Knowledge practices and student access and success in General Chemistry at a Large South African University

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ABSTRACT

This dissertation reports on an investigation into the structuring principles of the General Chemistry curriculum at a Large South African University (LSAU). Student learning in the introductory modules of General Chemistry is critical for access to a range of fields since it is a requisite course for a variety of degree programmes. However, there is ample evidence that success in this subject remains a major challenge, particularly for black students. My quest in this study was to explore how the curriculum could enable greater epistemic access and thus include more students in science programmes at the LSAU.

I investigated the organising principles underlying the curriculum practices of the General Chemistry module and explored the effects of the curriculum structure on student learning. Theoretically and conceptually, the study was underpinned by a social realist approach which holds that knowledge is stratified, differentiated, and has real emergent properties, powers and effects. The research question that I attempted to answer in this study was: *How do knowledge practices privileged in the General Chemistry curriculum at the LSAU enable or constrain student learning?* I adopted an intensive research design approach to conduct a qualitative case study using social realism and LCT as theoretical and analytical lenses. I used empirical data such as curriculum documents and interviews with lecturers to uncover the underlying generative mechanisms of the curriculum.

I adopted a multi-layered data analysis process to make visible the underlying organising principles informing knowledge practices in the curriculum so that I could explain their potential effects on student learning. The first level of analysis explored the context of the curriculum and associated knowledge practices, and examined the pedagogic discourse evident in the curriculum. The second level of analysis revealed the inner logic structuring the curriculum and the associated knowledge practices. I used Maton's Legitimation Code Theory (LCT): Specialisation to identify the specialisation codes, gazes and insights generated by the curriculum. For the third level of analysis, LCT: Semantics was used to generate the semantic profiles of learning activities to determine the extent to which the curriculum structure made cumulative learning possible.

From the findings, it is evident that the verticality of knowledge in General Chemistry points to a recontextualising principle that prescribes the selection and arrangement of knowledge, and the special relationship of actors and discourses. As a result, the strong framing of the instructional discourse of General Chemistry curriculum structure is likely to constrain epistemological access for large numbers of students. In order to improve epistemological access to the field, weaker framing of the instructional discourse in introductory science is necessary. Weaker framing of the General Chemistry curriculum would require, in particular, changes to pacing, and that the evaluative criteria are made explicit. This is especially necessary when certain abstract and complex curricular content is taught, especially in the first semester.

The findings also indicate that the nature of the organising principles in the curriculum are significant for improving epistemological access to knowledge. In terms of LCT: Specialisation, the General Chemistry curriculum generated a *knowledge code* and downplayed differences among social categories of students, thus positioning all equally in relation to the knowledge and practices of the field. Therefore, the structuring of the curriculum emphasises and legitimates students who have attained specialist knowledge without considering the nature of the new student coming into the educational setting. Simply, what is privileged is both the object of study (theoretical knowledge) and how it is studied (procedural knowledge). This finding is in line with the general outcomes of Chemistry education. In addition, the *purist insight* generated by the curriculum further attests to where the emphasis is placed in the curriculum. I argue that the lack of social relations in the curriculum poses a challenge for the holistic development of students as science knowers.

The analysis of the learning activities shows rapid code shifts that indicate changes in cognitive demand and modes of thinking required of students. I argue that signposting the changes in complexity of knowledge and in the mode of thinking required could make learning, and thus epistemological access, more possible. Given the imperative of access to powerful knowledge, I contend that the curriculum should be reshaped to enable epistemological access for more students.

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Abbreviations

CHE	-	Council on Higher Education
CHERTL	-	Centre for Higher Education Research, Teaching and Learning
CR	-	Critical Realism
DoE	-	Department of Education
DHET	-	Department of Higher Education
ELoD	-	External Language of Description
GCM	-	General Chemistry Module
HESA	-	Higher Education South Africa
HEI	-	Higher Education Institution
LCT	-	Legitimation Code Theory
LSAU	-	Large South African University
NSC	-	National Senior Certificate
SI	-	Social Inclusion
UNESCO	-	United Nations Educational, Scientific and Cultural Organisation
WK	-	Week

CHAPTER 1

1.1 Introduction

The transformation agenda in South African society and in higher education continues to be an urgent imperative. In relation to the curriculum and associated practices, the agenda is well captured by the question, “Whose knowledge and whose curriculum?” (Hoadley 2015; p. 735). The notion of access to knowledge through the curriculum is central to this study which explored how the structure of knowledge and *knowledge practices* in the first-year General Chemistry modules[1] at a Large South African University (LSAU) functioned to include or exclude students from the knowledge domain.

In the introductory chapter, I position my study within the broader social inclusion (SI) project of which this PhD study was a part. I begin the chapter by providing the background to this study, which is part of a series of studies investigating social inclusion in higher education. A brief discussion on the aims of the social inclusion project and its goal to advance the discourse of social inclusion in Higher Education (HE) is also provided.

I proceed to provide the research question and make some conjectures about the significance of the research in the context of the quest to ensure *epistemological access* and success for more students, given the transformation agenda in South African higher education. I examine the key concerns relating to the influence of knowledge and curriculum practices on first-year learning in General Chemistry at LSAU. Furthermore, I discuss my interest in the role of curriculum in structuring epistemological access for the majority of students. I then outline my motivation for the focus I have chosen for this study in the context of the social inclusion in higher education project. I conclude the chapter by outlining the structure of the dissertation and providing a brief synopsis of each chapter.

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[1] A module in this context refers to the planned sequence of learning apportioned under a specific topic that has subthemes and that is taught throughout the duration of a semester. In some instances, the term module is used interchangeably with the term course.

1.2 The background to the study - the social inclusion (SI) project

The SI project emerged from questions about student access and success arising from a meta-analysis of institutional data on teaching and learning generated in the context of institutional audits at South African universities (Boughey 2009, 2010; Boughey and McKenna 2011). The institutional audit data submitted to the Council on Higher Education (CHE 2010) focused on teaching and learning in research-intensive South African universities. The data sources for the meta-analysis were institutional self-evaluation reports and Higher Education Quality Council audit reports commissioned by the CHE for the first-ever national audit by the Higher Education Quality Council in South Africa. The meta-analysis led Boughey (2010) to argue that institutional self-evaluation reports evinced narrow conceptions of teaching and learning and of curriculum practices. She concluded that there was a need for more critical analyses of how institutions, through their academic and organisational structures, culture and practices privileged some students while excluding others from accessing the "goods" of the academy.

The SI project consisted of six PhD scholars investigating undergraduate curricula, teaching and learning, and academic staff development at public universities of all institutional types in South Africa. Although each scholar focused on a different field in higher education, such as psychology, teacher education, and science and physiotherapy, all six studies investigated how knowledge and curriculum practices include or exclude students at South African universities.

A notable characteristic of the SI project was that all the research projects had to use the same theoretical framework to investigate the phenomenon of social inclusion in higher education; however, each researcher formulated his / her own research question based on their area of interest. The project aimed to explore the issue of social inclusion in higher education by posing the broad question, "How do disciplinary knowledge/knower structures and their associated practices serve to include or exclude students?" This dissertation reports on my study in which I researched the curriculum practices in the first-year Introductory Chemistry curriculum.

1.3 Motivation for the study

In my role as an academic development practitioner at LSAU, I provided guidance to academics on curriculum design and development. In the process, I critiqued curriculum practices, including the appropriateness of the selection, sequencing, pacing and assessment decisions for student learning. I was especially concerned about how curricular content was made accessible to students. The creation of conditions for successful student learning was a major institutional goal at LSAU and although this goal was reflected in all the academic development initiatives, it yielded limited positive results. As a non-scientist, interested in science education in universities, this study offered an opportunity to understand the conditions that allow some students to succeed, and cause others to struggle with learning Introductory General Chemistry. The study therefore explored the conditions for providing students access to disciplinary knowledge and ways of knowing in General Chemistry at first-year university level at the institution.

Another motivation for the study was to harness knowledge about aspects of the General Chemistry curriculum to make better sense of how to improve student learning in the discipline. The perspectives on knowledge adopted by the social realist school in the sociology of knowledge led to some interesting observations about learning in the natural sciences. Educational research is a relatively weakly bounded and classified field, likewise Chemistry as a science is relatively weakly bounded and framed. Bringing two fields together, that is, the field of higher education studies and science education, in this study offers an atypical perspective to understanding knowledge-building in the two disciplines. Morais and Neves (2010) argue that researching the natural sciences using an education lens, pushes the boundaries of a very strongly classified science field into a sociological approach. Conducting research across these boundaries presented me with an intellectual and educational challenge that I wanted to take on.

1.4 The curriculum, curriculum practices and knowledge practices

The study explored how the structure of knowledge and knowledge practices in the first-year General Chemistry modules at LSAU functioned to include or exclude students from the knowledge domain. Knowledge practices in curriculum design and development include the planning, design, implementation and assessment of learning. Pohjola and Korhonen (2012) propose that different forms of knowledge are aligned with particular epistemic or knowledge practices. *Curriculum practices* are regarded as knowledge practices. Knowledge practices have effects in educational settings (Maton 2014). The notion of knowledge practices, in particular as demonstrated through curriculum design, is central to the study. For the purposes of the study, knowledge practices refer to activities associated with the creation, recontextualisation and transmission of knowledge through the curriculum. I shall examine the structuring of the curriculum in more depth in a discussion on the knowledge structure and knowing in General Chemistry in Chapter 2.

Maton's (2013) conceptualisation of knowledge-knower structures enables an understanding of knowledge practices in intellectual social fields of practice. An understanding of knowledge-knower structures makes it possible to explain how knowledge forms can enable and/or constrain access to certain forms of knowledge. It is through the structure of knowledge (knowledge structures) and knowledge practices that identities and consciousness (knower structures) are shaped.

The concept *curriculum* denotes the planned learning opportunities for students in a particular knowledge area. The curriculum constitutes all information expressed in course-related texts and documents. Foregrounding social inclusion in higher education has implications for curriculum design and development.

The literature on curriculum is replete with different conceptions and orientations to curriculum (Ornstein and Hunkins 2004, Dillon 2009, du Toit 2011). The responses to questions about why we teach what we teach, what constitutes the curriculum, what curriculum knowledge and content is worthy of being learnt should constantly be foregrounded in curriculum design. However, views on these questions do not provide answers to the structuring of knowledge and the implications thereof for teaching and learning. Curriculum design considers the learning outcomes and objectives, the selection and organisation of disciplinary content, the selection and organisation of learner experiences, methods and techniques of assessment.

Curricula should be designed to be fit for purpose. The notion of fitness for purpose is linked to the quality discourse in higher education. Fitness for purpose takes into account matters of inclusivity and accessibility of the curriculum, its relevance and appropriateness in relation to the context, and its ability to develop students' professional identities. If fitness for purpose is valued, it is important to understand practices that facilitate increasing epistemological access in a field such as General Chemistry.

The focus of this research project is on epistemological access or access to powerful forms of knowledge through the curriculum (Young 2008a). Equality of access to the most powerful forms of knowledge should be made possible for the previously excluded (Sayer 2000). Epistemological access is also referred to as epistemic access (Wheelahan 2010)[2]. The notion of epistemological access was conceptualised by Morrow (2009) who distinguishes between formal access into higher education and epistemological access, or access to disciplinary ways of knowing. He argues that epistemological access is a significant marker of success in student learning. The term 'access' has depth of meaning since it pertains to how students interpret, understand and use knowledge gained through teaching, learning and assessment activities. For Muller (2012),

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[2] In this dissertion I use the two terms interchangeably.

epistemological access is about providing “meaningful access to the ‘goods’ of the university” (p. 1). A more in-depth discussion on the notion of epistemological access and social inclusion can be found in Chapter 4 (Section 4.4)

1.4.1 Distinguishing between curriculum and pedagogy

Key for locating and appropriately positioning the study is the distinction between curriculum and pedagogy. For Bernstein (1975) the curriculum refers to the specific use of educational time where “certain periods of time and their possible contents are brought into a special relationship with each other” (p. 79). For the purposes of avoiding conflating knowledge practices found in the different fields of education, Bernstein (1975) differentiates between curriculum and pedagogy. Curriculum, he argues, refers to “what counts as valid knowledge” while pedagogy relates to “what counts as valid transmission of knowledge” (p. 85). The distinction is significant for highlighting the role curriculum plays in pedagogy and vice versa. Following on Bernstein’s assertions about curriculum and pedagogy, Young (2008a) proposes a more focused understanding of the basis for educationally worthy knowledge that is constructed into a curriculum suitable for student learning. Young, however, cautions against restricting the definition of curriculum to ‘an idea of a social and political construct reflecting particular sets of interests, values and beliefs” (ibid, p. 2).

Although pedagogy, i.e. the actualised curriculum, is an essential component of curriculum design, it was not included as part of the study. However, an analysis of the curriculum as taught and assessed at the module level, have made it possible for me to make inferences about the proposed pedagogy and therefore the implications of knowledge and knowledge practices in enabling or constraining epistemological access. For the purposes of this study curriculum is understood as encapsulating all undertakings related to the planning, design of teaching and learning, and assessment in a course that occur at the micro- or module level.

1.5 Purpose of the study

The aim of the study was to analyse the curriculum structure and the knowledge and curriculum practices of first-year General Chemistry to examine how the curriculum enables or constrains student learning. I examined the underlying *organising principles* which structured the entry-level General Chemistry curriculum, the effects of which can be explained in terms of their ability to enable or constrain learning for some students. As the aim of my inquiry was to explain the effects of the curriculum structure it was necessary to identify and describe the underlying mechanisms structuring curriculum knowledge in the first-year General Chemistry modules. It is envisaged that the findings of the study will contribute to an understanding of social inclusion in higher education in South Africa and inform curriculum practices for enhanced epistemological access.

Much research has been conducted into education and its effects or influences on society. This research focused on education in relation to external variables such as gender, poverty, and race, to name just a few factors (Akoojee and Nkomo 2007, Scott, Yeld and Hendry 2007). To this end, most research on curriculum design and student learning in entry-level courses has focused on explaining the *what and why* of teaching and learning in higher education rather than the *what and how* of the curriculum (Matoti and Lekhu 2008, Luckett 2011).

A key purpose of this study was to contribute to the gap in the literature on social inclusion, and knowledge and curriculum practices in higher education. As such, this study offers an in-depth inquiry into the *what*, *why* and *how* of curricular knowledge in General Chemistry. Successful learning of General Chemistry knowledge is essential for access to a range of fields as well as for specialisation in Chemistry**.**

1.6 Research question

The primary research question for the study is:

> How do knowledge practices privileged in the General Chemistry curriculum at LSAU enable or constrain student learning?

The secondary questions which supported the inquiry into the main research question were divided into three sub-questions as follows:

a) How do curriculum discourses influence the structuring of General Chemistry?

b) How do the organising principles of the knowledge practices in the General Chemistry curriculum legitimate knowledge and knowers?

c) How does the structuring of the curriculum contribute to epistemological access and cumulative knowledge-building and learning?

1.7 Rationale for the study

1.7.1 Access to knowledge as a right in higher education

Higher education institutions (henceforth HEIs) are centres for the generation and dissemination of knowledge. The discourse around knowledge and curriculum needs further exploration especially in relation to the influence of knowledge and curriculum practices on social inclusion or exclusion and student success. This is because knowledge is frequently understood as a means of propagating power and advantage (see for example, Northedge 2003, Young 2008a., Wheelahan 2010). As such, the study intended to examine how curriculum practices and the design thereof could be used to promote social inclusion to knowledge and, by so doing, provide access to powerful forms of knowledge.

The South African constitution[3] entrenches the rights of all students, regardless of race, gender, sex, colour, sexual orientation, disability, religion, belief, culture or language, to basic education and access to educational institutions. The constitution establishes the rights of all students to quality teaching and learning, and thus to access to knowledge. The implementation of constitutional rights in education means that there should be equitable access to educational opportunities for students at all levels of education from the foundation phase to further and higher education and training. Education generally, and higher education specifically, holds the promise of improving the quality of life for individuals, communities and society at large. It is widely assumed by government and society that making equal educational opportunities available to all by increasing and widening access to education, especially higher education – and, all things being equal – would have a positive impact on the development of people who are productive, caring and competent citizens, able to advance the national transformational agenda.

The #FeesMustFall protests in public HEIs of 2015 and 2016 have offered a stark reminder that there is a difference between physical access to higher education and access to the goods of higher education, including epistemic access. The focus of the #FeesMustFall protests was on free education for the poor and, while the issue of epistemic access and social inclusion for the majority of students was not foregrounded as part of the protests, it could be argued that the latter was, in effect, a large factor precipitating the protests.

Student success is a key indicator of the future well-being of our society. Therefore, studying student success especially in the sciences, is critical for ensuring that students entering higher

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[3] The Constitution of SA - Republic of South Africa, 1996a.

education gain access to powerful forms of knowledge that can contribute to the advancement and betterment of society. It is through the curriculum that certain values, principles, identities and ways of thinking and knowing can be developed.

1.7.2 Facilitating access to science education

The decision to investigate knowledge practices in General Chemistry is significant since success in the subject has far-reaching consequences for many other programmes in the university. Students in South Africa and elsewhere struggle with learning first-year Chemistry (Potgieter, Davidowitz and Venter 2008, Potgieter 2010, Gabel 1999, Taber 2000, Cooper 2010). Scott (2009) argues that "the first-year experience in terms of cognitive, personal and social development, largely determines student performance … (and) is a key foundation for advanced study" (p. 19).

This research was underpinned by the assumption that improved access to powerful forms of knowledge at first-year level would have a positive effect on the success rate of students higher up in their learning trajectory. An improvement in student success in General Chemistry would have a positive impact on student performance in a number of degree programmes, since the module is a requirement for further study in several other programmes. Although student success in learning science in higher education has been researched (as noted above in Section 1.7.1), few studies have investigated the relationship between the structuring of disciplinary knowledge in the curriculum, the curriculum practices, and their impact on epistemic access for students.

Concomitant challenges associated with student retention and graduation rates have received a great deal of attention in South African higher education over the last decade or so (Bunting 2004, Scott, Yeld and Hendry 2007, Van Schalkwyk 2007). Nationally, there is an urgent need to increase the number of science graduates in South Africa, especially among black students. The national agenda has implications for the LSAU since the institution confers Agricultural, Engineering, Medical and Veterinary Sciences degrees. All first-year students registered for these degrees have to study Introductory General Chemistry. First-year Chemistry students at the LSAU are selected and admitted on the assumption that they have met the minimum admission requirements for the study programme. An additional expectation is that those admitted will have the necessary pre-requisite knowledge to learn Chemistry at higher education level.

Upon entry into the Science Faculty, most students have very good matriculation marks, many having achieved several distinctions in the National Senior Certificate examinations.

Furthermore, evidence from an admissions instrument administered by the LSAU to first-year students demonstrates that most new students have a high perception of their own cognitive abilities and an even higher perception of their self-efficacy in relation to their studies[4]. However, many of these top performers drop out within their first-year, or do not succeed in tests and examinations which results in their exclusion from the faculty or from the university. Considering the above outcomes, it seems necessary to ask questions about the impact of curriculum practices on student learning and what the underlying principles are that shape these practices.

A study conducted at two research-intensive universities in South Africa showed the extent of student unpreparedness for university Chemistry (Potgieter *et al* 2008), while another highlighted how the backgrounds of black[5] students influence learning in the sciences (Matoti and Lekhu 2008). A disconcerting common finding of these studies is that student success is very limited among black students in general (Cloete and Bunting 2000, Akoojee and Nkomo 2007, Scott *et al* 2007). I concur with Blackie (2010) that an examination of the curriculum of Introductory Chemistry in higher education is an imperative activity whose time had come.

1.7.3 Curriculum inquiry

Curriculum inquiry in higher education is an imperative if the different goals for higher education are to be achieved. While there have been some advances in the field of curriculum inquiry since Barnett and Coate (2005) lamented the idea that the curriculum had not been adequately engaged with in higher education, and Le Grange (2011) pointed to the dearth of studies into higher education curriculum design in South Africa, these authors from opposite sides of the globe agreed about the need for more research engaging with curriculum beyond the obvious questions.

As far back as 1999, Gabel identified a need for further research investigating the role of the structure of Chemistry content knowledge in contributing to student learning. Johnstone (2000) stated that, although research has been conducted on understanding the teaching of Chemistry and the transmission of chemical knowledge, there are still many gaps concerning the "*what*[6]" of chemical knowledge taught. It is especially necessary to focus inquiry on the intrinsic properties of the curriculum for optimal student learning.

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[4] As presented at a Higher Education Learning and Teaching Association of Southern African Conference in 2012.

[5] Black as defined by the South African constitution denotes people from the African, Coloured, Indians and Chinese populations.

[6] Mention was made of the facilitation of access to science education in higher education.

There seems to be universal consensus about the content of Introductory Chemistry knowledge taught in General Chemistry[7]. There also appears to be agreement that one of the major challenges that constrain student learning in the subject is a lack of understanding of necessary chemical concepts and misconceptions (Bodner 1986, Holme, Luxford and Brandriet 2015). According to Potgieter *et al* (2008) due to the fairly homogenous nature of the first-year curriculum in most SA universities, the curriculum structure of the subject is not expected to undergo any major changes in the near future. With this in mind questions about how best to improve epistemological access and student learning are of paramount importance.

1.8 Location of the study

The study is underpinned by a social realist orientation to the sociology of education (Bernstein 1990, 2000), the sociology of curriculum (Young and Muller 2010, 2013), and the sociology of knowledge (Maton and Moore 2010).

Social Realism[8] is underpinned by a critical realist ontology that provides a language for theorising and exploring different forms of knowledge, their structuring and effects on educational practices, including curriculum/knowledge practices. In social realist terms, therefore, the focus of this inquiry was on the internal relations of knowledge and uncovering the underlying organising principles or the “rules of the game” (Maton 2010) in a curriculum with a particular focus on knowledge practices that structure the first-year General Chemistry curriculum, and the implications of these knowledge practices on student learning.

The study was located in the Science Faculty at the LSAU. The LSAU is one of the largest research-intensive[9] residential universities in South Africa, and had about 61500 students, of whom 46.9% were black at the time when the study was initiated. The LSAU’s vision highlights the university’s commitment to improving access with success for entry-level students. As such, the study was framed within the context of the LSAU’s endeavour to improve and strengthen the quality of teaching and student learning.

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[7] See Chapter 2 (Section 2.2) and Chapter 6 (Section 6.3.2) for discussions about the intended curriculum

[8] A more in-depth discussion on Social Realism can be found in Chapter 4, Section 4.5.

[9] These are institutions that produce the majority of postgraduates and future academics, had high student success and graduation rates, high proportions of academic staff with PhDs, high research outputs, high income and low staff-student ratios. The LSAU is one of five such universities in the country (Centre for Higher Education Transformation 2010).

1.9. First-year General Chemistry modules

General Chemistry, the curriculum of which is the object of my study, is one of the first modules students encounter when they register for a Bachelor of Science degree or Health Sciences degree. Inevitably the first-year student intake in the faculty is very high and diverse with the majority of students in these modules being non-science majors. Success in these modules is vital since mastery at the foundational level is critical for continued learning in the discipline. A more in-depth discussion of the nature of learning the discipline of Chemistry is presented in Chapter 2.

