D objects/phenomena at human scale	Naturalistic drawings of objects at human scale	Figure A3
			Comic strips	Figure A2
			Photographs (objects at human scale)	Figure A1

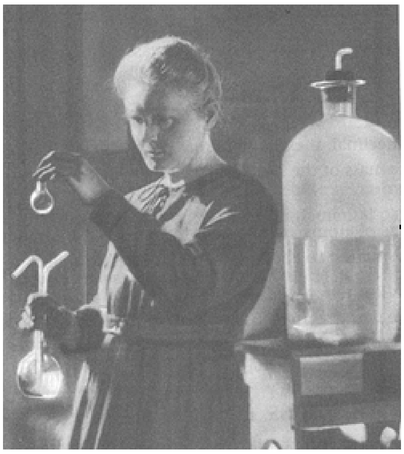

Figure A1: An example of photographs in the SG+ + category (Grayson et al., 2011, p. 20)

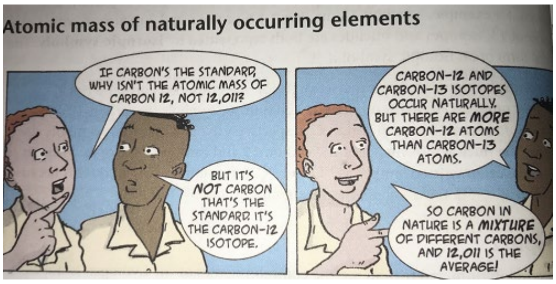

Figure A2: An example of comic strips in the SG+ + category (Grayson et al., 2011, p. 26)

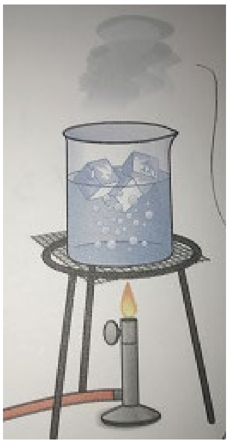

Figure A3: An example of naturalistic drawings in the SG+ + category (Grayson et al., 2011, p. 107)

Figure A4: An example of photographs in the SG+ category (Grayson et al., 2011, p. 29)

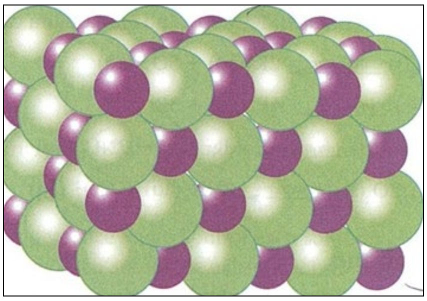

Figure A5: An example of atomic and molecular representations/models in the SG+ category (Grayson et al., 2011, p. 163)

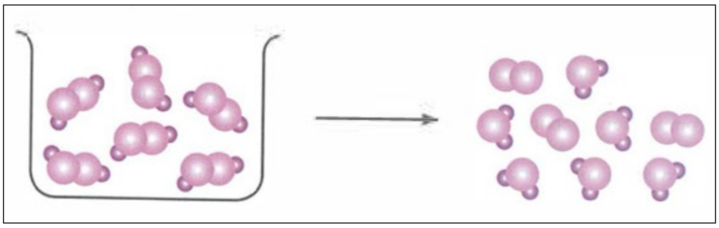

Figure A6: An example of schematic chemical reactions in the SGϴ category (Grayson et al., 2011, p. 111)