At the LSAU, as in most universities, a large number of students from a diverse range of programmes enrol in General Chemistry, and not many continue with the subject beyond the first introductory module (Cooper and Klynkowsk 2013). The Introductory Chemistry modules are pre-requisites for further study in other degrees in the university. All BSc degrees, except those in Engineering and Health Sciences, require students to complete first-year General Chemistry.

The LSAU follows a modular approach to programme design. The first year of Chemistry, referred to as General Chemistry, is offered over two semesters. In the first semester students study Inorganic and Physical Chemistry, while the second semester is divided into two sections, namely, the continuation of Inorganic Chemistry from the first semester, and Organic Chemistry. Like similar first-year General Chemistry classes in other universities in the country, the student numbers for the first semester are usually very large since the subject serves as a pre-requisite for several other programmes in the university. Historically, first-year Chemistry has a high failure and attrition rate; this is especially the case with the first semester module.

As is evident in this study, students have experienced challenges mainly with the first semester module and not with Organic Chemistry offered in the second semester. In order to locate the enquiry appropriately, it was most prudent to examine Introductory Chemistry (referred to as General Chemistry in the study) since learning in the subject is a determining factor in the success of student learning. Inclusion or exclusion to powerful forms of knowledge can enable or constrain student learning and future prospects of continuing in higher education, both in the field of Chemistry and in accessing other areas of knowledge where Introductory Chemistry is a requirement.

1.10 The structure of the dissertation

In this chapter, I provided an overview of the purpose and rationale for the study and outlined the research question. I explained that my research forms part of a bigger research project focusing on social inclusion in higher education in South Africa. I argued why the focus of my study was on curriculum and knowledge practices in Introductory General Chemistry. I noted that I was interested in the effects of the knowledge practices inscribed in the curriculum on student learning and epistemological access.

Chapter 2 lays the groundwork for understanding curriculum practices in the discipline of Chemistry. I provide a discussion on Chemistry as a knowledge field and General Chemistry, specifically, as a social field of practice and an intellectual field of study that has a specific knowledge structure and specific ways of knowing. In this chapter, I discuss approaches to curriculum practices, the constructivist epistemology adopted in General Chemistry and the effects of this on student learning of General Chemistry.

I introduce the theoretical and conceptual framework for the study in Chapter 3. Critical realism is used as the meta-theory for the study. Social Realism and the sociology of education form the theoretical framework of the inquiry. These theoretical approaches evince a layered conception of reality that is appropriate for researching the organising principles structuring the knowledge practices in the General Chemistry curriculum.

The contextual framework for the study is discussed in Chapter 4. Here I introduce the notion of social inclusion in higher education and show how it relates to epistemological access and to the processes of curriculum enquiry. Social Realism is underpinned by the meta-theory of critical realism. Given that a critical realist approach to education holds that knowledge is stratified and differentiated, and has real emergent properties, powers and effects (Maton 2014), a discussion on the knowledge and curriculum practices and social inclusion is offered.

In Chapter 5 the conceptual framework for the study is examined. I provide an exposition of Bernstein's work on the pedagogic device and knowledge structures (Bernstein 1975, 1981, 1990, 1999, 2000) in Section A. LCT: Specialisation and LCT: Semantics (Maton 2000, 2001, 2007, 2010, 2011, 2014, 2016), two aspects of Maton's Legitimation Code Theory, are discussed in

Section B where the conceptual tools and an explanatory framework for the analysis of knowledge and curriculum practices in General Chemistry is discussed.

The research methodology implemented in the study is presented in Chapter 6. The study adopted a qualitative and intensive research design underpinned by a critical realist approach. The processes engaged in for the identification and selection of data and the data generation activities are discussed. I further outline how I used the conceptual tools of the LCT to develop the data analysis processes and tools for the study.

The first section of the data analysis is presented in Chapter 7. I present the analysis of interviews with lecturers and of curriculum documents. Drawing from the data, I discuss the pedagogic discourse generated by the Introductory Chemistry module and the implications of this discourse for curriculum design and student learning.

Chapter 8 provides the data analysis from the curriculum documents to illuminate the nature of knowledge and curriculum practices, and explores the organising principles of the curriculum, using LCT: Specialisation. I provide an account of the dominant organising principles of the curriculum documents and discuss the potential effects on the structuring of the curriculum on student learning.

In Chapter 9, I present the final analysis chapter in which I use LCT: Semantics. I show the extent to which the curriculum practices, as evident in the learning activities, enable knowledge-building and cumulative learning in General Chemistry.

In Chapter 10, I discuss the key findings and conclusions of the study and discuss the implications of the research for understanding student learning of General Chemistry. I outline the contributions and limitations of the study, and offer recommendations for future studies of educational practices aimed at improving epistemic access and student success.

CHAPTER 2 – Chemistry knowledge and learning

> Chemistry is partly a liberal art, and is as much about thinking as it is about synthesis, experimentation, and computation. It is unfortunate that philosophy, which provides the most systematic analysis of ways of thinking, has been traditionally neglected by chemists (Scerri 2003, p. 473)

2.1 Introduction

In this chapter I discuss the epistemology, ontology and the ways in which the knowledge base of Chemistry as a discipline is approached in the General Chemistry curriculum offered at the LSAU. First-year Chemistry is presented as General Chemistry at most universities that offer Chemistry as part of degree programmes. There is extensive research on how the General Chemistry curriculum is structured, (Mbajiorgu and Reid 2006), how students learn in this field, as well as on the barriers to learning, the dominant misconceptions of Chemistry knowledge held by students, and common difficulties that students are confronted with as they engage with university-level Chemistry (see Johnstone 2000 and 2006, Mbajiorgu and Reid 2006, Taber 2011).

Chemistry education often follows a constructivist paradigm which highlights the extensive role played by the student in the construction of understanding and meaning in the process of learning (Bodner 1986, Taber 2011). The constructivist approach has given rise to particular conceptions about student learning in this field. I present an overview of the conceptions of learning which have implications for curriculum design and assessment in General Chemistry. I start by examining the significance of the nature of knowledge in the field of Chemistry. In this discussion, I use the term ‘Chemistry’ mainly to refer to the field as a whole and the term ‘General Chemistry’ to refer to the sub-field of the discipline, which is the focus of this study.

2.2 The nature of Chemistry knowledge

There is a general understanding in chemical education circles that chemical knowledge is a layered form of knowledge that is composed of three connected dimensions. Johnstone (2000, 2006) and Talanquer (2011) propose that the ‘triplet’ relationship suggests that chemical knowledge and understanding of our world is generated, expressed, taught, and communicated using these knowledge dimensions. The three components of chemical knowledge are said to have an explanatory, descriptive, and functional nature where phenomena can be explored by being experienced, observed, and described.

The three dimensions of Chemistry knowledge consist of the domains of the descriptive level (macroscopic), the interpretational (microscopic) and the representational level (symbolism). Figure 1, below, illustrates the conception of Chemistry knowledge suggested by Johnstone.

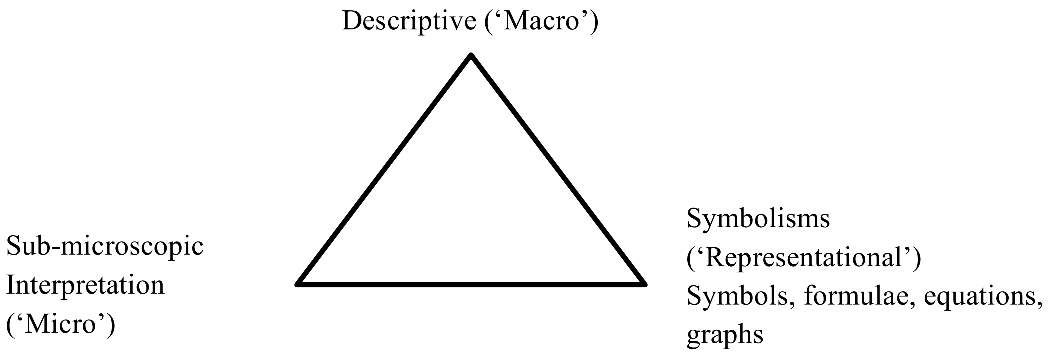

Figure 1. Levels of Chemistry knowledge representation (Johnstone 2000, 2006)

The first level is the macro level, or descriptive dimension that represents what is perceived in the world by the senses without the aid of instruments. The macro level constitutes the concrete and tangible elements of the world that humans come into contact with on a daily basis. Mbajiorgu and Reid (2006) refer to this dimension as the phenomenological dimension of Chemistry knowledge.

The second level is the micro /sub-micro level that consists of abstract knowledge. Knowledge at this level can only be generated with the help of instruments, and it is abstracted by inference from chemical processes. The third level is the symbolic domain, or the interpretation dimension, and refers to symbols, models, and equations through which knowledge is represented. At this level of the sub-micro, the behaviour of unseen molecular materials are interpreted in a representational language system. Signs and symbols are used to represent and communicate concepts and ideas. Learning Chemistry requires the ability to navigate between the three levels (Johnstone 2000, 2006).

Apart from the above-mentioned conceptualisation of the nature of Chemistry knowledge, Talanquer (2011) proposes another form of classification for Chemical knowledge that differs from that of Johnstone's – not in conceptualisation, but in terminology. The basic tenets are that there are three levels or components of Chemistry knowledge, namely, experiences, models, and visualisation where:

- Experiences include descriptive knowledge of chemical substances and processes acquired in direct ways (through the senses) or through indirect means (using instrumentation). When compared to the original triplet relationship of the Chemistry framework, the level of experiences appears to encompass both the macro and the micro levels of Johnstone's representation of Chemistry knowledge where things can be perceived through the senses and with the use of instruments. For example, the process of heat transfer, where heat moves from one body to another, happens at an atomic level and it is possible for the process to be experienced at the sensory level.

- Models include the descriptive, explanatory, and predictive theoretical models that chemists have developed to make sense of the experienced world. Models refer to the theoretical entities, and the underlying assumptions that are used to describe chemical systems by attributing to them some sort of internal structure, composition, and/or mechanism that serves the purpose of explaining or predicting the various properties of those systems.

- Visualisations encompass the static and dynamic visual signs (from symbols to icons) developed to facilitate qualitative and quantitative thinking and communication about both experiences and models in Chemistry. Visualisations refer to the chemical symbols and formulas, particulate drawings, mathematical equations, graphs, animations, simulations, physical models, etc., used to visually represent core components of the theoretical model.

Talanquer (2011) further suggests the addition of a fourth component to understanding the nature of Chemistry knowledge. He proposes that the human element should be added to the mix to emphasise the need to integrate the learning of the discipline within the broader contexts in which Chemistry affects the lives of citizens and communities. This suggestion has yet to gain popularity in the field.

Of the two conceptualisations of Chemistry knowledge, Johnstone's is more popular and has greatly influenced curriculum and pedagogy in the field of Chemistry education, and subsequently, the ideas about how students learn the subject. General Chemistry is no exception. I will discuss in Chapter 7 how knowledge and curriculum practices have been influenced by the triad conceptualisation of the characteristics of Chemistry knowledge specifically at the LSAU.

2.2.1 Curriculum design and the nature of Chemistry knowledge

According to Talanquer and Pollard (2010), in the past few years curriculum design in General Chemistry has followed a student-centred approach. For Sirhan, this means the adoption of principles for the selection and structuring of curriculum material according to the needs of the student, including the organisation of the order of presentation according to the psychology of student learning (Sirhan 2007). Similarly, Johnstone (2000) argues that from a student-learning perspective, the design of the curriculum and the teaching thereof should start from the macro level and build up to the micro and symbolic levels. For example, he suggests beginning with a concrete, everyday example and then proceeding to the abstract.

Mbajiorgu and Reid (2006) support this view and note that the micro and the symbolic constitute interpretations of the macro level. When macro level ideas are introduced first, students can relate this knowledge to what they already know and have experienced, "thus rooting Chemistry in real life rather than allowing it to become a subject of abstraction and symbolic complexity" (Mbajiorgu and Reid 2006, p. 16). Talanquer (2011) argues that understanding the macro level is essential for learning to happen. Learning in Chemistry at all levels requires the ability to represent Chemistry knowledge in the three forms of the macro, the micro and the symbolic domains. The skill of integrating these levels is where students have difficulties.

Although Johnstone (2000) advocates the merits of the triad nature of Chemistry knowledge, he acknowledges that, for the Chemistry curriculum, this presents a paradox since it represents both Chemistry's strength and its weakness. As a field of intellectual pursuit, Chemistry's strength lies in this ability to move across these three levels. Students' inability to navigate across the three levels of the macro, the micro and the symbolic domains is a major factor that constrains student learning in Chemistry. The following excerpt is an example of a common everyday understanding of the experience of cold temperature on the skin as expressed by one of the lecturers interviewed for this study who described how the effects of Chemistry can be experienced everywhere:

> Feeling the wind on your face - it still doesn't tell you that there are minute balls that are hitting your cheeks. There is something... there is a force that constantly hits your face, but what is it? Is it like a jelly or is it balls that hit your face constantly at the same time? (Respondent 3)

The extract expresses the macro level of Chemistry knowledge.[10] In an everyday social setting the description of wind against one's face would suffice as an explanation for the effects of cold

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[10] As discussed in previous Section on Johnston's classification of Chemistry knowledge.

temperature against the skin, but understanding the science behind feeling the wind on one's face requires knowledge of a different kind, knowledge that is more systematic; that is located at the micro level; it requires an explanation of the chemistry behind how air, as a mixture of a variety of gases, behaves when it hits against skin.

Thus, the paradox is that Chemistry's strength as an intellectual field presents an immense challenge when it comes to inducting the next generation of chemists into the knowledge base of the field. This complexity is reflected in the challenges that are faced in designing a curriculum that is accessible to most students. Sirhan (2007) is of the view that Chemistry is a logical subject and that it is tempting to use its inherent logic to build the curriculum. However, for some theorists the challenges to learning Chemistry knowledge is not related to its structuring but to how it is taught. For example, Gabel (1999) does not view the multi-facetedness of Chemistry knowledge as a barrier to Chemistry learning; instead he regards the pedagogical approaches to learning Chemistry knowledge as the problem, since the teaching tends to focus more on abstraction and on symbolic levels.

These viewpoints on the influence of the nature of Chemistry knowledge at disciplinary level (in the field of production of Chemistry knowledge base)[11] have an impact on the curriculum and curriculum design practices (in the field of recontextualisation[12] in the teaching and learning setting). I believe that curriculum designers should take cognisance of the nature of Chemistry knowledge when constructing teaching and learning opportunities and addressing the learning challenges that the complexity of Chemistry knowledge presents for many students of General Chemistry. Furthermore, curriculum designers should also take into account the different ideologies and viewpoints justifying choices made in the curriculum content.

In the following section I discuss how some researchers in the field understand the structure of the General Chemistry curriculum as a subset of chemical knowledge. The discussion focused on the structure of the curriculum for the purposes of first-year Chemical education.

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[11] The notion of the field of production is part of Bernstein's conceptualisation of the epistemic device which is discussed in detail in Chapter 5, Section 5.2.1

[12] In the field of recontextualisation of the pedagogic device, disciplinary knowledge is converted to curriculum knowledge. For a discussion on the concept of recontextualisation, see Chapter 5, Section 5.2.2

2.2.2 The structure of the General Chemistry curriculum

As was the case with the discussion above about the nature of Chemistry knowledge, several ideas have been proposed about the structure of the General Chemistry curriculum. Jensen (1998) proposed that the discipline of Chemistry has a logical structure that consists of nine categories. Each category can be characterised as being molar (concepts and models), molecular or electrical in nature, and as dealing primarily with the composition/structure, energy, or the time dimensions of chemical phenomena.

Gabel (1999) has questioned the appropriateness of the structure proposed by Jensen. She argues that there is a common structure that begins with the explanation of the theoretical concepts of atomic theory and bonding at the microscopic level, before presenting descriptive Chemistry at the macroscopic level.

Talanquer (2011) provides a simpler explanation of each category in the following manner:

> The molar level includes concepts and models that are used to describe, explain, and predict the bulk properties of substances and processes without any reference to their sub-microscopic structure. The molecular is composed of the number and types of atoms, molecules, or ions in a system and their dynamic interaction. The electrical is composed of subatomic components, in the form of electron distribution and dynamic (p. 182)

Johnstone (2000) offers a counter-argument about the structure of Chemistry knowledge for curriculum design. He states that although chemical knowledge was offered in a logical manner, the logic of the subject does not align with the available and well-documented knowledge and literature about how students learn. Instead, the curriculum usually aligns with the logic of the discipline. He maintains that the misalignment or the non-use of the information on student learning causes student learning difficulties in the discipline. As noted by a respondent in the study, the logic of the subject does not align well with the logic in which knowledge is presented, or with student learning in the subject,

> We (lecturers) have felt for a number of years that the order (of topics) is not always logical. You find that sometimes you introduce a topic and before you can teach it, you have to say, "We have not done Chapter 5, but in the first half of the lecture let me quickly give you the basics. And it makes no sense" (*for the student*[13]). (Respondent 2)

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[13] Own emphasis

Similarly, Mbajiorgu and Reid (2006), who conducted research on Chemistry departments and specifically Chemistry curriculum design and development in England, point out that the structure of the curriculum is usually defined by the logic of the subject. They suggest that the Chemistry knowledge required by a senior student majoring in Chemistry plays a vital role in influencing the decisions about the structure of the curriculum in the introductory level. For Mbajiorgu and Reid (2006) the aim of any higher education Chemistry curriculum is not only to educate *about* Chemistry but also to educate *through* Chemistry. Although this intention of educating through Chemistry is noted, Cooper and Klymkowsk (2013) assert that the structuring of the curriculum is strongly influenced by the choices of content knowledge relevant for first-year learning and also by prevailing pedagogic practices[14] and current student-learning theories. Cooper and Klymkowsk (2013) support the view that "curricular design is inconsistent with the realities (and the research observations) of how students learn" (p. 1116).

Sirhan (2007), Talanquer (2011), and Talanquer and Pollard (2010) and others have expressed discontent at the structuring of Introductory Chemistry in undergraduate programmes, and specifically in the first year because the structure of curricula appears to be more in line with the representational dimension of Chemistry and does not take sufficient account of the descriptive macroscopic dimension of the field. From the above discussion, it is clear that the various debates on the structuring of a Chemistry curriculum in Introductory Chemistry can pose a potential challenge for the successful introduction of new students into the field.

2.2.3 The role of the textbook in structuring the General Chemistry curriculum

In the main, curriculum design in Chemistry takes the form of a 'topical ladder' approach to learning Chemistry which demonstrates a range of complexity in the knowledge (Talanquer and Pollard 2010). At LSAU, the structure of General Chemistry is heavily influenced by the prescribed textbooks, a situation in line with Duit and Talanquer (2009), who state that the science textbook greatly influences curriculum design decisions in first-year Chemistry learning[15]. Chemistry lecturers tend to be guided by an evaluation of a textbook, as attested by one of the lecturers that I interviewed who stated that;

> to decide on what we are going to teach we take a typical textbook and that's worldwide (international)…, we look at the first-year textbook and say okay, does

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[14] The notion of pedagogic practices is further elaborated in Chapter 5, Section 5.2.

[15] A further discussion is provided on the use of the textbook for selection of the curriculum in Chapter 7 Section 7.3.2.

> this apply to us in SA? There may be some reasons why we should slightly deviate. (Respondent 3).

This practice of curriculum decision-making is supported by Talanquer and Pollard (2010), who refer to the General Chemistry curriculum as, "a giant toolbox full of tools that students must learn how to use without context or a meaningful purpose" (p. 75). According to these authors, the current General Chemistry curriculum fails to offer opportunities for most students to learn how to approach realistic problems from a chemical perspective, using the powerful and productive models, techniques, and ways of thinking developed in the field. They propose that the curriculum should be designed to demonstrate how *chemists think* and *chemical ways* of reasoning and practice. Citing the US National Research Council (NRC) report, "Beyond the Molecular Frontier" (2003), Talanquer and Pollard propose a model that acknowledges four main activities and essential questions characterising the work of modern chemical scientists. These are: analysis *(What is it?)*[16], synthesis *(How do I make it?)*, transformation *(How do I change it?),* and modelling *(How do I explain it?).* They further state that such central questions would be useful for designing a curriculum for both major and non-major Chemistry students and that it would allow students to recognise, explore, and apply chemical knowledge in different contexts. The key components of the curriculum design practices that they propose appear, on the surface, to be composed of creating long-lasting understandings by adopting effective assessment tools and learning experiences (Talanquer and Pollard 2010). Nevertheless, the proposed curriculum design does not consider the influence of the structuring of the inner logic of the knowledge that can be uncovered using a social realist analysis.

The curriculum design model proposed by Talanquer and Pollard (2010) is appealing because it acknowledges the social nature of knowledge, its construction, and its meaning by attempting to make the learning experiences more relevant and accessible for students. Carmichael (2010) argues that to develop an understanding of the transition between the domains of Chemistry knowledge and the ability to traverse the three levels of Chemistry knowledge at the first-year level is a transformational rather than a foundational process. He furthermore notes that it is a "process of induction and inculcation" (p. 66). The transformations referred to above are not just at a conceptual level, but also at a social and personal level, and involve the student as a person engaged in the learning process. Such an alternative concept of Chemistry learning would have

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[16] Original emphasis.

major consequences for changes in curriculum design practices and ways of thinking for the Chemistry lecturers at the LSAU where the study was conducted.

In this section I discussed the structuring of the Chemistry knowledge from the disciplinary knowledge base. I noted that inclusion of curricular content at the micro level of teaching and learning do not necessarily follow the logic of knowledge of the discipline. From the above discussion, it would seem that, in designing the curriculum, the selection of curriculum content must consider the nature of the student, understandings of student learning, and the type of knowledge that makes it possible to continue with Chemistry as a major.

2.3 An educational paradigm for curriculum design and learning in Chemistry

Chemical education researchers have produced numerous studies on the role of education in Chemistry and the educational paradigms appropriate for learning Chemistry. In the next section, I discuss the constructivist approach to curriculum design in Chemistry, which has been popular in the discipline for many decades.

2.3.1 The constructivist approach to Chemistry knowledge

The current model underpinning science education is constructivism (Johnstone 2000, Taber 2000 and 2011, Mbajiorgu and Reid 2006). Constructivism in science has a multitude of meanings and interpretations. According to Taber (2011), constructivism can be understood as a learning theory, a basis for progressive mainstream approaches to pedagogy providing a framework for educational theory. In addition, constructivism is a philosophical approach to human knowledge and an approach to social inquiry. Constructivism, as a learning theory, views learning as the development of cognitive processes and cognitive structures necessary for knowledge development. Constructivism claims that people learn in an iterative manner (Taber 2011). Actively taking responsibility for learning and creating meaning from the learning experiences by the student forms the cornerstone of a constructivist approach to education. For Taber (2000), from a constructivist perspective, the learning process relies on the student's ability to make connections between what was learnt in high school level Chemistry and the General Chemistry curriculum content the student is exposed to at first-year. Students must generate meaning and understanding for themselves by means of internal cognitive processes. Each student constructs their own meaning and understanding of the learning situation.

As an approach to curriculum design, constructivism focuses on the student's learning experience. The focus is on creating learning environments that will facilitate and support the student in constructing knowledge and creating meaning. The constructivist approach to curriculum design allows the student to participate in processes of thinking, learning, and coming to know. Although constructivism has dominated chemical education research for a very long time, more than 25 years ago, researchers like Bodner (1986) critiqued the constructivist approach in Chemistry as promoting an instrumentalist view of knowledge and knowledge creation. Bodner's critique can be attributed to the technical and positivist approach to curriculum design in the sciences that privilege epistemology (nature and theories of knowledge) as well as the cognitive abilities necessary for learning abstract and complex knowledge, such as scientific knowledge. However, the prevalence of the constructivist approach has prevailed despite the criticism.

2.3.2 Approaches to learning in Chemistry

In this section, I discuss cognitive and conceptual understanding approaches to learning most favoured in Chemistry education literature that are underpinned by a constructivist paradigm, as discussed above. The rationale for including this section about learning approaches is due to the close relationship between curriculum design and curriculum developers' or recontextualisation agents' (in Bernstein's terms[17]) conceptions of student learning. Mbajiorgu and Reid (2006) contend that, to appreciate the relationship between Chemistry knowledge and theories of learning, one needs to understand that Chemistry knowledge is presented in a particular learning environment with a range of characteristics that are peculiar to that context.

For example, the subject knowledge of the lecturer (pedagogical content knowledge[18]) and the experience of the lecturer as the recontextualising agent have a bearing on what is recontextualised as the curriculum. Furthermore, it is necessary to keep in mind that students have particular conceptions of the knowledge presented; they process the knowledge and then represent the knowledge in a range of tasks in ways that make sense to them. It is for this reason that a discussion on the various prevalent approaches to learning Chemistry are discussed in the next section. Lastly, I present this discussion to show how my study deviates from a constructivist orientation that only focuses on the epistemic and cognitive capabilities for learning. In contrast, this study took into account both the epistemic and the social relations of curriculum practices. I discuss cognitive constructivism, conceptions of learning and threshold concepts and consider the implications of these for curriculum and pedagogy.

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[17] An in-depth discussion on recontextualisation is provided in Chapter 5 Section 5.2.2.

[18] See Shulman LS (1986, 1987).

2.3.2.1 Cognitive development approaches

2.3.2.1.1 Information processing model

The information processing model as proposed by Johnstone (1993, 2000, and 2006) is a cognitive development model that emphasises the student's ability or lack thereof to learn large volumes of information. The model is premised on the idea that structuring the curriculum design and development activities to align with the way students process information should lead to better student performance. The intention is to organise learning so as to reduce the demand on the working memory, to prepare students for the introduction of new material through pre-lectures or pre-laboratory sessions, and to reduce noise or redundant material while making key material explicit (Johnstone 2006).

The model operates – as illustrated in Figure 2 below – on the premise that short-term Working Memory Space (WMS) and long-term memory have different functions in the processing of learning, and subsequently, in learning and building knowledge.

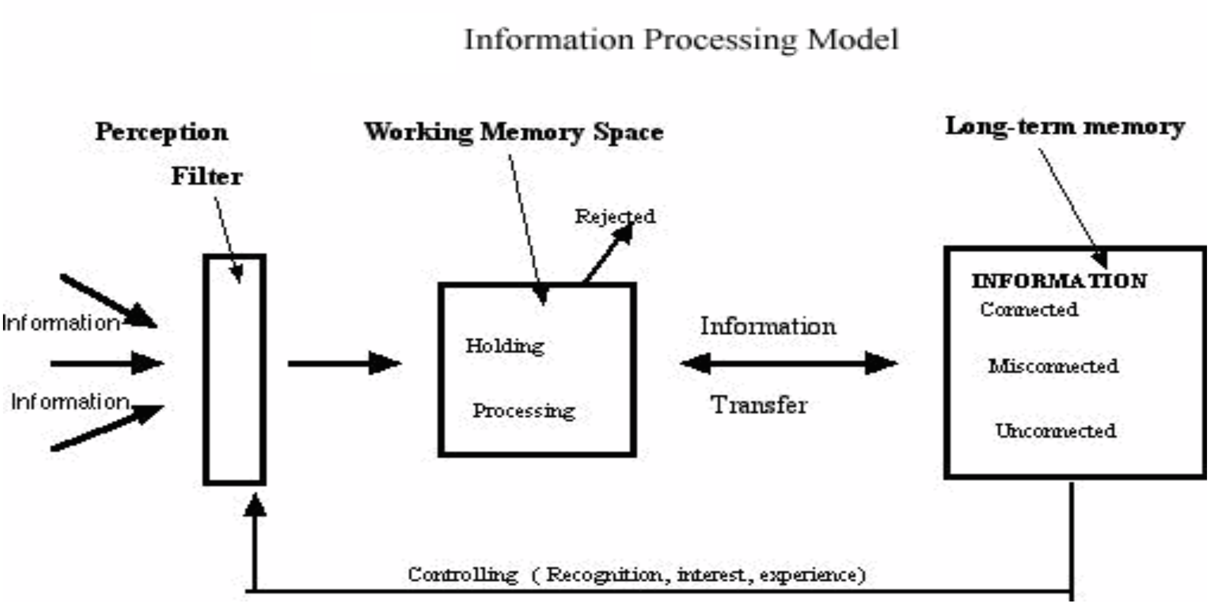

Figure 2. Information processing model (Johnstone 2006, p. 56)

The student receives information that is filtered as it enters the processing part of the brain, the WMS. Information is held temporarily in the WMS while the brain makes sense of it by preparing the information processing in the long-term memory. Information stored in long-term memory is made available for processing when connections and links in the information can be made. This process is facilitated much faster if the information in long-term memory finds suitable connections with the memory in WMS. As represented in Figure 2 above, the movement of information between WMS and long-term memory results in transfer and, supposedly, learning (Johnstone 2006). Learning is premised on the idea that the amount and the difficulty of information affects this process. Chemistry knowledge is complex, abstract, and dense and requires complex processing of information of the different levels of the Chemistry knowledge (the triplet relationship discussed in Section 2.2 above). This complexity has the potential to create information overload. According to Johnstone (2006), information overload in WMS results in no learning occurring since the WMS has limited capacity for processing information.

The information processing model is widely accepted in the chemical education research field as the most useful approach to explaining student learning and to make sense of the challenges that Chemistry knowledge presents to students (Gabel 1999, Sirhan 2007, Reid 2009 and Talanquer 2011). Given the WMS approach to student learning, Reid (2009) identified three studies that provide evidence that the limited capacity of working memory in designing the curriculum had positive effects for learning. From a cognitive constructivist approach to learning in the discipline, therefore, the model still holds widespread appeal for many in Chemistry education.

2.3.2.1.2 Cognitive load theory

Related to the WMS approach discussed above is *cognitive load theory* pioneered by Sweller (1988). Cognitive load theory is focused on the effects of the design of learning materials (task complexity) on effective student learning and the limitations of working memory and information processing. Van Merrienboer and Sweller (2005) have identified three forms of cognitive load when designing for learning, namely, *extraneous, germane* and *intrinsic loads.*

Extraneous load refers to the appropriateness of the curriculum design in relation to all the external factors that can distract students from paying attention to what is relevant to the curriculum. For example, the LSAU General Chemistry modules have an online presence through the module webpage on the Learning Management System. The knowledge content and materials placed on the webpage should be relevant to support students' current learning needs. Any additional materials and links that are not part of the content knowledge or formal learning can cause an extraneous load requiring the student to make decisions about what is relevant and what is not. Therefore, the inclusion of links with science information and interesting pages on scientific matters that the students can access, but that are not essential to the curriculum can be disturbing for the student.

Germane load refers to information and processes that relate directly to the degree of the effort demanded by the present learning and results in connections being made between new information and what is known. Germane load is also linked to the extent of interest and motivation associated with the learning, thus enabling the formation of schemas.

Intrinsic load refers to the interactivity of elements and the innate difficulty of certain topics, and how this impacts on student learning. Relevant to this study is the intrinsic load inherent in the curriculum texts, the complexity of Chemistry knowledge and how they impact on working memory topics, such as formula stoichiometry, and stoichiometry which, on face value, look similar but in terms of content are different topics and are examples of General Chemistry content with intrinsic load.

The different themes in the study guide can be found in different chapters in the textbook. These topics are inherently difficult and must be broken down into smaller subtopics or themes to facilitate learning. The curriculum design principles of sequencing and progression are key when considering how to ensure optimal intrinsic load of the learning materials. As a design principle, dividing the work into smaller manageable chunks of interconnected information, but maintaining the golden thread of the theme or topic would assist in reducing intrinsic load. The effort required for learning the difficult content is reduced, even in the subjects that are highly abstract in nature. *Extraneous load* and *germane load* can be manipulated through various teaching and learning design strategies much more easily than is the case with *intrinsic load*[19].

As noted above, General Chemistry requires complex learning of very abstract knowledge. The level of complexity is influenced by the cognitive demand of the knowledge. Complexity is also influenced by the degree of interactivity between various elements in a knowledge field. The principles of sequencing are significant for creating coherence and facilitating progression, and for promoting learning of complex content.

Both the information processing model and cognitive load theory are concerned with the brain's capacity to process information, and the influence of prior knowledge on new learning. For an entry-level subject like General Chemistry, it is important to understand that different topics have different demands in terms of cognitive load and in terms of ensuring capacity for transfer of learning to long-term memory. Such understanding is useful for shaping curriculum practices, especially in the introductory levels of the discipline.

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[19] I further mention the relevance of intrinsic load in Chapter 9, Section 9.6

2.3.2.2 Conceptual change

C*onceptual change theory* is another cognitive processing approach that can influence curriculum design and subsequent student learning. The notion of conceptual learning emerging from conceptual change is widely accepted as a major learning objective in the discipline of Chemistry. Posner, Strike, Hewson and Gertzog (1982) state that conceptual change processes can lead to either weak knowledge restructuring, which can be referred to as conceptual capture, or to strong knowledge restructuring known as conceptual exchange. Both conceptual capture and conceptual exchange can be compared to the assimilation and accommodation model for conceptual change. In assimilation, new knowledge is made to fit with existing information, whereas accommodation occurs when new information is restructured to aid appropriation because it does not fit the existing information. The assumption underlying conceptual change is that conceptual learning occurs as a result of "restructuring of pre-instructional structures in order to allow for understanding of the intended knowledge" (Duit and Treagust 2010, p. 673).

Conceptual change would happen in the first-year class, where knowledge previously gained from high school, and which often contains misconceptions, is reconfigured and replaced by more accurate knowledge resulting in more meaningful understanding of what is learnt (Taber 2011).

Conceptual learning assumes that learning is a rational process and that information can be conveyed in a rational manner that is accessible or understandable to the student given his or her prior conceptions. The conditions for conceptual change include dissatisfaction with existing conceptions (for example, as a result of the presence of anomalous data), intelligibility, plausibility, and fruitfulness of a new conception. Knowledge acquired as part of a process of conceptual change includes knowledge related to problem solving, critical thinking, reflective thinking, and metacognition. To facilitate learning of Chemistry knowledge, which is theoretical and conceptual in nature, the most desirable form of learning would be that which optimises the cognitive abilities for learning (Mayer 2002).

There seems to be a close link between conceptual learning and meaningful learning. For Duit and Treagust (2010), in order for students to get to real understanding of chemical knowledge, they have to be able to make meaningful connections between different concepts. *Meaningful learning* has been described as occurring when students build the knowledge and cognitive processes needed for successful problem solving (Mayer 2002). For Anderson and Schonborn (2008), meaningful learning occurs when students have sufficient prior knowledge upon which to anchor new ideas. Knowledge is experienced as relevant if there is existing information that can act as a referent for new knowledge.

Taber (2011) describes meaningful learning in much simpler terms as "a process of personal meaning making through that individual's current knowledge and understanding," (p. 44). The individual is responsible for interpreting experiences in the learning context and drawing relevant meaning from such experiences. Similarly, Palanca (2012) posits that meaningful learning, according to a constructivist framework, occurs where opportunities for unpacking concepts occur in such a way that students are able to relate, differentiate, organise, and integrate concepts. The integration of concepts is key for meaningful learning[20] (Mayer 2002, Duit and Treagust 2010, Sirhan 2007, Palanca 2012).

2.3.2.2.1 Conceptual understanding and meaningful learning

The overall objective of conceptual learning is conceptual understanding. Anderson and Schonborn (2008) explain that the notion of concept in conceptual learning is both complex and multi-faceted. For them, understanding a concept means the ability to:

- *Memorise knowledge* of the concept in a mindful manner, as distinguished from rote learning;
- *Integrate knowledge* of the concept with that of other related concepts so as to develop sound explanatory frameworks;
- *Transfer and apply knowledge* of the concept to understand and solve (novel) problems;
- *Reason analogically* about the concept by making connections between abstract concepts with concrete concepts for improving understanding;
- *Reason locally and globally* about the concept (systems thinking) (ibid: p. 311).

Similarly, a more recent survey conducted in 2013 of over 1400 academics from the American Chemical Society involved in teaching first-year Chemistry found that the definition of conceptual understanding in General Chemistry proved challenging (Holme *et al* 2015). They discovered that conceptual understanding of the core Chemistry ideas, theories, practices, patterns, and relationships necessary for first-year level learning could be narrowed down to five key features, namely;

- *transfer* – the ability to apply core Chemistry ideas to chemical situations that are novel,

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[20] The issue of meaningful learning is further elaborated in Chapter 8, Section 8.4 as part of assessment practices in General Chemistry and Chapter 9, Section 9.5.

- *depth* – the ability to reason about core Chemistry ideas using skills that go beyond mere rote memorisation or algorithmic problem solving,
- *predict* – the ability to expand situational knowledge to predict and/or explain behaviour of chemical systems,
- *problem solving* – the ability to demonstrate the critical thinking and reasoning involved in solving problems, including laboratory measurements,
- *translate* – the ability to translate across scales and representation (ibid: p. 1480).

These conditions for conceptual understanding and learning signify the complexity of the process of learning in the field. Anderson and Schonborn (2008) and Holme *et al* (2015) have identified common features for meaningful conceptual learning such as integration, transfer, and application for problem solving which should be taken into account when designing curriculum at the introductory level.

In sum, from the above discussion on the cognitive and cognitive constructivist approaches to learning in General Chemistry, it is evident that generally, the theorising of student learning in Chemistry places a great premium on the students' mental abilities and their capacity for information processing. The organisation of the knowledge content into manageable chunks of information, as well as the sequencing, pacing, and timing of the delivery of content should all be considered to accommodate the limitation of the WMS. From a social realist perspective, the cognitive approaches, although possessing good explanatory potential, provide a one-sided view of learning which focuses on cognitive abilities for knowing, and not on the knower. The next section offers an overview of the curriculum design approach focusing on promoting access to knowledge for meaningful learning.

2.3.2.2.2 Threshold concepts

A key concern in the study was epistemological access to knowledge. In many studies concerning epistemological access[21], an academic literacies approach has been found useful in enabling student access to disciplinary knowledges. The academic literacies approach does not seem to be used in Chemistry education in the environment where the research study was conducted. An approach that facilitates the idea of enhancing epistemological access and thinking about improving curriculum design, teaching, and student learning in General Chemistry is the notion of threshold concepts. Meyer and Land (2003, 2006), describe a threshold concept as "akin to a portal, opening up a new and previously inaccessible way of thinking about something", in

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[21] See for example, Ellery 2016, Wheelahan 2010.

contrast to a "core concept as a conceptual building block that progresses understanding of the subject" (pp. 4–6). These concepts represent "fundamental ways of thinking and practising in a discipline," (Land, Cousins, Meyer and Davies 2005). For Meyer (2010) the notion of threshold concepts entails the identification of transformative "waypoints" in student-learning journeys; a lens that focuses on the learning of concepts that really matter, involving both cognitive and ontological shift (ibid; p. 192). Transformation is the cornerstone to the change required for meaningful student learning and knowing which is profound and lasting

When a student does not understand a particular threshold concept and gets stuck, the chances of gaining access to and understanding of a particular topic is compromised. As such, threshold concepts, can be regarded as "troublesome knowledge" (Perkins 2006). Perkins (2006) identified five kinds of troublesome knowledge, namely, ritual and inert knowledge; knowledge that is conceptually difficult; foreign knowledge; alien, or tacit knowledge. As indicated in the previous section,[22] meaningful learning of Chemistry involves conceptual understanding. Chemistry knowledge can be referred to as troublesome mainly because it is conceptually difficult, especially for the first-year novice student.

Mostly, Chemistry knowledge at first-year level consists of concepts that represent troublesome knowledge, but once understood, this knowledge is transferable, irreversible, and integrative and allows connections to be made with other concepts (Park and Light 2009). Chemistry knowledge can also be regarded as troublesome knowledge in that it requires students to move from a common sense understanding of terms to discipline-based understandings of terms. The process of understanding the crucial concepts may then not cause cognitive dissonance for the student but be a transformational experience. The next section explores the relevance of understanding threshold concepts for supporting a social realist conception of the Chemistry curriculum and student learning.

2.3.2.2.2.1 Designing for transformational learning and threshold concepts

Johnstone's (2000) review of chemical education research, provides a historical overview of forty years of chemical education research at the foundation level. He noted challenges with some of the problematic areas of Chemistry teaching, particularly in relation to content areas like the mole, the misconceptions about matter, equilibrium, and free energy. Numerous researchers such as Taber (2000) citing Griffiths (1994) and Garnett *et al* (1995) have identified these topics and

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[22] See Section 2.3.21 on conceptual change and learning in Chemistry

several more as knowledge areas that are challenging to students, and that cause them to develop alternative conceptions of these knowledge areas.

Designing curricula in ways that take account of threshold concepts has gained popularity in many fields like the sciences, education, engineering, and economics (Carmichael 2010). As an approach to curriculum design, the process begins with a focus on challenging learning experiences by identifying concepts regarded as threshold concepts. More recently, in Chemistry education, Park and Light (2009) have identified atomic theory as a threshold concept that poses troublesome knowledge for students. Similarly, Talanquer (2015) notes that threshold concepts cannot be ignored in chemical education. He mentions topics like chemical equilibrium and chemical bonding which require meaningful understanding.

Talanquer (2015) defines a threshold concept in Chemistry as a "complex construct that can be expected to involve a variety of *conceptual, epistemological and ontological* elements" (Talanquer 2015; p. 4). The *conceptual elements,* as discussed above, refer to the basic concepts such as chemical reactions and chemical elements in chemical knowledge in the discipline. The focus of most Chemical education is the development conceptual understanding. The *epistemological elements* refer to understanding of disciplinary practices, that is, knowing how explanations and arguments are built in the discipline. The *ontological element* constitutes "thinking about the nature of entities and processes under consideration and the relationships between such components. For example, do students conceptualise electrons in an atom as solid objects or as standing waves?" (ibid; p. 5). For Talanquer (2015), taking into account all three elements (conceptual, epistemological and ontological) is necessary for the development of crosscutting threshold schemas necessary for student learning.

As will be explained in Chapter 5, General Chemistry knowledge is semantically dense.[23] Viewing curriculum design through the lens of threshold concepts means that learning is seen as a transformational experience with lasting effects. A social realist approach to curriculum design that includes a focus on threshold concepts is proposed as a means to enabling optimum student learning and affording students access to powerful and relevant knowledge. The threshold concept design model promotes a holistic approach to curriculum design with the student as the focus. As a curriculum design tool, the identification of threshold concepts provides curriculum designers with a mechanism for inquiry into the distinctive ways of knowing and practising in Chemistry (Carmichael 2010, Talanquer 2015). As part of crossing the conceptual divide and enabling

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[23] See Chapter 5, Section 5.11 for a discussion on LCT: Semantics.

student learning, Davidowitz and Chittleborough (2009) suggest introducing Chemistry knowledge in the curriculum through diagrams in order to help students make connections between the different levels of Chemistry knowledge, thus allowing for engagement, not just abstractly, but also perceptibly.

2.4 Summary

In this chapter I have presented a discussion on the nature and structure of knowledge in Chemistry as a field of study. The complex nature of Chemistry knowledge creates challenges for student access to the knowledge and knowledge practices of General Chemistry, and as a result, for the design of the curriculum. The curriculum design practices in General Chemistry are underpinned by cognitive constructivism and are premised on the brain's capability to engage and process new knowledge. The subsequent approaches to facilitating student-learning focus on the epistemic nature of knowledge and thus on students' abilities to achieve conceptual and meaningful learning in General Chemistry, and I have argued that, given the complex nature of learning in the field, it is important to understand how curriculum design practices in the discipline can contribute to facilitating epistemological access to General Chemistry knowledge.

As discussed earlier in Section 2.3.2.2, meaningful learning is a key objective of conceptual change and transformational learning. Given the nature of Chemistry knowledge, the introduction of the notion of threshold concepts as an approach to understanding student learning and as a basis for curriculum design that enables epistemological access to the ways of thinking and practising in a discipline offers mechanisms for supporting meaningful engagement with the troublesome knowledge in Chemistry. Simply, there are some rudimentary concepts that are more difficult to learn than others, but once learnt, the understanding of these concepts allows for further understanding of other concepts. When there is a focus on threshold concepts as an approach to promoting student learning, the boundary between everyday and scientific language is negotiated, and the learning experience is made more meaningful.

CHAPTER 3 -The theoretical framework

Reality has an objective existence, but our knowledge of it is conceptually
mediated: facts are theory-dependent but they are not theory-determined
(Danermark, Ekström, Jakobsen, Karlsson 2002, p.15).

3.1 Introduction

In this chapter I provide an overview of the literature on the key theoretical constructs used in the study.

Critical Realism as a meta-theory, specifically transcendental realism as developed by Roy Bhaskar (1998), provides the underpinning theoretical framework for the study. As an anti-positivist philosophy, critical realism espouses a depth ontology that describes reality as stratified, differentiated, structured and ever changing. A critical realist philosophical position provides a lens for explaining the layeredness of reality, and how this reality can be understood, as well as how it enables claims to be made about the nature of the world (Maxwell 2004). I chose this meta-theory because of the underpinning ontological orientation and its strong potential for enabling nuanced explanations of social contexts and processes. In this study, the theory enables the generation of explanations of the effects of curriculum design practices on student learning in a first-year General Chemistry course.

3.2 The theory and meta-theory

The question of what is theory, its relevance for research, and how it is used in research is central to all scholarly work. Maxwell (2003) describes theory as a set of concrete and abstract concepts that stand in relation to each other and to phenomena. He views theory as a structure that is intended to ‘represent or model something about the world’ (p. 42). He states that theory illuminates what is seen by drawing attention to particular events and phenomena, and sheds light on relationships that otherwise may not be understood, or may go unnoticed (ibid). Furthermore, the term ‘meta-theory’ is a broader conception of a theory that has greater explanatory potential *about* other theories and about the world. Wallis (2010) defines meta-theory as

> primarily the study of theory, including the development of overarching combinations of theory, as well as the development and application of theorems for analysis that reveal underlying assumptions about theory and theorising, (p. 78).

Broadly speaking, one can regard a meta-theory as providing a foundation that shapes the way we see the world, and that makes it possible to understand and integrate theories across disciplinary boundaries.