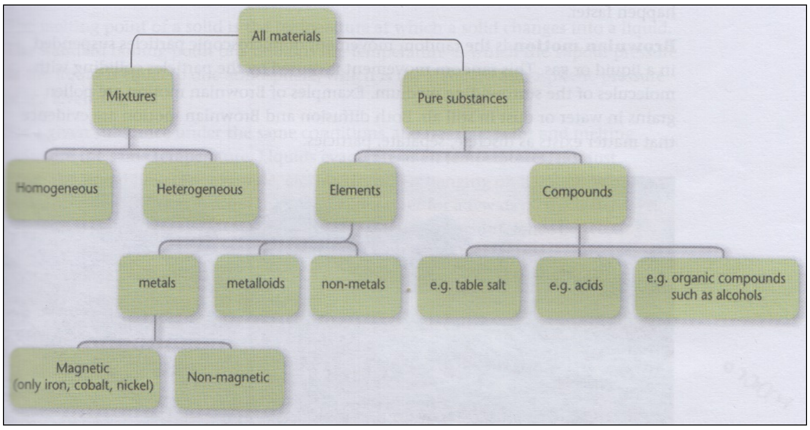

Figure A7: An example of classification schemes in the SGϴ category (Grayson et al., 2011, p. 11)

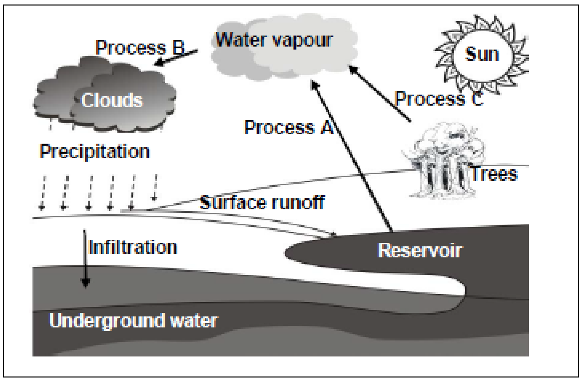

Figure A8: An example of Global cycles with processes represented by arrows in the SGϴ category (DBE, 2012, p. 14)

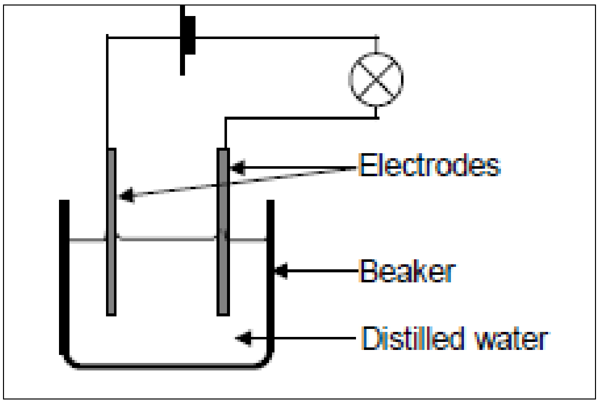

Figure A9: An example of Naturalistic drawing with symbols (eg electric circuit) in the SGϴ category (DBE, 2012, p. 11)

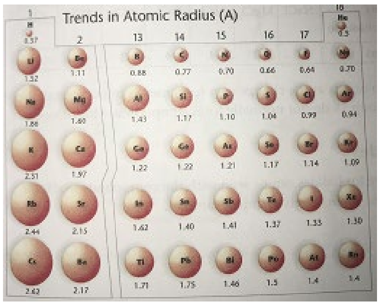

Figure A10: An example of a Periodic Table with some atomic detail in the SGΘ category (Grayson et al., 2011, p. 39)

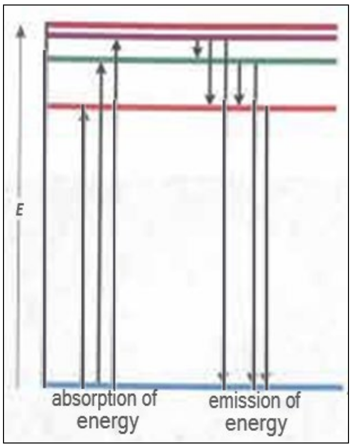

Figure A11: An example of an Energy level diagram in the SG- category (Grayson et al., 2011, p. 30)