In this study, basic critical realism (CR), known as transcendental realism, is used as the meta-theory informing my ontological and epistemological understanding of phenomena in the natural and social worlds. The philosophy makes a valuable distinction between *being* in the world (ontology) and *knowing* in the world (epistemology), with greater emphasis placed on the ontology for understanding the world. This distinction is a noteworthy feature of CR which propositions the criticalness of the theory as a tool for explaining what 'is' (ontological realism), from what 'can we know or what can be known' (epistemological relativism) and for making rational choices about what we know (judgemental rationalism). It is this explanatory potential of CR that gives it a critical advantage over other theories of science (Danermark *et al* 2002).

As a meta-theory, CR forms the philosophical under-labourer (Bhaskar 1998) to other theories used in processes of inquiry. The meta-theory has an undergirding function that supports and describes what the philosophy intends to do in research by providing a basis for understanding good practices in social science research, thus providing a good grounding for research practices in social science.

Ayers (2011) states that CR as a meta-theory provides the middle ground for epistemological, ontological, and methodological assumptions. This middle ground position is congruent with the idea of inquiry, exploration and discovery where there is no intention of proving or disproving a hypothesis, but of offering plausible explanations about the social and natural world.

3.3 Central tenets of critical realism

I now turn to a discussion on the central tenets of CR. Critical realism understands the world as existing relatively independently of our knowledge or our thinking about it, and knowledge itself is understood to be transient, changing and fallible (Bhaskar 2012). The fallibility of knowledge is a significant feature of CR that offers an alternative from the extreme empiricist, positivist and relativist perspectives on reality and epistemology. Scott (2006) argues that the notion of fallibility acknowledges "new ways of describing the social world as always operating and replacing old ones (ideas and theories) even if those new ones (ideas and theories) are in a critical relationship with the old ones" (p: 636). The view that things in the world exist without our knowing of their existence provides the basis for expanding perspectives on phenomena and the promise that there is infinitely more than we can ever know *in* the world *about* the world.

Transcendental realism posits three key principles for ontological depth, namely, the notion of transitivity, stratification, and transfactuality Bhaskar (1998). The following discussion explains transitivity and stratification and argues for their relevance to this study.

3.3.1 Transitive and intransitive dimensions of knowledge

Central to CR is the concept that the world operates independently of our knowing or thinking about it (Bhaskar 1998, Sayer 2000). A distinction is made between the objects of science, namely, physical processes in the natural sciences, and social phenomena in the social sciences. Things in the natural sphere such as sound, air, atoms and light existed before humans confirmed their existence and studied their properties and powers. The term *thing* as used in a realist orientation does not have a pedestrian meaning in this context. Fleetwood (2009) offers a useful description of *things* as entities or objects that have an intrinsic composition with specific properties and powers. Furthermore, things can be physical, artefactual, social, or ideal. Objects of science are referred to as objects of knowledge in this study and denote that which is intransitive.

The intransitive dimension refers to the objects of science that are relatively enduring and do not depend on human activity for their existence (*ontological realism)* but our *knowledge* of the objects of science is *transitive* because it can be revised in the face of new evidence (Sayer 2000). Knowledge of things in the intransitive dimension can be progressively known through interaction between the social world, theory and our experiences of the world (Burnett 2007).

The *transitive* dimension is composed of our knowledge of the world and constitutes the social aspects of science (*epistemological relativism)* (Shipway 2011). Transitive knowledge is socially produced and is subject to change as new evidence comes to light (Danermark *et al* 2002). Since CR views knowledge as socially produced, knowledge is relative in terms of time, and the social and political contexts of its production. The transitive dimension comprises the ideas and meanings held by people in society in the form of concepts, beliefs, discourses, theories, paradigms and models that attempt to explain the intransitive (Maxwell 2012a, Maxwell 2012b, Shipway 2011, Sayer 2000).

The ‘objects’ that are studied in General Chemistry represent the intransitive dimension of the natural world while the knowledge that emerges from that inquiry, and consequently the knowledge included in Chemistry curricula is socially produced knowledge and comprises the transitive dimension. Through the human activity of experimentation, the intransitive object of scientific knowledge is generated and becomes the numerous theories and laws that describe the world and how we know it, thus making the discovery of such knowledge a social practice. Whatever is discovered in the intransitive dimension (ontology) is framed and articulated in the transitive (epistemology) dimension (Shipway 2011). Understanding the distinction between the intransitive and transitive domains of knowledge avoids the pitfalls of conflating and drawing parallels between ontology and epistemology. Bhaskar (1998) refers to the *epistemic* fallacy[24] representing a serious weakness in most non-realist research. The epistemic fallacy suggests that the question of ontology, which is the question of what is *known*, is reduced to the question of *how we can know* what is. Critical realist research in its orientation and methodology attempts to avoid conflation of what the world is (nature of reality) with our understanding of how we know the world to be (nature of knowledge).

3.3.2 Depth ontology

Fundamental to CR is the notion of 'depth ontology' that describes the world as stratified, differentiated and changing. A critical realist orientation to the world proposes a complex and multi-layered concept of reality that makes it possible to examine and explain "the conditions under which reality might be changed" (Bhaskar 2012, p. 54). In what follows I discuss the three domains of reality: the empirical, the actual, and the real.

3.3.2.1 The empirical domain

The domain of the empirical involves our sense experiences *in and of the world* that are directly or indirectly observable. Elder-Vass (2005) regards experiences as socially defined conceptual frameworks that are constructed on the basis of our sensual perceptions. Not all events are experienced or observed, and so reliance on the empirical to explain the world provides a limited, surface view of reality (Collier 1994, Danermark *et al* 2002, Sayer 2000). Thus, assigning meaning to the world on the basis of experiences at the empirical level can be misleading and inaccurate due to the subjective nature of experiences and observations. The interpretation of experiences is rather subjective, contextual, and dependent on a specific frame of reference, and can be one-sided. Reliance on empirical observations for arriving at research conclusions can

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[24] Own emphasis denoting the significance of the conflation of ontology with epistemology as explained by Bhaskar (1998).

therefore be inadequate. In terms of Chemistry knowledge, the empirical domain relates to the empirical knowledge that we have or gather about chemical systems[25] through sense data.

In the study reported on in this dissertation, the empirical domain constitutes the *effects* of the curriculum as planned and implemented. Poor academic performance and the high failure rate in Chemistry can also be regarded as evidence of students' experiences of struggling with first-year in Chemistry.

3.3.2.2 The actual domain

The domain of the actual is the layer of reality where events occur. Events and phenomena are generated by the interaction between structures and mechanisms within a certain context in the domain of the real. The ever-present potential for the occurrence of events depends on the activation of generative mechanisms some of which we may be aware of while others escape our notice. A critical realist understanding of generative mechanisms or causal powers holds that an object's properties are intrinsic to the object and its structures. Collier (1994) explains that there are causal criteria that can be used to explain occurrences, practices and processes that happen in the world whether perceived or not. Examples of the actual domain from the study include the curriculum documents in the form of the study guide and textbook both of which represent organised knowledge. Curriculum design and development and assessment activities that take place in the classroom and the laboratory or through web-based and textbook activities are other examples of entities at the level of the actual.

3.3.2.3 The real domain

The domain of the real is the layer of reality where the structures, powers, and mechanisms of objects or things operate (Sayer 2000, Bhaskar 1998). Occurrences that are observed as events at the level of the actual, and experienced at the level of the empirical are caused by the interplay between structures and mechanisms at the level of the real. The mechanisms that generate an outcome are referred to as generative mechanisms. According to Bhaskar (1998) mechanisms and not events generate phenomena that manifest as events and form the intransitive objects of knowledge.

Although generative mechanisms can be active or inactive, they are regarded as possessing powers that can be realised or not realised, activated or not activated, experienced or not

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[25] See the discussion in Chapter 2, Section 2.2 on the triplet relationship of chemistry knowledge that constitutes the nature of chemistry as proposed by Johnstone, among others.

experienced. Danermark *et al* (2002) note that the generative mechanisms at the level of the real are regarded as stratified since they can be present in the different strata of the world ranging from the physical, biological, and social worlds.

Bhaskar (2010) provides an example of the different strata that make up the multi-tiered stratification of the world. He argues that "material objects such as tables and chairs are constituted by molecules, which are in turn, constituted by atoms, which are, in turn, constituted by electrons, which are, in turn, constituted by more basic phenomena or fields" (Bhaskar (2010, pg.3). The table below shows how each domain of reality is constituted.

	Empirical	Actual	Real
Experience	√		
Event	√	√	
Mechanisms	√	√	√

Table 1. Domains of reality (Bhaskar 2008, p. 13)

An example of the real in the context of this study is the form taken by the content knowledge that constitutes the curriculum. The curriculum as the object of study is an entity that has causal powers. The organising principles of the knowledge included in the curriculum are the mechanisms that structure this knowledge. Therefore, the knowledge structure has causal efficacy in relation to the degree to which students can access[26] and acquire knowledge. Similarly, it is important to remember that the focus of the study was not on classroom practices, but on the pedagogical processes inscribed in the study guide and in assessment tasks, that is, the intended and the assessed curriculum.

Furthermore, the beliefs and conceptions that are held by the lecturers that influence decisions about how to structure the curriculum can be located in the domain of the real because these constitute *mechanisms that have the potential to* impact on learning, resulting in certain

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[26] The notion of access to powerful knowledge was discussed in Chapter 1 (Section 1.4). Gaining access to this knowledge is referred to in the literature as epistemological access. A further exposition of the concept of access in relation to social inclusion is provided in Chapter 4. The term 'epistemological access' has depth of meaning since it pertains to how students interpret, understand, and use knowledge gained through teaching, learning, and assessment activities.

tendencies and effects. These tendencies can manifest in the domain of the actual as decisions about the selection, sequencing, and pacing of the knowledge in the curriculum, and later recontextualised in the teaching and learning tasks and activities in the study guide and the lectures. This study was concerned with examining the *what, how* and *why* of the curriculum that could enable or constrain student learning. A central question of the study was how the various knowledge and curriculum practices can result in outcomes that exclude or include students through their design and development.

3.3.3 Emergence

A distinctive feature of the CR depth ontology is the capacity of lower levels of the reality spectrum to give rise to events and experiences at a higher level. This process is known as *emergence*. The notion of emergence in-depth ontology means that entities or things possess emergent properties that are intrinsic to them and give rise to other entities. Such movement is usually from the level of the real to the level of events and experiences, and implies a connectedness and fluidity of the entities (Easton 2010). Emergence accounts for how occurrences and experiences can be activated by generative mechanisms and actualised.

In the social world, experiences at the level of the empirical emerge from events at the level of the actual, which in turn, can be attributed to causal mechanisms that emerge from the level of the real. In describing the emergent properties of water, Elder-Vass (2005) argues that

> … the properties of water are clearly very different from those of its components, oxygen and hydrogen, when these are not combined with each other in the specific form that constitutes water. One cannot, for example, 'put out a fire with oxygen and hydrogen'. Hence water has emergent properties (p. 318).

The curriculum is an example of an entity that has emerged from the field of education, but it is irreducible to the field of education (Shipway 2011). The study guide emerges from the selection and organisation of knowledge for the curriculum. The content knowledge in the learning activities is not reducible to the knowledge found in the field of production and the field of recontextualisation from which these activities have been derived. The properties of the curriculum differ from the properties of the knowledge field and from the people who reproduced the curriculum.

3.4 Critique of critical realism

CR has several detractors who criticise the philosophy for numerous reasons. Jeffries (2011) in his critique of CR suggests that, although CR differs from empiricism and materialism, it has adopted eclecticism in terms of positioning and can be combined with metaphysics, metaphors and religion with no distinguishing paradigm. He states that in CR there are no laws, no deductions and no predictions. He further finds the rejection of empiricism by CR as a flaw in the theory (CR). According to Jeffries, the key proponents of CR, such as Bhaskar, Lawson and Fleetwood often contradict themselves by making inconsistent arguments that are also incoherent.

Jeffries' position on critical realism indicates a lack of understanding of the core tenets of the philosophy which aims to offer explanatory critique by exposing and eliminating ideological obstacles and inconsistencies and demonstrating that the work of science is grounded in the stratified world of real and enduring entities. The potential of the theory to explain the social causes of societal phenomena is significant to CR (Danermark *et al* 2002).

Hammersly (2009) questions the criticalness of CR and the degree of objectivity that can be attained in CR studies. He cautions that research that intends to produce knowledge that is transformative is more prone to bias and value-laden findings. The research conclusions that are reached, as well as the descriptions and explanations of evidence, contain value judgements (Hammersly 2009). To counter this argument, CR posits that value judgements are minimised through the use of thinking tools that allow for reductive, transfactual and counterfactual arguments for identifying mechanisms at play.

3.5 The relevance of critical realism for exploring knowledge and knowledge practices

Central to the CR project is uncovering structures and mechanisms. The choice of adopting a critical realist approach in this research was congruent with my aim to explain the nature of the underlying organising principles that structure the first-year General Chemistry curriculum, and their potential effects on student learning. Through examining the knowledge practices and their identification, and uncovering the generative mechanisms that inhere in the curriculum, the realist approach offers greater explanatory power by allowing me to ask the 'What can be?' question instead of the 'What is?' question (Sayer 1998). The typical nature and starting point of questions in CR seek understanding of the world by asking what the world must be like for certain things to happen (or to be as they are). Therefore, the question of 'what must the knowledge practices be like in the first-year General Chemistry curriculum to either enable or constrain successful student success?' forms the backbone of the study.

Central to CR philosophy is the claim that the world cannot be changed rationally unless the world is interpreted adequately (Bhaskar 1998, Sayer 2000). Interpretation can be attained through understanding the layeredness of reality, and the interrelatedness of structures and agency for the purposes of explaining causation, powers, and tendencies in the natural and social world.

Fairclough, Jessop and Sayer (2003) define causation as being about "what produces change [the activation of causal powers and generative mechanisms] it is not about [whether observers have registered] a regular conjunction of cause and effect events" (p. 3). Maxwell (2012a, 2012b) argues that causation is real. The concept of causality in CR differs from constructivist and positivist views of causation because a CR explanation of phenomena does not seek regularity or consistency in the relationship between variables.

Causation in critical realist research focuses attention on the importance of the context in which the social phenomenon is occurring. Causal processes in social phenomena occurring in an open system mean that explanations are contingent on context. In this study, the notion of causation is not linked with establishing cause and effect associations, and observations of regularities, but causation denotes the processes involved in identifying generative mechanisms that bring about events and experiences. Critical realism, through a different lens and by asking different questions differently, offers the opportunity to interrogate issues that plague society.

By employing a critical realist orientation in the study, I achieved a threefold objective. Firstly, since CR allows questions about the nature of reality in the world, I was empowered as a researcher to be critical about my assumptions on how reality can be understood. Critical realism offers a unified approach to the natural and social sciences while recognising real, but different, structures and processes in the physical, biological and social worlds. These worlds are part of a reality that is stratified with each having distinct objects of knowledge. The objects of the natural world are naturally produced while the objects of the social world are produced and reproduced socially. The phenomenon under investigation, the General Chemistry curriculum, is located in the social world and is socially produced, while the objects of knowledge of Chemistry are part of the natural world.

Secondly, CR provided a framework that underscores critical social inquiry with an emancipatory agenda to explaining social phenomena (Shipway 2011, Danermark *et al* 2002). This emancipatory social agenda of CR is regarded as a significant feature of what gives CR its distinctive criticalness. Burnett (2007), citing several critical realists, notes the contentions in the use of the term ‘emancipation’ and proposes the term ‘transformative’ instead. I concur with Burnett’s assertion that transformation proposes an alternative approach to making a difference. A transformative stance in CR is more appealing and provides an understanding of the implications of conscious action necessary for uncovering mechanisms for producing profound change in practices. It also implies a greater commitment to an agenda that will have benefits for the wider society.

Thirdly, CR enables the differentiation of knowledge and acknowledges that different kinds of knowledge have different powers, epistemically, morally, and aesthetically (Young and Muller 2013). In this study, by virtue of the nature and the structure of Chemistry knowledge, the knowledge is regarded as specialised knowledge that calls for a certain type of knowing. Young and Muller note that specialised knowledge possesses the capability to develop identities and certain kinds of knowers. A significant curriculum principle worthy of exploring is what knowledge is selected. Specialised knowledge closely links with the discourse on powerful knowledge and social justice in learning[27].

3.6 Structures

Critical realism regards structures as entities that have real causal powers and effects. A structure can be defined as a set of internally related objects that have their own powers, mechanisms, and emergent capabilities (Danermark *et al* 2002). Structures in the domain of the real operate independently of our knowledge or experience of them.

In sociology, there are numerous conceptualisations of structures, and specifically, of social structures. Danermark *et al* (2002) explain that structures do not exist separately from individuals; they are always the medium as well as the outcome of social action. In the social world, structures possess causal powers or generative mechanisms that operate in an open system. These generative mechanisms have the potential to bring about action and changes depending on whether they are activated by a trigger or not. Scott (2014) argues that powers can be possessed, actualised or activated, or not actualised and activated. The potential activation of mechanisms is an inherent characteristic of open systems.

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[27] See the discussion on powerful knowledge in Chapter 4 (Section 4.4 and 4.5).

Critical realism differentiates between open and closed systems. The social world is conceptualised as an open system, therefore the objects of knowledge in the social sciences are located in open systems. An open system is characterised by the extent to which objects and participants in the system traverse boundaries during interactions in and with the environment and subsystems in a particular context. The university is an example of an open system which comprises a range of subsystems, structures, and generative mechanisms with causal powers. Sayer (2000) notes that the main feature of open systems is that the same causal powers found in the system can produce different outcomes, depending on the prevailing contextual conditions at a given time. Thus, present in open systems are multiple mechanisms which can be activated or not activated, depending on the prevailing conditions.

3.6.1 Social structures

The curriculum can be understood as a social structure, the existence of which requires human action.

A realist premise on social structures is that, at the level of the real, social structures have powers and tendencies that have effects in the world. Tendencies exist in and through time and space, and as such, have real effects. Social structures are regarded as emergent entities that are essentially constituted by groupings of social relationships. Social structures are always "the context in which action and social interaction take place, at the same time as social interaction constitutes the environment in which the structures are reproduced and transformed" (Danermark *et al* 2001 p. 181). Bhaskar argues that social structures are pre-existing and relatively enduring entities that can be transformed or reproduced through human interaction (Bhaskar 1998, Sayer 2000, Danermark *et al* 2002, Archer 2004).

Archer (2004) explains that social structures are social products that are derived from and through agency. As social products, social structures are situated in the context of human interactions since they are only operable in and through human activity (Bhaskar 1998, Sayer 2000, Danermark *et al* 2002, Archer 2004). Archer describes social structures as both the "ever-present condition and the continually reproduced outcome of intentional human agency" (Archer 2004 p. xvii). Underlying social structures can enable or constrain human action (Shipway 2011). Since human action is ever changing, the notion of social structure signifies interplay between structures and agency within a given context. Some actions may be impeded while others may be facilitated by the prevailing structural and agential properties and powers.

Our understanding of social structures is concept dependent, and these structures depend upon human activity for their continued existence. The concept ‘dependence of social structure’ can be demonstrated through examining the notion of curriculum. The knowledge that is selected for the curriculum is a socially produced entity requiring human engagement. Curriculum, as a social structure, can be changed if there is adequate understanding of existing generative mechanisms and their effects in the teaching and learning environment.

In education, the interplay of structure and agency has implications for the curriculum as a social structure that is underpinned by certain ideas and beliefs about knowledge. For example, the design of the intended curriculum for the General Chemistry modules depends on human input. The designed curriculum as a social product can be changed through human activity. An assumption I held at the initial stages of the research was that the lecturers in the context I researched each had different conceptions of the curriculum. I expected that their divergent conceptions would influence what they deemed key to select for the General Chemistry curriculum; how they thought the curriculum content needed to be sequenced, paced, and assessed. That is, my contention was that each lecturer exercised his / her agency to influence curriculum decisions based on their beliefs and conceptions about the nature of General Chemistry and how students can best learn in this course. However, it became apparent that lecturers, in this context of team teaching, were not particularly involved in making curriculum decisions related to the selection, sequencing, pacing, and assessment of curriculum content. Although they were consulted as part of the team, the final decisions were made by the module coordinator. Due to time constraints and the large student numbers, flexibility in teaching style was also somewhat restricted, thus constraining lecturer agency.

3.6.2 The curriculum as a social structure

The object of inquiry in this study was the curriculum. The curriculum as an object of knowledge can be referred to as a social structure found in the open system of the university. The curriculum is a socially produced and socially defined entity. As an entity, the knowledge in the curriculum is real and has real effects in the world and for those who study it. For example, there is evidence that access to knowledge can be enabled or constrained by the form of the knowledge and knowledge practices. The curriculum is composed of several interrelated components. It is a plan for teaching, learning, and assessment, based on the selection of a knowledge base that is sequenced and paced in particular ways, based on what lecturers understand good teaching and optimal learning to be.

In General Chemistry, the curriculum was comprised of the content, the learning outcomes, the study guides, and the assessment tasks and planned learning activities. These elements, individually, had an indispensable role to play, but collectively they had much greater significance in achieving the broader educational objectives.

From a realist perspective, the curriculum operates at all levels of reality as indicated in Table 2 below. Table 2 displays how the research into the curriculum in the study was positioned in relation to the different levels of CR.

Domains of reality	Example	
Empirical	Experience	Teaching and learning environment Student-learning experiences
Actual	Event/practices (outcomes – occurrences)	Learning activities and assessments tasks
Real	Structures (objects/entities)	Knowledge in the curriculum (curriculum content)
	Generative Mechanisms (possessing causal powers)	Knowledge practices (curriculum design) Organising principles of knowledge and codes

Table 2. Depth ontology as applied to the notion of curriculum (own diagram)

In the domain of the real, the curriculum exists as a social structure, with content knowledge that is organised in a particular manner. Numerous mechanisms can be found at this level, which can be activated or not activated. In the context of this study, I have identified that the organising principles underlying knowledge practices in the curriculum denote the *generative mechanisms* that can have effects on the structure of the curriculum. The learning outcomes outlined in the curriculum also serve as generative mechanisms for invoking specific teaching and learning activities in the domain of the actual in pursuit of the attainment of the outcomes. The curriculum structure is revealed through the organisation of the teaching, learning, and assessment activities found in the domain of the actual. Engagement with the teaching, learning, and assessment activities generate student experiences that can be observed in the empirical domain. Depending on the nature of the mechanisms and the context within which these mechanisms operate, there can be different outcomes and effects, which can be positive or negative for student learning.

The curriculum is designed in a specific social and cultural context by the lecturers. At the LSAU, there are structures in the form of committees that are shaped by certain ideologies and belief systems about what constitutes knowledge in particular and education in general; ideologies and beliefs that emanate from the broader macro context (society) and meso context (university). These ideologies and belief systems guide the curriculum and its assessment. Lecturers as agents and as members of society, and academic staff members in the university bring to the curriculum design process their own properties and powers that are influenced by historical and current contexts: values, beliefs, and ideologies.