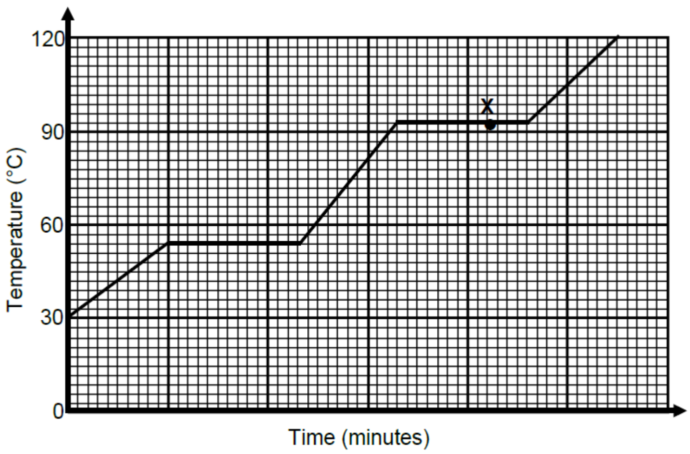

Figure A12: An example of a Graph in the SG- category (DBE, 2012, p. 8)

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TABLE 3: THE PERIODIC TABLE OF ELEMENTS/*TABEL 3: DIE PERIODIEKE TABEL VAN ELEMENTE*

KEY/*SLEUTEL*: Atomic number/*Atoomgetal* (29); Electronegativity/*Elektronegatiwiteit* (1,9); Symbol/*Simbool* (Cu); Approximate relative atomic mass/*Benaderde relatiewe atoommassa* (63,5)

1 (I)	2 (II)	3	4	5	6	7	8	9	10	11	12	13 (III)	14 (IV)	15 (V)	16 (VI)	17 (VII)	18 (VIII)
1 2,1 H 1																	2 He 4
3 1,0 Li 7	4 1,5 Be 9											5 2,0 B 11	6 2,5 C 12	7 3,0 N 14	8 3,5 O 16	9 4,0 F 19	10 Ne 20
11 0,9 Na 23	12 1,2 Mg 24											13 1,5 Aℓ 27	14 1,8 Si 28	15 2,1 P 31	16 2,5 S 32	17 3,0 Cℓ 35,5	18 Ar 40
19 0,8 K 39	20 1,0 Ca 40	21 1,3 Sc 45	22 1,5 Ti 48	23 1,6 V 51	24 1,6 Cr 52	25 1,5 Mn 55	26 1,8 Fe 56	27 1,8 Co 59	28 1,8 Ni 59	29 1,9 Cu 63,5	30 1,6 Zn 65	31 1,6 Ga 70	32 1,8 Ge 73	33 2,0 As 75	34 2,4 Se 79	35 2,8 Br 80	36 Kr 84
37 0,8 Rb 86	38 1,0 Sr 88	39 1,2 Y 89	40 1,4 Zr 91	41 Nb 92	42 1,8 Mo 96	43 1,9 Tc	44 2,2 Ru 101	45 2,2 Rh 103	46 2,2 Pd 106	47 1,9 Ag 108	48 1,7 Cd 112	49 1,7 In 115	50 1,8 Sn 119	51 1,9 Sb 122	52 2,1 Te 128	53 2,5 I 127	54 Xe 131
55 0,7 Cs 133	56 0,9 Ba 137	57 La 139	72 1,6 Hf 179	73 Ta 181	74 W 184	75 Re 186	76 Os 190	77 Ir 192	78 Pt 195	79 Au 197	80 Hg 201	81 1,8 Tℓ 204	82 1,8 Pb 207	83 1,9 Bi 209	84 2,0 Po	85 2,5 At	86 Rn
87 0,7 Fr	88 0,9 Ra 226	89 Ac															

58 Ce 140	59 Pr 141	60 Nd 144	61 Pm	62 Sm 150	63 Eu 152	64 Gd 157	65 Tb 159	66 Dy 163	67 Ho 165	68 Er 167	69 Tm 169	70 Yb 173	71 Lu 175
90 Th 232	91 Pa	92 U 238	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Figure A13: An example of a Periodic Table with no atomic representations in the SG-category (DBE, 2012, p. 17)

- Atoms of non-metal elements form covalent molecular structures consisting of separate molecules, e.g. H_2.
- Atoms of different non-metal elements can also combine to form molecular structures, e.g. H_2O.

Figure A14: An example of Chemical formula and Symbols (H_2 and H_2O) in the SG- - category (Grayson et al., 2011, p. 104)

$1s^2 2s^2 2p^6 3s^2 3p^4$
$1s^2 2s^1$
$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$
$1s^2 2s^2 2p^6 3s^2 3p^6$
$1s^2 2s^2 2p^6 3s^2 3p^5$
$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$

Figure A15: An example of spectroscopic electron configurations in the SG- - category (DBE, 2012, p. 10)

$$SO_2(g) + O_2(g) \rightarrow SO_3(g)$$

Figure A16: An example of chemical equations in the SG- - category (DBE, 2012, p. 11)

Write down the NAME or FORMULA of compound **X**.

Figure A17: An example of unknown chemical elements represented by variables in the SG- - category (DBE, 2012, p. 15)

Appendix B: Excerpts from Turnitin originality report for this thesis

KJ_PhD_Thesis

ORIGINALITY REPORT

12%	10%	5%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

Submission date: 05-Jul-2021 09:04AM (UTC+0200)
Submission ID: 1615878074
File name: 27222_Kavish_Jawahar_KJ_PhD_Thesis_487006_728368419.doc (7.62M)

Appendix C: Ethics Clearance Letter

UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

10 January 2014

Mr Kavish Jawahar 200278003
School of Education
Edgewood Campus

Dear Mr Jawahar

Protocol reference number: HSS/1515/013D
Project title: A multiliteracies analysis of textual curriculum alignment - The case of South African Physical Sciences

No-Risk Approval

In response to your application dated 25 November 2013, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol has been granted **FULL APPROVAL.**

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment /modification prior to its implementation. In case you have further queries, please quote the above reference number. Please note: Research data should be securely stored in the discipline/department for a period of 5 years.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

....

Dr Shenuka Singh (Chair)
Humanities & Social Science Research Ethics Committee

/pm

cc Supervisor: Dr Edith R Dempster
cc Academic Leader: Dr MN Davids
cc School Admin: Mr Thabo Mthembu

Appendix D: Inductive thematic categories for exemplar exam subquestions

Sub question Category	Examples in Question paper	Sub question Marks	Total Marks	% of Total
1. Definition (5)	1.10. Choose option that describes 'hydrosphere' 2.2. 'Define the term sublimation' 4.6.1. 'Define the term molecule' 5.6.1. 'Define the term isotope' 8.3.1. 'Define the term empirical formula'	2 2 2 2 2	10	6.67
2. Counting (8)	1.2. 'How many different types of nitrogen molecules' 1.7. 'number of atoms in one formula-unit of …is' 4.2.2. 'write down its number of valence electrons' 4.3.2. 'write down its number of protons' 6.3. 'Write down a balanced chemical equation' 6.4. 'balance the equation' 7.3.1. 'Write down a balanced equation' 9.2.2. 'Write a balanced equation'	2 2 1 1 ¼ 1 ¼ 1/3	10	6.67
3. Name/State (10)	4.1.1. 'write down the household name' 4.5. 'Name the type of crystal lattice' 4.6.2. 'Name the type of bond' 5.3.2. 'Write down the Flame colour' 6.5. 'Name the chemical law' 7.1.2. 'Write down the general name' 7.2.1. 'Write down the name'	1 1 1 1 1 1 ½	11	7.3