In addition, Burnett (2007) suggests that, as a social structure, the curriculum has its own qualities that are independent of the designers. A realist perspective acknowledges that the curriculum possesses properties, possibilities, and tendencies. This means that the intended curriculum has the propensity to have its own effects on those that experience it. What is intended through the curriculum may not be what is realised in learning. The resultant intended curriculum has the potential to enable or constrain learning, and student experiences can be positive and successful, or negative, resulting in failure to learn.

Students as role players in and recipients of the curriculum also possess properties and powers to engage with the knowledge and knowledge practices; however, certain structural and cultural conditions may constrain or enable optimal learning. The purpose of the research project that I report on in this dissertation aimed to examine the organising principles of the curriculum and the effects of the knowledge structure and associated knowledge practices inherent in the General Chemistry curriculum for enabling or constraining student learning.

3.6.3 Generative mechanisms as structuring principles in the curriculum

The aim of the study was to analyse the curriculum design practices as knowledge practices. In particular, I was interested in examining the underlying organising principles of these practices and their effects on the resultant curriculum. My contention was that these underlying mechanisms constituted generative mechanisms structuring the curriculum, and as such, had the ability to enable or constrain learning for students. Generative mechanisms are properties inherent in things that enable them to act in particular ways or to have particular effects. Mechanisms have causal powers, that is, the ability to bring about events or occurrences whether observable or not. Sayer (2000) notes that in order to explain the existence of mechanisms, it is necessary to discover or uncover the nature of the structure or the object which possesses that mechanism. Therefore, an investigation into knowledge and curriculum practices involved not only looking at what knowledge was included in the curriculum, but also the kind of student identities that could potentially have been developed through various teaching, learning, and assessment practices. In the South African context, the curriculum as a practice should be such that it enables access for a diverse group of students. Understanding the underlying generative mechanisms structuring the curriculum for diverse groups of students is important in the LSAU context, especially in light of the current imperative to increase student throughput, retention, and graduation in the sciences.

3.7 Chemistry knowledge through a critical realist lens

As mentioned in Chapter 2, Chemistry knowledge evinces a layered ontology consisting of the domains of the macro, sub-micro and the representational. Similarly, critical realism advocates a depth ontology, namely, the stratification of reality into the empirical, actual and real domains of reality. As indicated in Table 3, the macro level – the visible (matter) – can be compared to the empirical domain; the sub-micro – invisible (particulate) – to the actual domain, and the representational – symbolic – to the real domain. All these domains exist simultaneously in parallel and they constitute intransitive and transitive objects of Chemistry knowledge. Table 3 below illustrates the intersection of Chemistry knowledge and critical realist ontology.

Levels	Critical Realism	Explanation/ Description	Examples in the knowledge content
Macro	Empirical	Tangible, concrete materials	Change in state of matter perceived by senses without the use of instruments, i.e. the process of ice melting; a solid changing to liquid
Interpretation /symbolic	Actual	Representational	Symbols, structure, models, formulas, equations mathematical manipulations, graphs (i.e. perceived through mental images and models)
Sub-micro	Real	Abstract, particulate nature of matter	Atoms, molecules, ions, (i.e. perceived with the aid of an instruments)

Table 3. Chemistry knowledge and depth ontology (own diagram adapted from Davidowitz and Chittleborough 2009)

Table 3 illustrates how a realist view of the discipline of Chemistry offers possibilities for dovetailing the question of *what is known,* with the question of *how we can know what is known* in the discipline so that we can devise ways to improve student success. The predominant educational approaches in Chemistry advocate constructivist philosophies, methodologies and approaches to curriculum design in the discipline. Proponents of constructivist thought advocate an understanding of the world as meaning making by individuals who are constantly making meaning and constructing their world as they interact with it. As such, the constructivist thinking is reflected through the emphasis placed on the curriculum design approaches which are constructivist in nature to accessing General Chemistry knowledge. However, CR offers an alternative philosophical approach to inquiry, raising questions about how to understand the nature of reality since CR posits that there is a reality that is independent of our knowing, therefore knowledge of the "world is not reducible to, or a construction of, our concepts of it" (Sayer 2000; p. 91). A social realist approach to curriculum design practices can be a starting point to bringing into a relationship the epistemology and ontological approaches to student learning in General Chemistry for improved curriculum, pedagogic and assessment practices.

3.8 Summary

In this chapter I have provided an account of why I have adopted a critical realist philosophy for this study. Critical realism is anti-positivist. The depth ontology of CR provides a framework for constructing powerful accounts of why things are the way they are. This means that CR espouses a focus on what lies beneath that which can be observed and experienced through the senses in the empirical domain in both the social and natural worlds. Critical realism as a meta-theory provides the basis for a social ontology that views reality as structured, differentiated and stratified. A key intention of the study was the identification and understanding of the nature of the underlying mechanisms of the curriculum in the first-year science modules. Critical realism provided the basis for asking questions about the nature of the reality in which knowledge practices in General Chemistry exist. Critical realism explanations do not seek to show well-established regularities or one-on-one causal connections; instead the researcher seeks to discover connections across a range of phenomena via knowledge of the underlying structures and mechanisms that work to produce these connections.

A realist approach advocates that the properties of the knowledge itself are interrogated so that the ways in which knowledge affects student learning are understood. The complex layeredness of Chemistry knowledge is aligned with a layered ontology that is adopted in the study. The ability to make connections between the different layers of the representation of Chemistry knowledge holds the key to student success in learning in the subject.

CHAPTER 4 – The contextual framework

> The excessive instrumentalism underpinning the delivery model of education and research may, in the interests of overcoming resistance to change, be undermining the conditions for access to knowledge, which is the historic purpose of education and its expansion (Young 2008a, p. 100).

4.1 Social inclusion and the curriculum

In the previous chapter, I discussed critical realism as a meta-theory underpinning this study on knowledge practices inscribed in the General Chemistry curriculum and how these practices could serve to include or exclude students. In this chapter, I explore the contextual framework in which the study occurs. I introduce the conceptualisation of social inclusion in higher education. Social inclusion is the educational and social phenomenon that is being investigated through the focus on curriculum practices. I describe the challenges to defining the concept and describe the key characteristics of social inclusion in higher education in the context of a social realist orientation to knowledge.

A brief elaboration of the curriculum development models and the curriculum design framework relevant to the study follows the discussion of social inclusion.

4.2 Challenges to defining social inclusion

The discourse of social inclusion is associated with broadening access and widening participation to those members of society who have previously been marginalised as a result of various forms of disadvantage, discrimination, disabilities and / or other socio-economic challenges (Armstrong, Armstrong and Spandagou 2009, Topping and Maloney 2005). In the South African context, the discourse of social inclusion is used largely at a policy level and is linked to the rhetoric of redress of past racially inscribed injustices, and of the development discourse which forms part of the national transformation agenda.

Implicit in processes of inclusion are processes of exclusion – whenever some are consciously included, others are un/necessarily excluded. Exclusion and/or inclusion usually denote the extent of engagement and participation of individuals, groups and communities in society. However, inclusion in education is defined by UNESCO (2005: p. 13) as

> [A] process of addressing and responding to the diversity of needs of all learners through increasing participation in learning, cultures and communities, and reducing exclusion within and from education. It involves changes and modification in content, approaches, structures and strategies, with a common vision which covers all children of the appropriate age range and a conviction that it is the responsibility of the regular system to educate all children.

Although the above definition focuses on children, it is nevertheless relevant for higher education. O'Connor and Moodie (2008) argue that, in the context of higher education, the discourse of social inclusion appears to be overruling the discourses of access and equity. Non-participation in higher education is linked to an inability to participate fully in society. An inability to participate successfully in higher education has repercussions for people's abilities to make informed decisions about their socio-economic, educational and financial well-being and standing in society (O'Connor and Moodie 2008, Wheelahan 2010).

One of the aims of the study was to extend the social inclusion discourse beyond its application in the arenas of special education, disability, and deficiency to incorporate mainstream higher education practices. Discussions on social inclusion are not divorced from issues of access, participation, and equitable outcomes. Given the social challenges in South Africa, the investigation required a critical approach to explaining the role of knowledge and knowing, thus moving the argument for social inclusion or exclusion beyond the empirical societal attributes and predictors of student success to a greater understanding of the organising principles in General Chemistry education (Szens, Tsakaratma and Maton 2015).

4.3 An account of the social inclusion model

The conceptual challenges arising from the use of the term 'social inclusion' can be attributed to the varied ideologies framing the discourse of inclusion. Gidley, Hampson, Wheeler and Bereded-Samuels (2009) propose a layered approach to social inclusion. They argue that social inclusion has three distinct but interrelated components that represent degrees of inclusion, namely, access, participation and success[28]. In the following section, I discuss each of these dimensions of inclusion as outlined by Gidley *et al* (2009) which provide a basis for conceptualising curriculum design within the framework of social inclusion and exclusion.

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[28] Gidley *et al* (2009; p. 23) note that the term 'social inclusion' is an important linguistic shift from the negative framing of 'poverty' 'disadvantage', 'deprivation' and 'exclusion' to the more positive framing of 'inclusion deficit' models to 'human potential' models.

4.3.1 Access

The first dimension of the social inclusion model is access, which is usually associated with student enrolments. This conception of access has been over shadowed by other powerful discourses that prevail in society and have influenced higher education. Globalisation, massification of higher education, neoliberalism, and the skills and competency discourses have been the key drivers influencing the access agenda internationally (Muller 2000, Akoojee and Nkomo 2007; Bozalek and Boughey 2012).

Many universities in South Africa and elsewhere have been facing challenges related to increasing and widening access and participation in higher education (Cloete and Bunting 2000, Massen and Cloete 2004, Boughey 2005, Haggis 2006). In South Africa, the issue of access has been foregrounded in public discourse since the advent of democracy in 1994. One of the outcomes of democratising HEIs in South Africa has been improved access for black students, especially in the historically white universities**.** The demographics of the student body have changed drastically over the last two decades to reflect the makeup of the national population. From 2010 to 2015, enrolments of black students have risen to 70% of the total student population (VitalStats, CHE 2016).

As illustrated in the diagram below, the notion of access, particularly in the South African context, is closely linked with student success, equity, participation, and social inclusion. Figure 3 shows that the dimensions of access, equity and participation are interconnected elements in the conceptualisation and the implementation of social inclusion practices, and of the discourse of social inclusion in the context of student success.

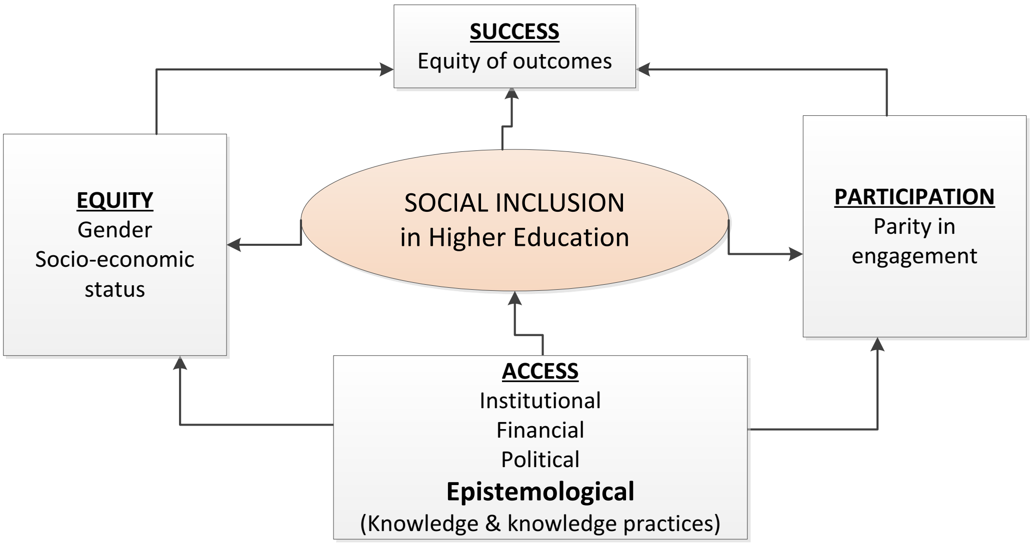

Figure 3. Elements of social inclusion in higher education (own diagram)

A report by Higher Education South Africa (HESA 2014), an organisation overseeing public higher education in the country, indicates that, although access to higher education has drastically improved over the past 20 years, there are factors that have adverse effects on students' success. While the increase in student numbers is commendable, there is now a stronger concern for greater access to knowledge for those that have entered the higher education system. As illustrated in Figure 3, the notion of access subscribed to in the dissertation refers to all forms of access to knowledge (epistemological access) as a social justice issue. McKenna *et al* (2016) suggest that, although strides have been made in improving institutional access (physical access) into institutions of higher education, the numerous initiatives for improving access to knowledge and, invariably, student success have borne little fruit. As evidenced recently in the South African HEIs, the call for social inclusion and student access to learning has been marked by violent student uprisings in most of the country's institutions, mainly due to calls for increased financial access[29]. All forms of access within higher education should also allow for access to powerful forms of knowledge, and parity in participation[30].

4.3.2 Participation

The second dimension of social inclusion proposed by Gidley *et al* (2009) relates to the concepts of participation and engagement. Participation in higher education refers to the total number of students within the 20–24 age group in higher education in a given year (Scott 2009). The participation rates of students in public higher education institutions have steadily increased, particularly for students from the previously disadvantaged groups. Between the years 2010 to 2015, the participation rate[31] for African students, rose slightly to 16%, compared with that for other race groups. The rate for Indians increased to 49%, while that of white students decreased from 57% in 2010 to 53%. The participation rates of coloured students remained the same (15%) between 2010 and 2015 (CHE VitalStats 2016). There are numerous reasons for the decrease in the participation rate of white students in public institutions, one of them being the increase in private HEIs in the country due mainly to the turmoil and unrest experienced in public institutions through the #FeesMustFall[32] protests.

The failure and drop-out rates of black and coloured students is significantly higher than that of white and Indian students as demonstrated through the graduation rates, which vary according to the different races.

Scott *et al* (2007) argue that the problem of differential success rates, which is an indicator of participation, can be addressed through improving teaching and learning.

4.3.3 Success

The third dimension of social inclusion suggested by Gidley *et al* (2009) is social inclusion through success and empowerment, and is underpinned by a human potential ideology. The

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[29] The notion of financial access and economic efficiency is an applied economics concept explaining the effectiveness of the development of human capital and resources in terms of formal education and training (see Chapter 8; Funding in South African Higher Education Reviewed: Two Decades of Democracy - CHE 2016).

[30] As indicated in the rationale, see Chapter 1, Section 1.7.1 on access as a right to higher education.

[31] The participation rate is the total headcount enrolment in higher education over the national population of 20–24 years old that is calculated as a percentage (VitalStats CHE 2016).

[32] See the discussion in Chapter 1, Section 1.7.1 on the rationale for the study.

concept of student success is further complicated by the wide variety of performance indicators available for monitoring and evaluating student success.

The numerous influences on academic attainment and success in the first year of study, and in subsequent years, are the subject of a number of studies (Akoojee and Nkomo 2007, Zewotir, North and Murray 2011). Notable is a cohort study of student success rates which concluded that the variance in graduation and completion rates was still largely differentiated by race (Scott *et al* 2007). The low success rate of black and coloured students is of great concern since it appears to negate the gains that have been made in physical access, and poses a huge stumbling block to the transformation agenda of South Africa. Scott *et al* (2007) argue that the problem of differential success rates can be addressed through improving teaching and learning. McKenna *et al* (2016) support the view that improving teaching and learning across the higher education sector through innovative practices is an imperative for improving student success. The complexity of the challenges facing higher education in post-apartheid South Africa places undergraduate student learning at the core of attempts to improve student success. The intricate relationship between access and equity, and successful participation form the cornerstone for the argument for improved social inclusion in higher education teaching and learning.

Inevitably, as noted by Gidley *et al* (2009), the social inclusion discourse evokes concerns about standards, quality, excellence, retention, attainment, and achievement. Given the different histories of South African universities, each of the above components of social inclusion is bound to elicit different responses from different stakeholders. For example, in an institution where excellence in teaching and learning is advocated, the introduction of the social inclusion discourse in institutional policies is likely to induce immense discomfort and elicit questions regarding the maintenance of quality and standards at the university. Bitzer (2010) notes that there are tensions between the maintenance of academic quality and the achievement of equity in high-ranking institutions of higher education. I would argue that the discourse of social inclusion offers higher education a more nuanced approach to conceptualising equity through education.

4.4 Social inclusion and epistemological access

Leibowitz (2009) and Gale and Tranter (2012), citing Fraser's (2008) conceptualisation of social justice, argue that the discourse on social justice acknowledges the three-dimensional nature of social justice, namely, distribution, participation, and recognition. The concepts of distributive justice, retributive justice, and recognitive justice or representation emerge from these dimensions. *Distributive justice* refers to the fair distribution of resources to all citizens, while *retributive justice* refers to opportunities for representation for all. *Recognitive justice* entails acknowledging and having respect for all cultures and identities. All three forms of social justice have, however, to be addressed in societies that have experienced huge social disparities like South Africa. Gale and Tranter (2012) suggest, in relation to higher education, that it is no longer sufficient to view social inclusion from the perspective of representation only, but that the aim should be epistemological equity. Thus, a social justice agenda for higher education should not only include the notion of equity of access, opportunities and outcomes, but should also address student success, and equity of outcomes.

Social inclusion in higher education is approached from a social justice orientation and is described as one of the objectives of the 2013 White Paper on Post-School Education in South Africa. Since the advent of democracy in South Africa the notions of social justice and equity of access in higher education have been well documented in various policy documents (DoE 1997, 2001 and DHET 2014).

Given my interest in the learning and teaching of Chemistry, I saw a need to examine how curriculum and knowledge practices in General Chemistry enable or constrain social inclusion to or exclusion from the knowledge field. In particular, my interest was in understanding how success can be achieved by the majority of students studying General Chemistry at first-year level by interrogating the knowledge and curriculum practices at LSAU.

Wheelahan (2010) describes epistemic access as acquiring access to powerful knowledge that gives the acquirer access to understanding the natural and social worlds, and the ability to participate in and shape society's conversations about itself. The notion of powerful knowledge is a sociological concept that means having access to specialised knowledge – specifically knowledge that makes a difference to the prospects of the quality of students' lives and to society in general[33]. As has been indicated by authors such as Young (2008a), Young and Muller (2013), Moore (2007) and Maton (2001, 2009, 2014 and 2016) knowledge itself is an object of study. They argue that access to powerful forms of knowledge is a social justice issue that requires greater attention in educational research.

Given that access to knowledge is an important issue of distributive justice, inquiry into curriculum provides a means for understanding how to improve access to more powerful forms

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[33] For a further elaboration on specialised knowledge, see the discussion in Chapters 5, 7, 8 and 9.

of knowledge by focusing on knowledge as subject and object of study (Wheelahan 2008, 2010, Maton and Moore 2010 and Sayer 2000). Access to powerful knowledge has implications for the quality of learning through the curriculum and the formation of student identities. Therefore, this study aligns with the social realist focus of foregrounding knowledge as the object of study. I regard access to powerful knowledge as a curriculum principle worthy of scrutiny. I would argue that social inclusion in higher education can be a means of democratising access to knowledge. To this end, it is necessary to uncover knowledge practices that can best serve this purpose.

At university, epistemic access relates to access to disciplinary ways of reasoning and knowing. For Boughey (2005) the notion of epistemological access involves,

> "… more than introducing students to a set of a-cultural, a-social skills and strategies to cope with academic learning and its products. Rather, it is about bridging the gaps between the respective worlds students and lecturers draw on. Bridging those gaps not only requires negotiation and mediation, but also making overt the rules and conventions that determine what can count as knowledge".

Blackie (2012) argues that access to scientific knowledge gives students the ability to participate as productive scientist-citizens who can critique and engage in public discourse about science.

In this study, student success is linked to the attainment of epistemological access to the knowledge practices of General Chemistry. In the next section, I outline the significance of epistemological access and why the study focuses on the curriculum.

4.5 Social Realism and the knowledge question

I have adopted a social realist lens for exploring knowledge and knowledge practices in enabling or constraining epistemological access for students in the context of the General Chemistry course at LSAU. A realist approach to curriculum inquiry draws its arguments from a social realist orientation to knowledge and knowing. The sociology of education has evolved over the past two decades from a focus on investigating the social factors that influenced education, to a focus on the properties and tendencies of knowledge and its structuring principles (Bernstein 2000, Young 2008b, and Maton 2014).

Social Realism is grounded in critical realist thinking that argues that knowledge is stratified and differentiated. From a realist perspective, all knowledge is fallible, since the world exists independently of our knowledge of it. How we know the world is not the same as how the world itself is. The transitive nature of knowledge implies that knowledge is always subject to falsification, revisions and improvements. Moreover, a realist perspective of knowledge construction acknowledges that knowledge is real, has real effects, emergent properties and powers. Social Realism offers a language for theorising and exploring different forms of knowledge, how knowledge forms are structured, and the effects of access to knowledge practices embedded in curriculum. Moreover, a social realist approach enables "seeing through appearances to the real structures that lie behind them and acknowledge that these structures are more than the play of social power and vested interests" (Maton and Moore 2010: p4).

Social Realism espouses different kinds of knowledge that are valued differently in different spheres of society, and as such, different kinds of knowledge are granted different and unequal status in different contexts (Young 2008b, 2014 and Wheelahan 2010). For example, formal or codified disciplinary knowledge has explanatory power across a range of contexts, and thus carries greater value in explaining how the world works than does informal, everyday practical knowledge which has value in specific, limited contexts (see, for example, Bernstein 1990, Young 2008b). Social Realism can illuminate knowledge practices, their emergent properties and their effects on the world. Since knowledge is "intrinsically and inescapably social" (Moore 2000: p20) an understanding of the social basis of knowledge and its stratification is key when considering the influence of curriculum processes and its implications on decisions made in education settings. The development of the theory of knowledge is a move towards an epistemologically powerful theory of knowledge for socially progressive purposes (Moore 2007).

The social realist school of knowledge and the curriculum has developed recently. Social Realism is a school of thought whose proponents all argue for knowledge to take its rightful place as a legitimate object of study: Young (1998, 2008a), Sayer (2000), Moore (2000 and 2013), Maton (2000, 2001, 2009, 2013, 2015), Moore and Young (2001), Maton and Moore (2010), Wheelahan (2008, 2010), Luckett (2009, 2010, 2011) and Shay (2008, 2012). Moore (2013) provides a succinct description of Social Realism as a sociological approach that attempts to work through the implications of CR with regard to relations within and to knowledge. Drawing on the social realist approach, this study acknowledges that knowledge is socially produced, has effects and emergent properties that are not reducible to those who produce it. Having access to knowledge – specifically powerful knowledge – makes a difference to the prospects of the quality of students' lives and to society in general[34].

The following section offers a discussion on the curriculum models that are prevalent in Chemical education. The discussion begins with a broad overview of curriculum models aimed at enabling

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[34] See discussion in Chapter 1 Section 1.4 on powerful knowledge.

student learning and improving access to knowledge in higher education. I then proceed to describe the curriculum design framework adopted at the LSAU and deliberate on its capacity for providing access to knowledge in General Chemistry.