	7.3.2. ‘Name the type of reaction’ 9.2.3. ‘State one negative effect’ 9.3.2. ‘write down the name (or formula’)*	1 1 2		
4. Explanation/ Justification (8)	1.4. Choose correct explanation 2.3. ‘Use kinetic theory to explain’ 3.2. ‘Give a reason for the answer’ if substance in heating curve is water or not 3.4. Explanation for obs of what happens to temp while substance melts 7.1.1. ‘Give a reason’ – why bulb in diagram doesn’t glow 7.2.2. ‘Give a reason why’ – nitric acid is added after white ppt forms 9.2.1. ‘Give a reason for the answer’ about which sample of water is unsafe for human consumption 9.3.1. ‘Give a reason why’ – chlorine is added during water purification	2 3 1/2 2/3 1 1 2	13	8.67
5. Interpretation (15)	1.1 Chromatogram [variable] 1.9. Choose correct interpretation of balanced chemical equation [number] 2.1. Column B option G (Cu)* 3.1.1. Interpret graph [variable] 3.1.2. Interpret graph [variable] 3.3.1. Interpret graph [state] 3.3.2. Interpret graph [state] 3.4. Interpret graph [variable – temp] 5.1. ‘Which element (P, Q, R, S, T or Y)’ 5.1.1. [number] 5.1.3. [number] 5.6 drawing of isotopes in sample of element 6.2. [symbol]	2 2 1 1 1 2 1 1/3 1 1 3	20	13.33

	9.1.1. Interpret diagram [process] 9.1.2. Interpret diagram [process] 9.1.3. Interpret diagram [process]	1 1 1 1		
6. Comparison (different from interpretation of data in question, or representation) (18)	1.3. Electronic configuration of ions in compounds, to Argon (for synonymy) 2.1.1. Matching column – e.g. or type, to category(hyponymy) 2.1.2. Matching column – category, to e.g. or type (hyponymy) 2.1.3. Matching column - category, to e.g. or type (hyponymy) 2.1.4. Matching column – e.g. or type, to category(hyponymy) 2.1.5. Matching column – e.g. or type, to category(hyponymy) 2.1.6. Matching column - category, to e.g. or type (hyponymy) 2.1.7. Matching column – quant item with ratio it is synonymous with 3.2. substance represented by heating curve, to water (for synonymy or not) 5.1.2. hyponym of noble gas (hypernym) 5.2.1. elements to PT groups for (co-hyponyms of group) 5.2.2. hypernym detail of co-hyponyms 5.3.1. Calcium to atomic info in table 6.1. 'Which one of the above equations…represents' 6.1.1. hypernym to hyponym 6.1.2. hypernym to hyponym 7.2.3. choose correct Bottle (A or B) for $BaCl_2$	2 1 1 1 1 1 1 1 ½ 1 2 1 1 1	20	13.33

	meronym 9.2.1. pH in terms of being ‘safe for human consumption’	1 2 1/2		
7. Representation (17)	1.5. ‘represent’ Ionisation energy 1.6. Chemical formula 1.8. ‘represent’ Physical constant 4.1.2. ‘write down the chemical formula’ 4.2.1. ‘draw’ Afbau diagram 4.3.1. ‘write down’ sp notation 4.4. ‘represent’ reaction using Lewis diagram 4.6.3. ‘represent’ molecule using Lewis diagram 5.4.1. ‘write down the formula’ 5.4.2. ‘write down the formula’ 5.5. ‘write down its $^{A}{}_{Z}X$ notation’ 6.3. ‘write down a balanced chemical equation for the word equation’ 7.1.3. ‘write down the formulae of the ions’ 7.2.1. ‘write down the (name and) formula’ 7.3.1. ‘write down a balanced chemical equation’ 8.3.2. Empirical formula 9.2.2. ‘write a balanced equation for the reaction’ 9.3.2. ‘write down the (name or) formula’*	2 2 2 1 3 2 4 2 1 1 3 ¾ 2 ½ ¾ 1/5 2/3 2	37	24.67

8. Calculate (9)	5.6.2. ‘use the above information to calculate the relative atomic mass’ 6.6. ‘show that mass is conserved’ 7.1.4. ‘Calculate the concentration’ 8.1.1. (Calculate the) mass 8.1.2. (Calculate the) volume 8.1.3. (Calculate the) mass 8.1.4. (Calculate the) number of chlorine atoms 8.2. ‘Calculate the number of moles water of crystallisation’ 8.3.2. ‘Determine the empirical formula…show ALL calculations’	1 3 5 5 3 4 3 4 4/5	32	21.33