4.6 Curriculum development models

Curriculum design models signify the different traditions in educational philosophy and the underpinning orientations towards curriculum development. Curriculum models serve to influence and guide curriculum design processes. Moore and Young (2001) argue that different curriculum models are also closely linked to the dominant assumptions about knowledge and the curriculum. Moore and Young (2001) make a distinction between the two forms of thinking about curriculum: neo-conservative traditional curricula, and technical-instrumentalist curricula. The former demonstrates an orientation and beliefs about knowledge and learning that are traditional and more covert that is prevalent in traditional universities. In such a model, the notion of proper learning is "essentially the contemplative process that has its roots on monastic tradition and the role of the curriculum and its attendant examinations is to engender respect for whatever are the canonical texts" (ibid; p. 447). A strong sense of tradition is sustained through texts, institutional culture and practices in the academic disciplines. On the other end of the spectrum is the technical-instrumentalist model where the curriculum is viewed as a means to a particular end. The curriculum is only useful if it can meet whatever society's needs are at the time. For example, the current discourse on the knowledge society can influence the development of curricula to provide "persons that exhibit qualities of trainability and flexibility that is assumed is needed in the future knowledge society" (ibid: p. 448).

A similar classification of curriculum models acknowledges the technical and the non-technical models of design. The non-technical model of curriculum design is a negotiated curriculum process that does not emphasise the systematised manner of curriculum development, but focuses on the learning opportunities and experiences offered to students. An example of such a model would exemplify the problem-based approaches to education where the process of learning is emphasised more than the actual outcome of such learning. The non-technical models place an emphasis on activities that are student oriented and process focused (O'Neil 2010).

The technical model is more inclined to adopt a product[35] perspective to curriculum design where emphasis is on plans and intentions for the desired outcome. An example of the technical model is the Backward Design model by Wiggins and McTighe (2005) where the authors assert that this

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[35] See Ralph Tyler (1949).

form of design proposes a robust approach for planning for student understanding through design. This model of design basically has three steps which require beginning the design process with the end in mind. The first step requires clear statements of the intended outcomes by identifying the desired results. This is followed by determining the acceptable evidence, and lastly, the planning of the learning experiences and instruction. Although the Backward Design approach has a product orientation to curriculum design, the methodologies adopted encourage the examination of practices in order to attain the desired outcome or product from learning.

South African higher education is underpinned by an outcomes-based approach to teaching and learning, and thus curriculum design models. The design process begins with stating the intended curriculum outcomes in the form of module outcomes and specific learning outcomes for each topic or theme. This form of curriculum follows the technical model of curriculum development. Although the curriculum model of the General Chemistry module at the LSAU is subject and discipline centred, it is both product oriented and process oriented. According to the cognitivist approach to student learning, knowledge exists as mental or conceptual abilities, therefore curriculum development is for the purpose of mental development. For a product-oriented model, the focus on the outcomes of learning in General Chemistry is goal oriented, where the key aim is the attainment of specific scientific content knowledge. As mentioned in Chapter 2[36] the ability to understand the transition between the domains of Chemistry knowledge and the ability to traverse the three levels of Chemistry knowledge at the first-year level is central to knowing in Chemistry (Carmichael 2010). Furthermore, this ability is central to induction into the disciplinary knowledge and values, and the subsequent development of their identities as science students. Given the social inclusion and epistemic access debate, the key questions to be asked is "What knowledge is being included and legitimated, and why it is so, and what purpose will it serve?"

The next section offers an elaboration on the curriculum design context at the micro level of the pedagogical setting. The discussion begins with an overview of the curriculum models and then proceeds to offer the curriculum design framework at the LSAU where the study was conducted.

4.6.1 Curriculum design – the module context

As mentioned in the introduction to this dissertation, the notion of curriculum refers to all the activities related to the dissemination of knowledge to students in a learning context. Curriculum

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[36] See the discussion on the nature of Chemistry knowledge Chapter 2, Section 2.2.

design includes the systematic and interlinking processes of curriculum construction, implementation and evaluation. All the undertakings related to the planning, design, implementation and evaluation of teaching and learning activities in a particular educational setting are considered as forming the curriculum.

Ornstein and Hunkins (2004) argue that curriculum design is the process of conceptualising the curriculum and arranging its major components to provide direction and guidance for structuring teaching and learning. Du Toit (2011) suggests that the existence of numerous definitions of the concept of curriculum signals the different forms that curriculum design can take. He identifies three forms of curriculum design: the first is where curricula are designed around academic disciplines or knowledge fields (subject-centred designs); the second centres on student learning and adopts a student-centred approach to curriculum design, while the final form focuses on solving the larger social problems through problem-based and inquiry-based curriculum approaches. Curriculum design therefore not only takes account of knowledge content, but also incorporates values and beliefs about education, views on how students learn, priorities about schooling, and views about the world.

For Mbajiorgu and Reid (2006), curriculum design in Chemistry privileges an 'applications-led' orientation to curriculum design. They assert that the application-led curriculum is not context based but is determined *by the applications* (italics in the original: p 8). Simply, the assertion implies that the curriculum is designed in relation to the development of the needs of the students and for future needs:

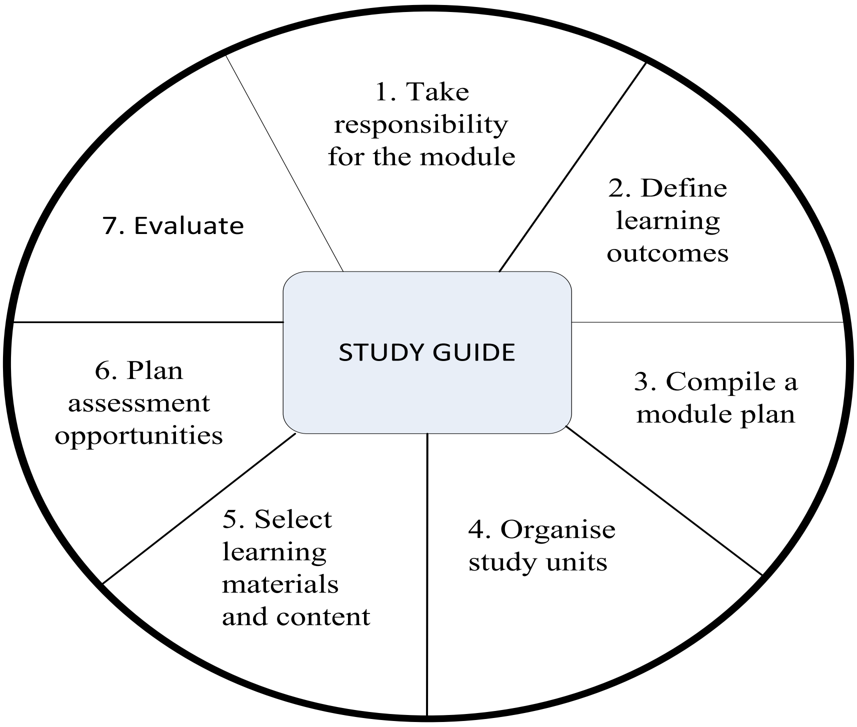
> The students are introduced to Chemistry that is needed to make sense of the world around as they know it, giving insight into the perspectives and methods of chemical inquiry as well as its outcomes (Mbajiorgu and Reid 2006: p. 16).

In the discussion so far, it is evident that curriculum and its development is a complex process due to the complexity of disciplinary knowledge. The curriculum design has to take account of and facilitate the kind of complex learning that first-year General Chemistry students have to do. Furthermore, the process of curriculum design is greatly influenced by the conception of curriculum held by the curriculum designers, the understanding of the purpose of the curriculum in the specific context, and the intended outcomes of learning that the curriculum has to facilitate.

The study took into account the intended or planned curriculum as represented in the curriculum documents, such as the study guide, with a specific focus on the aims and objectives (outcomes), the learning content, the learning materials and resources. The purpose of the planned curriculum is to provide a roadmap for the teaching and learning process. In the next section, I elaborate on the curriculum design process engaged in by the curriculum designers at the LSAU.

4.6.2 LSAU curriculum design framework

Curriculum design in General Chemistry occurred within the context of the LSAU curriculum design and development framework, which included three levels of curriculum design and development activities, namely, the macro level (programmes[37] at faculty level), the meso level (modules that constitute a programme at department level) and the micro level (the unit level where teaching and learning occurs in the educational setting, as indicated below in Figure 4. In terms of the curriculum design model at the module level illustrated below, the outcome of the design process was a study guide for students. The study guide was one of the curriculum documents analysed for this study. It provided data on learning objectives, learning activities, and the module outline linked to the knowledge content[38].



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[37] A programme is a purposeful and structured set of learning experiences that lead to a qualification (CHE 2004, Criteria for Programme Accreditation - HEQC).

[38] A further discussion on the curriculum documents and the study guide in particular are mentioned in Chapter 5.

Figure 4. Curriculum design and development process at the micro level at LSAU

The curriculum design process as outlined in Figure 4 was the focus of the study. The process involves seven steps which begin with the appointment of the module coordinator. A module coordinator was necessary, especially in first-year modules, since these were usually taught by a team of lecturers. Team teaching[39] was the primary teaching approach in these modules where no fewer than three lecturers teach the same cohort of students in each semester. The appointed module coordinator takes responsibility for the planning of teaching and learning in the module, as well as the administrative tasks required for the module.

The second step involves the actual planning which begins with defining the learning outcomes[40]. A module plan is then compiled where the different learning units and topics are identified and selected. The learning units or topics are then organised into different study units. The module coordinator then decides on the selection of the appropriate learning material and content, and plans the presentation of the learning by coordinating the teaching schedules. The assessment opportunities available in the module are also decided upon. Since the first-year General Chemistry module is taught by a team of lecturers, the initial plan is then presented to the lecturers and agreement reached on the allocation and distribution of lecturing responsibilities for the semester.

The last step, which is the evaluation of the module, constitutes the gathering of student feedback at the end of each semester through a student feedback instrument. This stage provides information on the student experience of teaching and learning to the lecturer which is used in the process of planning the module for the following year. A staff meeting is held every week to discuss any curriculum issues that may have arisen in the lectures, as well as to discuss the following week's lectures. As part of the data collection stage of this study, I had asked to be invited to one of these meetings as an observer, but the opportunity did not arise.

This outline of the curriculum design process can potentially be viewed primarily as a technical, systematic process that adopts a subject- and discipline-oriented curriculum model. The curriculum as product model (O'Neil 2010) used in this context exerts strong control over the entire teaching and learning environment, from content selection to assessment. Hussey and

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[39] The notion of team teaching is further discussed in Chapter 6 Sections 6.3.4 in relation to the context of the case and the teaching and learning environment.

[40] Although institutional documents on teaching and learning principles refer to learning outcomes, it should be noted that the terms 'learning objectives' and 'specific objectives' are used in the study guides examined in this study.

Smith (2008) caution against the narrow conception of learning outcomes at the higher education level that is conceived by this perspective to curriculum design and what outcomes-based education is modelled on. They oppose the stringent requirement for the definition of outcomes against which attainment is measured, especially since there are numerous outcomes that can remain undefined.

Above I have outlined the curriculum design framework underpinning the process for curriculum development undertaken at the LSAU. The various elements of design that were taken into consideration in the study included the outcomes, core content, selection and organisation of content as depicted through the curriculum structure, the selection and organisation of students' learning experiences through the teaching and learning strategy, including the learning activities, and the assessment strategy.

4.7 Summary

I chose to investigate epistemological access to knowledge in the Introductory General Chemistry curriculum at LSAU. The curriculum, as a structure for planning teaching and learning, is integral to achieving the purposes of higher education. As such, it was the main focus for an investigation into the role of knowledge and curriculum practices in promoting social inclusion in higher education. I began the investigation into knowledge and curriculum practices with the supposition that such a systematic inquiry would offer the opportunity to understand how one could improve society by improving access to certain forms of knowledge. However, in order to do so I needed to understand the various forms of knowledge, their power and effects on learning, and on student identities.

In sum, I have provided a brief account of social inclusion as a goal for the social justice agenda in higher education in South Africa. This agenda is associated with enabling access to knowledge for a diverse group of students. I discussed the elements that are taken into account in the social inclusion discourse in higher education, and in relation to knowledge. In addition, I have alluded to the idea that special attention should be given to the forms of knowledge and subsequent forms of learning nurtured by the curriculum**.** An investigation into knowledge and curriculum practices involves not only looking at what knowledge is included in the curriculum, but also the kind of student identities which are likely to be developed through various teaching, learning, and assessment practices.

The curriculum design model adopted at the LSAU was presented. The research task I set myself was to uncover the organising principles regulating knowledge practices in the General Chemistry curriculum as I believe that these have implications for enabling or constraining student success. The curriculum, including the pedagogy and assessment practices in General Chemistry, shape particular student identities.

Given the curriculum development model at LSAU, and the nature of Chemistry knowledge, it is possible for a lecturer to view the curriculum as a product. I would assume, though, that this is not the intention of the Chemistry department. Or is it? If it is not the intention that the curriculum plan should be read as a product-oriented curriculum, what happens to ensure that it is differently conceptualised by the lecturers who teach it? Or is the conceptualisation of the curriculum as product, and the resultant transmission-based pedagogic process part of the reason why so many students are not successful in learning General Chemistry at LSAU?

CHAPTER 5 - Conceptual framework

Section A: The languages of description

5.1 Introduction

The chapter is divided into two sections. In Section A, I discuss the conceptual tools proposed by Basil Bernstein, a British sociologist of education, that relate to pedagogic relations and the structuring of knowledge. Of import in this research project was the conceptualisation of pedagogic discourse that emerges from the transformation of disciplinary knowledge into educational knowledge through the curriculum. The structure of the curriculum is influenced by the structure of knowledge field, though the two are not the same. Student identities are shaped or disciplined by engagement in certain knowledge forms and practices (Bernstein 2000).

Bernstein argues that, in doing research, it is necessary to develop what he termed 'languages of description'. He distinguishes between internal and external languages of description. The former is the conceptual language and the relations between theoretical concepts used in the research, whereas the latter refers to a translation device that enables the researcher to make sense of the relationship between the empirical data and the theory. This chapter focuses on the internal language of description used in this study that has enabled me to describe and make sense of the knowledge practices in General Chemistry examined in this study. I shall explore the design of the external language of description in the next chapter.

In Section B, I discuss Maton's epistemic-pedagogic device, which is a development of Bernstein's theories and conceptualisation of knowledge structures. Maton (2014) expanded the framework inherited from Bernstein by integrating and extending the concepts into a new theory called Legitimation Code Theory (LCT). Maton claims that in any social field, there is always knowledge and there are also always knowers. He argues that actors in intellectual fields make claims about their fields, and who can claim to be legitimate members of the field. These claims constitute what he calls 'languages of legitimation'. Intellectual fields exist because they produce and reproduce knowledge and knowledge practices. LCT foregrounds knowledge and provides conceptual tools for identifying the underlying organising or structuring principles of knowledge practices. LCT provided the conceptual and analytical tools for uncovering and explaining the knowledge practices in General Chemistry. In this study, I worked with LCT: Specialisation, and LCT: Semantics.

I first examine Bernstein's pedagogic device.

5.2 The pedagogic device

Bernstein developed a theory and a conceptual framework for explaining the structuring of knowledge in the field of education, and showed how relations to and within knowledge types shape identity and consciousness. Bernstein's pedagogic device (PD) illuminates the logic of the relational processes in the construction of educational knowledge as represented through pedagogic discourse[41] (Bernstein 1981, 1990). In the next section I discuss the pedagogic device as a model for exploring the structuring principles of pedagogic discourse and pedagogic codes.

The pedagogic device whose end result is pedagogic discourse differentiates between three related fields of practice and contexts, namely, the fields of production, recontextualization, and reproduction. Together the three fields form the pedagogic device. Each field of the pedagogic device has rules that regulate and mediate access to knowledge - its production, appropriation, acquisition, and evaluation. The study was located in the field of recontextualisation. In the next section I discuss the pedagogic device as a model for exploring the structuring principles of pedagogic discourse and the pedagogic codes.

5.2.1 The field of production

Disciplinary knowledge is generated and cultivated in the field of production through research activities. Knowledge is produced in institutions like universities whose main functions in society are knowledge creation and dissemination. The field is supported by distributive rules that govern access to knowledge production and its circulation to the different groups within society. The distributive rules are revealed and realised through various practices, mechanisms, attitudes, and beliefs that control the dissemination of different types of knowledge created in the field of production. According to Bernstein (1990), the questions that occupy this field include who gets access to what type of knowledge, when, how and why. In a society characterised by great disparity, it is necessary to interrogate how access to knowledge production (and dissemination)

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[41] I discuss pedagogic discourse in the next Section.

is controlled through the influence of power and control, that is, through relations to knowledge (Young 2013).

5.2.2 The field of recontextualisation

Knowledge is selected from the field of production, simplified, organised, and modified in the field of recontextualisation to form the curriculum. The field of recontextualisation functions in accordance with the "recontextualising principle which selectively appropriates, relocates, refocuses and relates other discourses to create its own order and orderings" (Bernstein 1990, p 175). The recontextualising principle allows for the selection and relocation of knowledge from the intellectual field to what is deemed suitable knowledge in the form of a curriculum in the teaching and learning setting. The principle is significant in understanding the notion of power and ideology in curriculum design and development, and the subsequent pedagogic practices in an educational setting. Bernstein (1990, p. 62) describes pedagogic practice as "a cultural relay, a uniquely human device for both the reproduction and the production of culture". He suggests that pedagogic practice refers to the rules of the *what* and how of learning**.**

It is through the recontextualising principle that pedagogic discourse manifests. Bernstein defines pedagogic discourse as "a principle for appropriating other discourses and bringing them into special relation with each other for the purposes of their selective transmission and acquisition" (1990, p. 183). Diaz (2001) describes pedagogic discourse as a "device for generating the meant in the very logic of social relations and interactions" (p. 93). The 'meant' in this instance is the principle underscoring the message being communicated such as through the curriculum by those who control, select, organise, and distribute knowledge as part of maintaining social order. Diaz's description of the 'meant' as pedagogic discourse is congruent with Bernstein's description of pedagogic discourse as a rule which embeds two discourses, a discourse of skills and competencies of various kinds and their relations to each other, and a discourse of social order.

5.2.2.1 Forms of pedagogic discourses

According to Bernstein (1990), pedagogic discourse further generates two types of discourses, namely the regulative discourse (rules of social order, behaviour, and attitudes) and the instructional discourse (rules of discursive order). The instructional discourse is embedded in the regulative discourse which is about the value or moral order that underpins the curriculum. Instructional discourse refers to the different elements that constitute pedagogic practice, that is, the selection, sequencing, pacing, specified criteria and evaluation of knowledge that is transmitted. Selection involves decisions on the knowledge content that is to be taught to students. In this study, the knowledge themes or the topics, knowledge content, and learning activities in the study guide are examples of selected material. Sequencing refers to the order in which the topics are presented in the curriculum. Pacing denotes the rate at which students are expected to learn the content as indicated in the timetables; it is also about how much time is devoted to particular areas of content. The evaluation criteria refer to assessment tasks and the assessment criteria used to judge student achievement. The criteria are specified for assessing the learning that is attained and what is valued as legitimate knowledge.

For Morais and Neves (2010), instructional discourse refers to knowledge and cognitive competencies that are relayed through pedagogic processes. The instructional discourse is always embedded in the regulative discourse which defines the parameters of transmission and acquisition in the pedagogic context. From a knowledge practices stance, the instructional discourse is a reflection of the regulative discourse. In the context of curriculum design, both discourses should be evident in the intended and examined curriculum. Curriculum texts act as message systems for pedagogic discourse because they contain both the discourse of skills and competence (instructional rules) required, and the discourse of rules governing (regulative rules) the discipline (Bernstein 1990, 2000). An elaboration of the analysis of the instructional discourse in General Chemistry is presented in Chapter 7.

The regulative discourse refers to the value or moral order underpinning the curriculum. Singh, (2002) expanding on Bernstein's concepts, described the regulative discourse as the "moral regulation of the social relations of transmission and acquisition of rules of appropriate conduct, character and manner in the classroom" (p. 567). In the case of General Chemistry, the regulative discourse pertains to the statements of the values and philosophy underpinning the curriculum. For example, the introduction to first-year General Chemistry, in the first semester module, begins with a reference to the focus of the modules in the following manner:

> In this course, the emphasis is mainly on general chemical concepts and principles that serve as a basis for more advanced concepts in Chemistry, as well as in other disciplines" (General Chemistry 101 Study Guide; p. 1).

The intention of the above excerpt is an example of regulative discourse that alerts the student to the purpose and intentions of the module, the nature of the knowledge, its structuring, and the purpose and conditions of the learning. From the outset, the student is made aware of what she/he is supposed to learn in this module, that is, the concepts and principles of Chemistry. The student is also made aware of the foundational nature of the module and its relationship to other knowledge areas. However, the structure of the curriculum also has a great influence on the practices that occur in the field of reproduction discussed in the next section.

5.2.3 The field of reproduction

The last level of the PD is the field of reproduction where curriculum knowledge is reproduced in practice in the classroom. The field of reproduction provides the setting for realisation of pedagogic practices as the curriculum is implemented. The pedagogic discourse undergoes further recontextualisation and transformation through the enactment of the various pedagogic practices necessary for student learning. The dissemination of the recontextualised knowledge occurs through teaching, learning, and assessment activities in the pedagogic setting.

Pedagogic practices in this field serve as a measure of the extent to which the distributive rules, recontextualising rules, and reproduction rules have been applied in a particular context. The curriculum is implemented through pedagogic processes that include the sequencing and pacing of the teaching and learning interactions, and the evaluation of the learning.

The research was located mainly in the fields of recontextualisation and reproduction. The curriculum documents and textbook for the General Chemistry modules that were the primary data sources for this inquiry represent knowledge in the field of recontextualisation where knowledge was selected, delocated and relocated for the teaching and learning of first-year General Chemistry. Within the learning context, these documents form the official pedagogic discourse (OPD) taken from the Chemistry discipline and transformed into textbooks, and further transformed into study guides and workbooks for facilitating student leaning. This is the pedagogic discourse of reproduction (PDR). In the sciences, and specifically in General Chemistry, the lecturers, as recontextualising agents, develop the curriculum using the prescribed textbook (the OPD). The textbook itself represents recontextualised knowledge from the intellectual field of Chemistry (the field of knowledge production) which has been pedagogised and transformed for the purpose of student learning. In General Chemistry, the structure and organisation of the curriculum usually follows the outline of the prescribed textbook. Lastly, within the pedagogic setting there exist rules, referred to by Bernstein as recognition and realisation rules. The recognition rules refer to what is acknowledged as legitimate knowledge and is recognised as the basis of achievement.

The transformation of knowledge from the field of production to the field of recontextualisation presents an opportunity for the play of ideology. Bernstein (1999) refers to this transformation space as a discursive gap. He cautions that a discursive gap can open up possibilities for various extraneous variables to influence curriculum design and development. This means that the curriculum as pedagogic discourse is characterised by certain ideologies, values, and beliefs held by those controlling the recontextualisation arenas. Luckett (2011) and Shay (2011) argue that during recontextualisation, the recontextualising agents, who, in the case of higher education, are the academics, combine discipline knowledge with other external discourses to produce the curriculum. The external discourses can be in the form of discourses on learning theories, student abilities, etc. It is in the field of recontextualisation where decisions are made by recontextualising agents. The academics' decision-making powers and their beliefs and values about teaching and learning influence what knowledge is worth including in the curriculum at any given time.

In summary, the pedagogic device illustrates Bernstein's attempt to explain the movement of knowledge across the different fields in the production of pedagogic discourse as a message system in education, as well as the subsequent education practices. Researching knowledge practices in the curriculum of General Chemistry entailed examining the logic of the structuring of knowledge for teaching and learning through curriculum design. The key interest of this inquiry was whether the inner logic of the curriculum enabled or constrained learning in General Chemistry for the majority of students. The answers to this question could contribute to understanding the mechanisms of social inclusion and access to knowledge through the curriculum.

5.3. The epistemic device and the epistemic-pedagogic device

Following Bernstein's code theory, and Bourdieu's field theory, Maton extended Bernstein's conceptualisation of the PD by proposing the epistemic-pedagogic device (EPD). The enhanced device enables the exploration of how knowledge comes to be viewed as legitimate (Maton 2000, 2015) and whether knowledge "claims are legitimated on the basis of relations of power or by principles intrinsic to knowledge itself" (Moore and Maton 2001, p. 156). There are some significant differences between the pedagogic device and the epistemic-pedagogic device. Instead of referring to the *rules* of the device, Maton argues that the device is governed by a particular *logic* and that the use of the word *logic* is more appropriate, since it avoids the pitfall associated with the notion of practices as deterministically governed by rules (Maton 2014). He further contends that the distributive logic (instead of the distributive rules as referred to by Bernstein) applies to all the fields of the pedagogic device and not just the field of production. Decisions of who gets access to what knowledge are made in all fields of the PD. Understanding the logic of the different fields of practice enables one to understand the rules of who gets access to what knowledge and how this occurs. The logic regulates access to transcendental meaning, i.e. to non-everyday knowledge (Maton 2014, p. 52).

A significant distinction between the pedagogic device and the epistemic-pedagogic device is that the former makes a distinction between the different types of knowledge and education practices, whereas the latter sheds light on the inner logic of knowledge and student dispositions for gaining access to the different forms of knowledge practices. By explaining the inner logic of knowledge and understanding the principle of positioning of the pedagogic discourse, I was able to explain the knowledge practices emanating from the organising principles and the subsequent knowledge and curriculum practices as espoused in the General Chemistry curriculum, and could develop inferences about the potential effects of these on student learning.

5.4 Pedagogic codes

As a way of explaining the distinctions between different disciplines and the manner in which they relate to each other, Bernstein (1981) proposed that knowledge is distinguishable by principles of pedagogic codes. He used the concepts of classification and framing to generate pedagogic codes and to articulate these principles. These pedagogic codes relate to the nature, structuring, or organisation of the knowledge between and within disciplines, and the power relations between and within categories of knowledge. Classification denotes the degree of insulation *between*[42] fields or categories (Bernstein 1975, 1981, 1990, 2000). The nature of the boundaries and the strength of insulation indicate the field's power and how it regulates its relations with other fields. Classification can be weak or strong. Strong classification (C+) or weak classification (C-) in a discipline is determined by the nature of the boundaries and extent to which the discipline is able to allow knowledge from other disciplines into its domain. Classification has implications for power and decision-making about the 'what' of knowledge and curriculum in relation to the disciplinary knowledge base.

In the context of this study, Chemistry is said to exhibit strong classification (C+) where the Chemistry knowledge has discernible boundaries and rules that strongly insulate the subject from other science subjects, thus maintaining its distinctiveness and specialisation. It is easy to distinguish Chemistry knowledge from knowledge that is not Chemistry. The discourses of the field of Chemistry have inherent features and properties that legitimate practices and shape

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[42] My emphasis.

subsequent identities and relationships in the discipline[43] of General Chemistry such as being a chemist and thinking like a chemist. An example of strong classification of the field of science is given by one of the Chemistry lecturers who said that:

> You can go through life without ever having to ponder about what light is. And okay … somebody from the Humanities writing a poem about light will think about light in a totally, totally different way and he is not wrong, but he is not scientific because he doesn't deconstruct it into its principle particles and analyses *(sic)* it and make it consistent. He uses light as a metaphor for enlightenment or an uplifted feeling or what have you and it is not wrong; however, as scientist we have to think about differently. (Respondent 6)

Framing, on the other hand, refers to the extent of control *within* curriculum as demonstrated by the design. Framing can be weak or strong. There is control in the internal logic of the curriculum in terms of the selection, sequencing, pacing, specified criteria, and evaluating of knowledge (Bernstein 2000). Stronger framing (F+) indicates that the lecturer has more control over the decisions relating to the different elements of the curriculum, such as what is selected as content knowledge, how much time will be spent on a theme, and how the assessment will be conducted and by whom. Weaker framing (F-) refers to the students having more input or control of the learning in the curriculum, and assessment is more flexible. These scenarios depict different pedagogic approaches that are influenced by power and control in pedagogic contexts, thus evincing different pedagogic discourse.

Chemistry as a field of study exhibits strong framing: the lecturer controls and decides what is to be learnt, how it will be learnt, when the learning will happen, and how this learning will be assessed (Potgieter *et al* 2008). At LSAU, the same practice could be observed where there was strong framing, strict timetable scheduling of all learning activities – both in the lectures and in the laboratories. Strong framing was also evidenced through the highly-structured forms of interaction between the lecturer and the student. I discuss the influence of framing on the instructional discourse in the data analysis in Chapter 7 with a brief analysis of the pedagogic device using the critical realist lens which highlights the emergent nature of the fields of production, recontextualization, and reproduction.

Although the fields refer to different levels of function and practices in the different educational settings, they are hierarchically connected conceptually, but analytically different. In addition,

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[43] The terms 'intellectual field' and 'discipline' are used to denote, for the former, 'intellectual field', the broad knowledge arena located in the field of production; whereas for the latter, 'discipline' signifies the knowledge found in the field of recontextualisation.

from a critical realist perspective, the pedagogic device can be regarded as reflecting the layered nature of educational fields. Each field represents a different layer of reality of the educational arena. Although each field has its own logic, one field emerges from another and is irreducible to the field from which it emerged. Recontextualisation emerges from the knowledge production arena, and the reproduction arena emerges from recontextualised knowledge. Each field thus possesses its own properties and powers with emergent discourses and variable subsequent effects. Basically, this implies that the practices in each field have outcomes and effects which cannot be attributed to other fields because, although the fields are relationally connected, they are independent entities that can produce their own message systems in education.

5.5 The structuring of disciplinary knowledge

Bernstein (1999) distinguishes between two forms of knowledge: horizontal and vertical discourse. Horizontal discourse is composed of segmented, common sense, everyday knowledge that is understood and localised within a certain group of individuals and particular contexts. Bernstein (1999) notes that horizontal discourse plays a significant role in the structuring of social relations and the development of a particular consciousness for access to this discourse.

The form of discourse that offers formal, codified or school knowledge is referred to as vertical discourse. Vertical discourse is composed of specialised knowledge that is coherent, explicit, and systematically organised (Bernstein 2000). Access to this discourse requires exposure to the rules and conventions necessary for acquiring and achieving appropriate command of the discourse as usually found in the educational setting. Specialised knowledge tends to be more abstract and conceptual in nature. Northedge (2003) refers to such access in academic disciplines as entry into specialised discourse of specialist knowledge communities. The knowledge communities are characterised by a distinctive discourse, accepted legitimate knowledge, and require various forms of participation. There are bound to be stronger boundaries distinguishing one discipline from other disciplines, with each having a unique voice and identity.

5.5.1 Horizontal knowledge structures

Within vertical discourse, Bernstein further differentiates between horizontal and hierarchical knowledge structures in intellectual fields. A horizontal knowledge structure is mainly characterised by segmentally organised knowledge composed of a series of unconnected specialised languages.

$$L^{1}L^{2}L^{3}L^{4}L^{5}L^{6}L^{7}\ldots L^{n}$$

Figure 5. Representation of a horizontal knowledge structure

As depicted in the diagram above, knowledge-building in fields with a horizontal knowledge structure is characterised by a series or collection of different subjects or languages, each with its own rules and procedures, as illustrated. Intellectual fields with a horizontal structure are mainly found in the Humanities and Social Sciences (Bernstein 2000).

5.5.2 Hierarchical knowledge structures

On the other hand, a hierarchical knowledge structure is characterised by a different arrangement of knowledge which requires coherence, explicitness, and a systematically principled structure of meanings. In this knowledge structure, the knowledge is integrated and subsumed at different levels of learning. A hierarchical knowledge structure describes how knowledge is created, distributed, recontextualised, and evaluated in a particular discipline. Bernstein (2000) notes that an hierarchical knowledge structure, as depicted in the diagram below, begins with a broad base of fundamentals and general propositions and theories that build upwards to the specifics of specialisation.

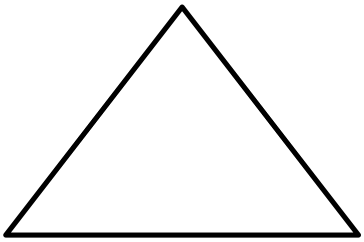

Figure 6. Representation of a hierarchical knowledge structure

The above diagram represents the conceptualisation of the structuring of knowledge in the intellectual field as well as the progression of learning in the field that has a hierarchical structure. The nature of the organisation of the curriculum moves from the bottom of the pyramid to the tip. The base of the pyramid represents an area where the curriculum has fundamental knowledge that is essential and forms the basis for further learning in the discipline. The knowledge that forms part of the base also includes pre-requisite knowledge that students are expected to have as they move up the pyramid. Subsequently, as the student progresses with their studies in the programme, the number of subjects decreases, such that a tapering of subjects gives rise to a more nuanced focus on specific knowledge for specialisation. Specialisation denotes development of learning through integration and subsumption to greater complexity and abstraction.

It should be noted that the discussion thus far has focused on the structuring of knowledge fields. The structuring of the resultant curriculum is strongly influenced by the structuring in the knowledge field, but does not necessarily have to display the same knowledge structure (Muller 2009). For the sciences, the first year of learning in higher education is where the fundamentals of the discipline are taught with the intention of creating a foundation for greater development of higher order propositions, theories and abstraction in later years. Therefore, learning progression is linked to the hierarchical nature of a knowledge structure which is also closely associated with the notion of verticality.

In the following section I discuss the principles of verticality and grammaticality of disciplinary fields, and the implication for knowledge-building which is relevant for establishing the bedrocks for understanding cumulative knowledge-building and learning (Maton 2016) in a subject like General Chemistry.

5.5.3 Grammaticality and verticality

Knowledge structures are further distinguishable through their grammars (Bernstein 1999, Muller 2000) and through the dimensions of verticality and grammaticality (Muller 2005, Maton and Moore 2010).

Verticality characterises knowledge in hierarchical knowledge structures. Muller (2005) views verticality as "the way some knowledge structures develop through integration and subsumption of knowledge towards more general propositions" (ibid). Horizontal knowledge structures demonstrate less verticality since knowledge develops through the addition of different theories or "languages", as in education. An Educational Psychology programme exhibits weaker verticality because the field builds knowledge by adding to the array of theoretical frameworks that make up the content knowledge of the field. For example, the field of Educational Psychology is made up of numerous theories such as developmental psychology, learning theories, neuroscience, and cognitive sciences, among others that do not necessarily, and often do not, build on what came before.

Maton's (2007) assertion about how the verticality of a discipline constitutes the basis for the recontextualising principle, as well as Muller's (2009) statement that "disciplinary form poses a constraint on appropriate curricular form" (p. 216) provide a good basis for understanding the implications of knowledge structure on curriculum structure. This means that, for cumulative learning, there is a greater need for disciplines with high levels of verticality to demonstrate the application of the recontextualisation principle through careful sequencing, alignment, coherence, and articulation when constructing the curriculum. Maton (2009) defines cumulative learning as the ability to integrate earlier learning to enable problem solving in novel contexts.

In hierarchical knowledge structures, such as in the discipline of Chemistry, verticality implies a greater need for the progressive acquisition of knowledge because knowledge becomes progressively more abstract and generalisable. The stronger these principles, i.e. the greater the likelihood for increased verticality, the greater the need for strong internal coherence, logical sequencing, and articulation as knowledge builds from year to year. The extent of coherence and the type of coherence broadly influences how much the curriculum in the pedagogic setting resembles the disciplinary knowledge in the field of production. A hierarchical curriculum structure, as is the case for General Chemistry, means that the knowledge acquired in the first year must form the basis for further knowledge acquisition in subsequent years.

Muller (2009) distinguishes between conceptual and contextual curriculum coherence. The former refers to disciplines that have a "high codification (and that display) a hierarchy of abstraction and conceptual difficulty" (p. 216). Knowledge-building in such a knowledge structure is through integration and subsumption of earlier knowledge. Each unit of knowledge is supposed to build onto another, or have some linkages to the previous unit. For example, the science disciplines have big, key theories that are used to explain certain phenomena in the natural world.

The General Chemistry curriculum exhibits knowledge that is highly conceptual and abstract, with a greater requirement for conceptual coherence. The conceptual difficulty of the knowledge provides two sides of a coin where the difficulty poses strength for the discipline, as well as a weakness in terms of student struggles with learning in the science discipline. Conceptual difficulty can hinder student learning for some of the students, thus limiting epistemological access to knowledge.

The design of the curriculum of a field with a hierarchical knowledge structure like General Chemistry is underpinned by the principles of knowledge sequencing, coherence, articulation, and progression. Learning in such a knowledge structure occurs through a systematic process of progressive sequencing and integration where the abstractness of knowledge increases as knowledge progresses and learning develops.

Grammaticality refers to the extent to which some knowledge structures generate a relatively explicit conceptual language to explain the world, while others do not. According to Maton (2013), social realists claim that all intellectual fields possess degrees of grammaticality. Luckett (2010) explains that strong grammar denotes a knowledge structure that has an 'external language of description' that allows it to construe what is to count as empirical referents for the concepts it signifies, and to translate these unambiguously back to the world of signs, the 'internal language of description' (p. 4). Examples of fields with strong grammars are Economics and Mathematics; this is because their conceptual language has the capacity to draw on empirical research evidence to support knowledge claims (Bernstein 2000).

5.6 The knowledge structure of Chemistry as a discipline

As noted above, Chemistry as scientific field of practice is regarded as a central science. Its central positioning in the sciences is due to the close association and interdependence it enjoys with other sciences like Mathematics, Biology and Physics. According to Muller (2013), a distinguishing characteristic of a discipline is that its knowledge has been preserved and developed by specialist communities who have defined the parameters of thinking about what is of greater or lesser worth, true or false, in the fields at any particular time. Chemistry as an intellectual field is a social field of practice that belongs to a category of disciplines characterised as 'singulars' by Bernstein (2000).

Muller (2013), drawing on Bernstein (2000), defines a 'singular' as a discipline that has carved out a space for itself over time, giving it a unique name, a specialised discrete discourse, with its own intellectual field of texts, practices, rules of entry, examinations, licences to practice, distribution of rewards and punishment. Disciplines generate strong disciplinary identities through the possession of specialised knowledge and a specialised disposition to certain forms of conduct regarding disciplinary matters (Muller 2014).

Using Bernstein's conceptualisation of knowledge structures, one can theorise about the form that knowledge can take in General Chemistry and make inferences about the possible curriculum structure and pedagogic practices that are likely to emerge, given the structure of knowledge in the intellectual field of Chemistry. General Chemistry, as part of the Chemistry discipline, exhibits a hierarchical knowledge structure whose organisation of knowledge is "explicit, coherent, systematically principled and hierarchical and develops through integration knowledge at the lower levels and across an expanding range of phenomena" (Bernstein 1999, p. 161). Scientific knowledge grows by the evolution of ever more abstract and general propositions

(Muller 2000). The form of organisation of the knowledge relates to the notion of verticality of the field, where in an hierarchical knowledge structure, the knowledge develops through integration and subsumption. Blackie (2014) argues that the hierarchical knowledge structure means that "thorough understanding of any aspect of the Chemistry rests on a massive bulk of underpinning theory all of which must be assimilated to some degree before any real understanding can be achieved" (p. 2). For Matoti and Lekhu (2008), the underpinning, foundational knowledge is *anchoring* concepts upon which subsequent knowledge builds. One of the lecturers interviewed expressed the foundational nature of General Chemistry as

> [t]he alphabet – you have to know the alphabet to be able, in order to be able to write. So, we basically build the alphabet for them and then by the end we expect them to write, to be able to put the concepts together from the start (Respondent 5).

Induction into the foundational knowledge is indispensable for progressing with further studies in disciplines that require the cumulative systematic building and acquisition of knowledge. As previously mentioned, the type of learning emanating from this knowledge-building process is what Maton (2013) refers to as cumulative learning.

Since the hierarchical knowledge structure suggests a certain form of organisation of learning through the curriculum, the following section will expand more on the corresponding knower structure.

5.7 The knowledge and knower structures

As part of building on the inherited framework, Maton (2002, 2007) expanded on Bernstein's theory of knowledge structures by introducing the corresponding notion of knower structures. According to Maton (2007, 2013 and 2014), for every knowledge structure there is a corresponding knower structure, as illustrated in Figure 7 below. He argues that the introduction of the knowledge-knower structure concept offers greater understanding of how knowledge practices develop certain kinds of knowers by specialising identity, consciousness, and relations. The principle behind knowledge-knower structures is that, in the construction of knowledge, both epistemic and social characteristics[44] are always present, with one of these features being more

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[44] At this stage I refer to these as epistemic and social characteristics of knowledge and knowers because I have yet to discuss the epistemic relations and social relations in Section B of this Chapter.

prevalent than the other, depending on the knowledge field. Each knowledge structure generates a certain kind of ideal knower or ideal student (Ellery 2016).

For example, disciplines in the Humanities with horizontal knowledge structures are said to generate a hierarchical knower structure where there is a tiered organisation of knowers "based on the image of the ideal knower which develops through the integration of new knowers at lower levels and across an expanding range of different dispositions" (Maton 2007, p. 91). The concept of a knower is closely associated with the form of gaze or a particular form of knowing that is developed through the acquisition of knowledge, especially in intellectual fields with horizontal knowledge structures.

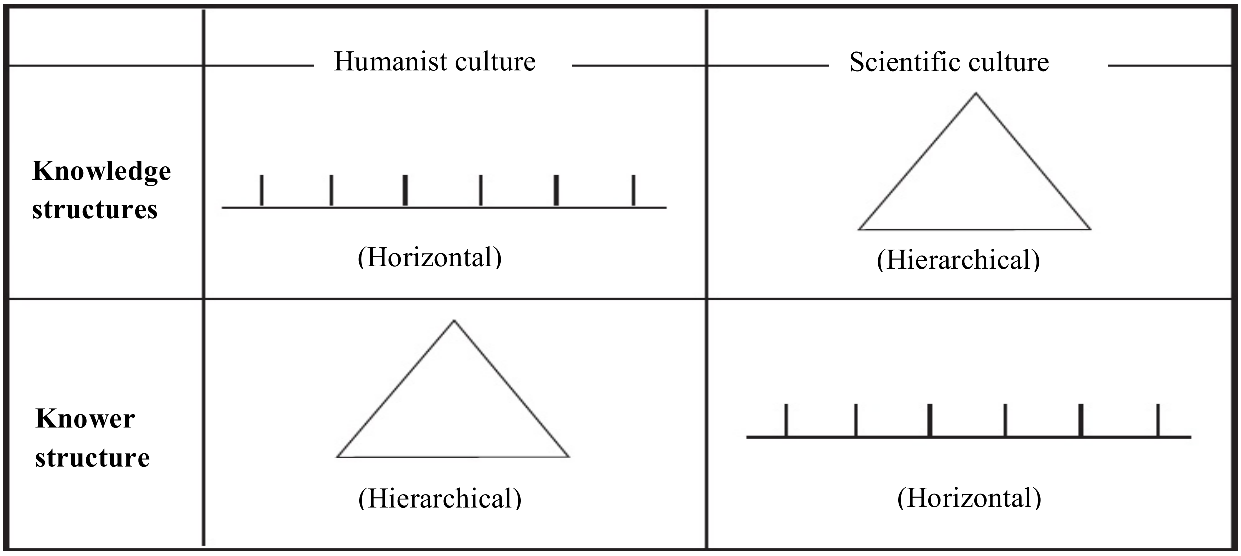

Figure 7. Knowledge-knower structures (Maton 2014, p. 70)

Hierarchical knowledge structures such as the sciences have corresponding horizontal knower structures that are characterised by ideal knowers that are strongly bounded and segmented, as depicted in Figure 7 (Maton 2014). For example, in a hierarchical knowledge structure, the dispositions and opinions of the scientist would not be more significant than the scientific knowledge that she possesses and produces.

In a group of scientists (knowers), what counts is the actual knowledge of concepts, theories, procedures and skills sets that have been acquired. It is the theories and discoveries of new knowledge that have premium status in the field, rather than the individuals as knowers. For example, scientists have discovered theories in the field concerning acids and bases, such as Brönsted-Lowry Acids and Bases, and the Lewis theory, among a few taken from 'Theme 11: Acids and Bases' in the study guide. The theories explaining acids and bases represent knowledge that is strongly bounded and inward facing. Simply, the knowledge with specialised meanings are known and only relatable to the insiders in the field. Through knowledge integration and subsumption that leads towards more general propositions, the knowers are segmented because of the numerous definitions and variations made to the initial theory that was discovered. Each discovery is an advancement of the original theory, albeit increasing in abstraction and complexity of the knowledge. Therefore, for epistemological access, the description of knowledge and knower structures is significant in the study for understanding cumulative knowledge-building and the potential for the development of knowledge.

5.8 Summary

In this section I have outlined the conceptual depth offered by Bernstein’s conceptualisation of education and knowledge practices as a process that involves movement of knowledge between different fields of practice. The pedagogic device provides a model for explaining the different phases of knowledge creation, its transformation into curriculum, and reproduction in educational settings. I explained Bernstein’s concepts of knowledge structures and presented a preliminary examination of the knowledge structure of first-year General Chemistry. The field of Chemistry is characterised by an hierarchical knowledge structure. The structure of the curriculum is congruent with the knowledge structure of the discipline. Understanding the knowledge structuring of the discipline is necessary for explaining the structuring of knowledge in the form of curriculum and the type of learning associated with the discipline. I also introduced Maton’s view that, for every knowledge structure, there is a knower structure. The conception of a knower takes into account how knowledge practices develop certain kinds of knowers by specialising identity, consciousness, and relations. By acknowledging the knowledge-knower structure in curriculum practices, I embraced a concept aimed at uncovering the effects of the structuring of the curriculum on whether it enabled or constrained student success.

Section B: Languages of legitimation

> The knowledge paradox – knowledge is treated as having no inner structures with properties, powers, tendencies of their own, as if all forms of knowledge are identical, homogenous and neutral (Maton 2014, p. 2)

5.9 Introduction – Legitimation Code Theory (LCT)

Legitimation Code Theory is Maton's development of Bernstein's model of the pedagogic device[45], the theory of knowledge structures and his conceptualisation of educational pedagogic codes into a conceptual framework for analysing and explaining the structuring of knowledge and knowledge practices in social fields (Maton 2014). Legitimation Code Theory conceptualises the different relations within knowledge practices that are significant for explaining the inherent characteristics of educational practices and for positioning by actors. Legitimation Code Theory moves away from typologies and dichotomies as in the two forms of knowledge structures (horizontal and hierarchical knowledge structures) to topologies that offer the possibility of more nuanced explanations and descriptions of knowledge than is possible through dichotomous analyses. Legitimation Code Theory does this by providing a multi-dimensional conceptual toolkit for exploring practices and contexts in social fields (Maton 2014, 2016).

As both a conceptual and an explanatory framework, LCT offers a methodology for exploring substantive research problems. Legitimation Code Theory offers a conceptual toolkit and a methodology for analysing empirical problems.

The theory is premised on the view that society is made up of a series of relationally autonomous fields of practice where there is constant struggle over resources and status. In the educational arena, there are constant tensions about what counts as legitimate knowledge, and whose knowledge is privileged. Languages of legitimation are conceptualised into different dimensions and principles for analysing achievement in a knowledge field, using legitimation codes. Maton (2013) refers to legitimation codes as "the organising principles of dispositions, practices and fields" (p. 17).

For the purposes of this research I wanted to offer an analysis and explanation of how the structuring of the curriculum enabled or constrained the kind of cumulative learning required by the knowledge structure of General Chemistry. Understanding the underlying principles was

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[45] Bernstein's theories were greatly influenced by P. Bourdieu, a sociologist and philosopher - See Young, M. (2008a.)

significant for understanding how the relations within General Chemistry knowledge shape and position knowers of first-year Chemistry. One of the aims of this study was to give an account of how knowledge claims were legitimated through the prevailing discourses among the team responsible for the General Chemistry modules. LCT provided a toolkit for examining the internal logic or the underlying organising principles that structure the curriculum.

Of the five dimensions that Maton conceptualised, two were used in the study, namely, LCT: Specialisation, and LCT: Semantics. In the next section I explain the concept of LCT: Specialisation, followed by an explanation of LCT: Semantics. I discuss the usefulness of exploring the organising principles of the General Chemistry curriculum to explain how the curriculum enabled or constrained student learning.

5.10 LCT: Specialisation

Maton (2001, 2007, 2013 and 2015) argues that educational knowledge has two coexisting but analytically distinguishable sets of knowledge relations, namely, epistemic relations (ER) and social relations (SR). Through establishing these relations, the organising principles of a field can be conceptualised as specialisation codes. These specialisation codes have integrated Bernstein's pedagogic codes of classification and framing to determine the relative strength of each of the relations. According to Maton, epistemic relations and social relations can be used to describe "the focus of knowledge claims and the basis of knowledge claims to legitimacy" (2013: p. 31). Basically, in the context of the study, the organising principles provide understanding of the intrinsic logic structuring the knowledge that gives rise to possibility and legitimacy of the curriculum and knowledge practices.

The following section discusses the possible relations existing within knowledge and which enable the focus on knowledge to explain the effects that curriculum designs have for access to knowledge and to knowledge-building for cumulative learning.

5.10.1 Epistemic relations

Epistemic relations are the relations between a knowledge claim and its object of study, which is, what can be known and how it can be known. In epistemic relations, the emphasis is on the possession of specialised knowledge of specific objects of study. Legitimate disciplinary knowledge that forms specialised identities in intellectual fields is acquired through specialised procedures, skills and principles. The relations generated can be relatively strong or weak. In an intellectual field like Chemistry, there are specific procedures, formulas, and theories that underpin knowledge practices in the discipline of General Chemistry. Here the possession of authorised knowledge in the form of theories, techniques, and principles are emphasised as the basis for achievement (Maton 2007, 2014). For example, the following is an extract from the learning objective of the General Chemistry curriculum,

- Convert between the different temperature scales.
- Apply the rules for the assignment of the number of significant (Theme 1– specific objective – Study Guide).

The above is an example of stronger epistemic relations since the focus is on specific knowledge, procedures, and skills required; there is little room for the student to interpret or to choose an approach or response to the tasks based on their own experiences or preference. Specialised content knowledge is emphasised as determining the basis of achievement. Who the student is, is insignificant; what is relevant is what they know (Maton 2014). There is stronger classification and framing of discourse (ER+) and weaker classification and framing of social relations (SR-) thus generating the knowledge code, ER+, SR-. On an epistemic plane, the knowledge code is located as illustrated below in Figure 8.

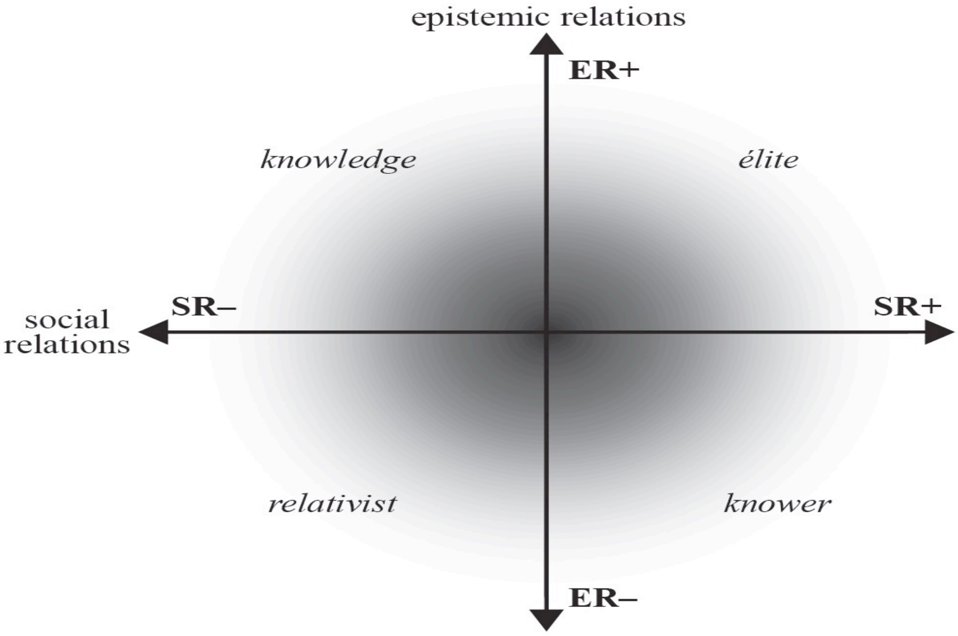

Figure 8. LCT: Specialisation plane (Maton 2014, p. 30)

5.10.2 Social relations

The social relations (SR) are the relations between a knowledge claim and the personal characteristics of the subject or the author of the knowledge claim. Social relations are characterised by the privileging of features related to the knower over features related to the object of knowledge, where the focus is on the 'who' of knowing in a social field of practice rather than on the 'what' and 'how'. A knower's attitudes and dispositions are privileged more than or rather than the knowledge possessed.

Strong social relations (SR+) and weak epistemic relations (ER-) generate a knower code. A knower code is characterised by greater emphasis and value placed on personal attributes and dispositions of the people or authors in that discipline, "where knowledge claims are by somebody about something" (Maton 2001: p. 165). Disciplines in the Humanities and Social Sciences usually evince knower codes. The knower code is represented as ER-/SR+. General Chemistry evinces weak social relations (SR-) which signify that the subjective characteristics of the individual in the field are not regarded as significant as the basis of achievement in the field.

For analytical purposes Maton includes two more codes, namely, the elite code and relativist code (see Figure 8 above). The former is when legitimacy is based on possession of both specialist knowledge and being the right kind of knower, while for the latter, legitimacy is determined by neither possession of specialist knowledge nor by knower attributes (Maton 2010) as indicated in the Figure 8 above.

Understanding the phenomenon of inclusion and exclusion by inquiring into knowledge practices requires answers which may not be easily generated, except through employing a fine-grained analysis of organising principles of the knowledge privileged in the curriculum. In the next section I offer a more nuanced discussion of the variations found in specialisation codes that illuminate practices.

5.10.3 Insights and gazes

Maton developed tools that extend Bernstein's (1999) notion of gazes generated in practices embodying social relations. He also distinguishes between different kinds of knowledge codes by conceptualising the modalities of epistemic relations as *insights*[46]. The mechanism for distinguishing between knowledge code fields offers a more nuanced way of analysing how

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[46] By convention *insights* is always written in italics (Maton 2014).

different fields with strong verticality are legitimated differently. Differentiating between the different kinds of insights in different knowledge practices can illuminate what the field values in building powerful and cumulative knowledge. Simply, knowledge practices with strong epistemic relations can be "specialised by both *what* they relate to and *how* they so relate" (original emphasis ibid: p. 175).

Maton analytically distinguishes between *ontic relations* (OR) and *discursive relations* (DR). *Ontic relations* refer to practices in a field and the part of the world towards which they are oriented – essentially, how knowledge practices bound and control legitimate objects of study or the extent to which the discipline values its object of study. An example is knowledge practices in General Chemistry that focus on the 'what' of Chemistry per se, for example, knowledge of chemical elements is central to Chemistry knowledge and practices (OR+).

Discursive relations, on the other hand, are concerned with relations between knowledge or practices in the field (object of study) and their relation to other knowledge and practices. The intellectual field of Chemistry is usually referred to as a *central science*. Its centrality is due to its relationship with other sciences such as Physics, Mathematics, and Biological Sciences where concepts and theories are essential components of Chemistry knowledge[47]. General Chemistry as a sub-discipline is no different. Where procedures for constructing the object of study are in relation to knowledge and practices in Physics or Mathematics, for example, the *discursive relations* are privileged (DR+).

As can be seen above, both *ontic relations* and *discursive relations* are concerned with the object of study, but what differentiates these relations is their focus. To further clarify the applicability of these relations in terms of insights, Maton identifies four principal modalities namely, situational, doctrinal, purist, and knower or no insight. Below is a brief description of each insight as depicted in the Figure 9 below:

- ***Situational insight***[48] (OR+, DR-): knowledge practices place emphasis on the importance of *what* is being studied but not necessarily *how* it is studied. Greater value is placed on the object of study and the knowledge, but not the approaches to the knowledge, as is the

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[47] See Chapter 7 Section 7.3.2.1 on the discussion of the selection of the curriculum for the affirmation of the centrality of chemistry as a science by the respondents in the study.

[48] By convention in LCT *insights* and *gazes* are written in italics (Maton 2014).

case for example in Anthropology, where the study of being human can be approached and explored from various angles such as the arts, evolution, culture etc.

- ***Doctrinal insight*** (OR-, DR+): knowledge practices place less emphasis or value on *what* is studied than on *how* it is studied, i.e. the approaches adopted in problem solving, for example in Religious Studies.
- ***Purist insight*** (OR+, DR+): knowledge practices place a premium on both the object of study *and* how it is studied, for example in Chemistry. As will be discussed in the data analysis Chapter 8, Section 8.6 of the dissertation[49], both the approach of *how* to study a particular phenomenon is as important as the *what* of the phenomenon that is being studied.
- ***Knower or no insight*** (OR-, DR-): knowledge practices place no value on what is studied or how it is studied, for example Avant-garde arts.

These modalities can be represented on an epistemic plane depicting a continuum of strengths.

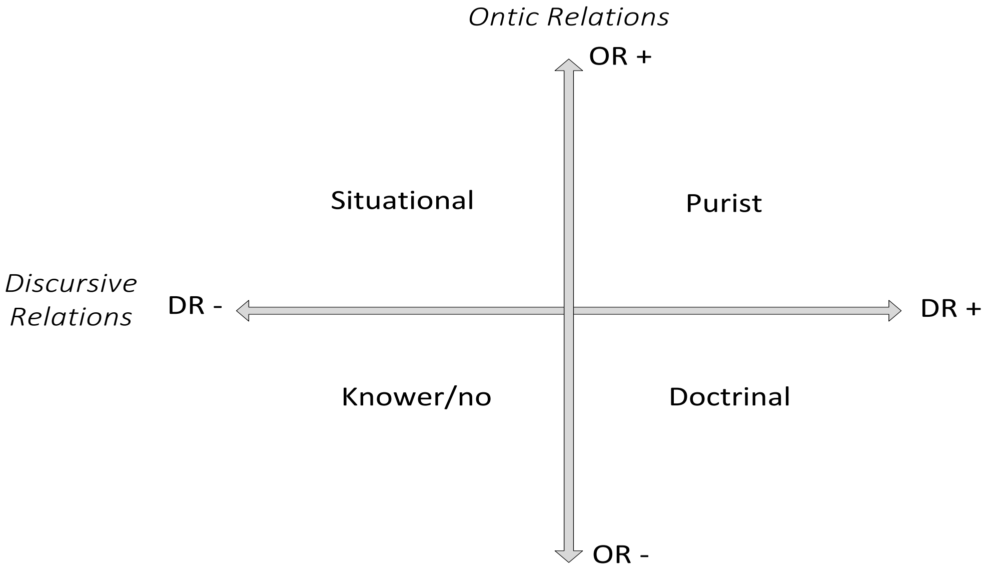

Figure 9. LCT: The epistemic plane - *insights* (Maton 2014, p. 177)

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[49] See Chapter 8 Section 8.6 for a discussion on the *insight* that may be developed by the General Chemistry curriculum.

These modalities represent the different insights that can be attained in an intellectual field that evinces a knowledge code or fields with stronger epistemic relations. The modalities reveal how knowledge-building in a knowledge code field can develop and inevitably demonstrate the cumulative learning possibilities in a discipline. In General Chemistry, both the *ontic relations* and *discursive relations* are relatively strong since the focus is both on the 'what' and the 'how' of knowledge with the commitment being on solving the natural science problems and using legitimate approaches approved by science.

Below is an excerpt taken from the data that demonstrates the relations where emphasis is placed on both the knowledge and the approaches to be used in accessing knowledge.

> The use of your molecular model set is recommended to build models of molecules. In this way, molecular geometries are easily observed. The normal procedure is first to draw the Lewis structure of a molecule, and then to build the model (GCM 101 Study Guide 2013).

The above is an example that indicates relatively stronger *ontic relations* and relatively stronger *discursive relations* (OR+, DR+); thus privileging both the object of study (which is the knowledge of molecules and molecular structures) and how it is studied (procedural knowledge and subject specific skill, techniques and methods for determining usage of appropriate procedures). This dual focus generates a *purist insight*. From the analysis of the data, I established that General Chemistry curriculum generates a *purist insight*[50]. A further discussion can be found in Chapter 6 which supports the selection of this modality of insight for General Chemistry in this context. Knowledge and curriculum practices have properties, powers and effects which include or exclude students from epistemic access.

As noted above, Maton refined Bernstein's notion of *gazes* by creating a more nuanced way of differentiating between knower code disciplines. Maton asserts that social relations generate a certain kind of knower with a certain kind of *gaze*. A *gaze* enables a knower to recognise the knowledge that counts as legitimate knowledge, and also to be recognised as a legitimate knower. There are four *gazes* that can identify the kind of knowers that are privileged through various knowledge practices. For social relations, the different *gazes* are represented on a continuum of strengths signifying the ideal knower in a discipline as depicted below in Figure 10.

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[50] See Chapter 8, Section 8.6 for a discussion on the analysis.

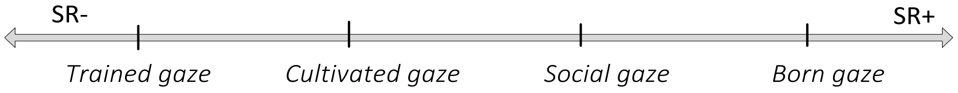

Figure 10. LCT: *Gazes* (Maton 2014)

At the extreme end of the continuum as indicated in Figure 10, is the born *gaze* which is associated with relatively strong social relations. Here, knowing is linked to a seemingly natural aptitude in a particular area of competence, or where certain aptitudes have biological or genetic explanations (Luckett 2010). The born *gaze* is characterised by an inherent way of knowing something, for example, if a chess player is referred to as a prodigy then s/he possesses a born *gaze* (SR+).

The social *gaze* is attributed to an individual's disposition as a result of belonging to particular social categories like class, gender etc., or, for example, through association with a particular group such as the Catholic Women's League. Such a group has its own protocols, conventions and requirements for membership. The social relations are relatively strong since legitimacy can be claimed by memberships to the group.

A cultivated *gaze* is based on the acquired *gaze* gained from prolonged social interaction and enculturation in a particular setting. An example of a cultivated *gaze* is the child enrolled in a private school where knowledge practices can be acquired and learnt through interacting with others in the group setting. The social relations are weaker than is the case with the previous two *gazes* since practices can be learnt through immersion over time.

The weakest of the social relations is where the ideal knower possesses a trained *gaze*. Maton points out that student identity that is developed in an intellectual field with a knowledge code is a trained *gaze*, where an individual is trained in specialised knowledge, principles and procedures (Maton 2014; p. 95). The focus of the learning is always on the object of study and not on the characteristics of the knower. In the case of General Chemistry, developing a trained *gaze* facilitates Chemistry thinking as an ideal trait for the student (Ellery 2016).

In sum, through LCT: Specialisation a critical exploration was undertaken of the basis of legitimation of knowledge claims and the prevailing legitimation discourse of the recontextualisers in the General Chemistry modules, as evidenced through the design of the curriculum and the learning and assessment activities in these modules. Luckett and Hunma (2013) examined how epistemic access was enabled through curriculum design in the Humanities.

They argue that it is necessary to examine knowledge practices and to expose the recontextualising and evaluative logic of the academics in the field to the students through the curriculum. They show that, in the Humanities, knowing is linked with the different *gazes* and lenses that must be acquired in order to succeed.

I make a similar argument for knowledge practices in General Chemistry and I endorse the need to make explicit the recontextualising and evaluative logic. This logic of the curriculum should be made accessible by making the rules of the game clear. The nature of the knowledge structure in General Chemistry requires that the rules of the game are made more implicit to enable successful learning for the majority of students. Muller (2009) also advocates making the key ways of thinking and practising accessible to students. In my study, the organising principles of the course content, tasks and assessment activities were analysed to determine the nature of the insight generated through the curriculum. As a key concern of the study, it was important that I got a sense of how the knowledge practices in General Chemistry curriculum were enabling or constraining learning. Through the tools of LCT: Specialisation I was able to understand the structuring of the knowledge practices in a field that has stronger epistemic relations.

In the following section, I discuss the second dimension of LCT concepts that I adopted in the study that enabled me to develop my understanding of cumulative learning and how it is dictated by the knowledge structure and enabled in the General Chemistry curriculum.

5.11 LCT: Semantics

LCT: Semantics is used for analysing the extent of context dependence of meanings (semantic gravity) and the level of condensation of meanings (semantic density) in educational knowledge and fields of practice. LCT: Semantics provides the tools to conceptualise knowledge practices by demonstrating varying degrees of relative strength or weakness of semantic gravity or semantic density in educational practices. Maton (2014a) states that “practices of production, recontextualisation and reproduction can each be understood as realisations of different degrees of semantic gravity and semantic density” (p. 110).

5.11.1 Semantic gravity

Semantic gravity refers to the degree to which meaning relates to its symbolic or social context (Maton 2014). Knowledge that is strongly related to its context evinces relatively strong semantic gravity (SG+). This kind of knowledge is easily relatable to context and one would assume, easier to make sense of, whereas knowledge that is less context dependent or is context independent has relatively weaker semantic gravity (SG-).

The strength of semantic gravity refers to the extent to which meaning relates to the concrete context of information, or of what the student knows. As mentioned previously, since General Chemistry has a hierarchical knowledge structure, the knowledge in the field is inclined to exhibit weaker semantic gravity and stronger semantic density. Chemistry knowledge has high abstraction and requires understanding at three levels, namely the macroscopic, microscopic (molecular) and the symbolic representations (Johnstone 2000) as discussed in more detail in Chapter 2. Mostly, Chemistry knowledge is presented in an abstract manner (microscopic and symbolic representation) which denotes weaker semantic gravity. Examples of everyday phenomena are plentiful (macroscopic level) which would denote stronger semantic gravity. Even when the knowledge content begins with concrete examples, the task of solving the problem and calculating values calls for high levels of abstraction.

5.11.2 Semantic density

Semantic density refers to the degree to which meaning is condensed within symbols (terms, concepts, phrases, expressions, gestures, etc.). The stronger the semantic density (SD+) the more meaning is condensed in a particular specialised or social symbol (Maton 2013, 2014). Chemistry disciplinary terminology is semantically dense. Even where words and terms have everyday meanings in General Chemistry they are expressed in chemical language (Blackie 2014). See for example, the following discussion by Respondent 1 about how meanings are condensed in the conception of elements:

> Should you know the first elements, all these elements of the Periodic Table *(pointing at the Periodic Table on the wall)*, you see that they have different colours and those different colours (*pointing to the Periodic Table*); these elements with orange-like colours have a certain characteristic. But should you know that this is element number so and so, you are going to know that oh, this one is going to react like this, I mustn't put it in water. It will cause an explosion. This one – I mustn't inhale it because it's going to kill many people. I mustn't do such and such a thing. This one – (*pointing at the red element at the bottom of the Periodic Table- uranium[51])* is the one that is used for the bombs. But if you do not know the Periodic Table you won't know, you are just going to look at it like this and not know what these colours stand for (Respondent 1).

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[51] The chemical element of atomic number 92 that appears below the main body of the Periodic Table.

A basic requirement for first-year General Chemistry is knowledge of the Periodic Table which is the representation of chemical elements that are arranged in a table format of seven rows (period) and eight columns (groups) along with an additional two rows below that.[52] The elements are written in ascending order of atomic numbers. Knowledge of the Periodic Table with the different elements, their symbols and numbers are necessary for solving problems (mathematical algorithms) and for understanding the properties of elements in reactions (Chemistry).[53]

One of the objectives of the curriculum is that the student should understand the physical meaning of the information given on the Periodic Table which comprises 118 elements. Symbols in Chemistry have numerous meanings related to the different theoretical and practical applications. I shall explain this using the example of the element, iron.

In brief, iron can be described using its chemical formulation as a chemical element with the symbol **Fe** (Iron – from Latin: *ferrum*) and atomic number 26. It is a member of the group 8 elements (chemical meaning). Iron is found in the sun and other stars (esoteric meaning). Iron is an essential mineral for health and well-being, but too much iron is extremely toxic for the human body (biological meaning). Iron is used in fireworks to make sparks. The colour of the sparks will depend on the temperature of the iron (industrial meaning).

As can be noted, multiple meanings are captured in the term, iron (Fe). In General Chemistry, terms thus have strong semantic density (SD+), and in other contexts terms may have strong semantic gravity. The term iron (Fe) exhibits strong semantic density due to its multiple meanings, but in some contexts the meanings have strong semantic gravity. In order to understand the significance of the term in General Chemistry, the student requires the capacity to hold different meanings, that is, the chemical, the industrial, and the biological meanings in tension. Attaining a balance between such tensions speaks to the complexity of designing a curriculum for optimum student learning at the introductory level such as in General Chemistry.

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[52] Two examiners of the PhD noted that the position of the additional two rows is at the bottom of the Periodic Table by convention, but the real position of the chemical elements is to the left of the block in the middle.

[53] The examiner noted that it is not just a matter of understanding the symbols in the Periodic Table but more importantly it is necessary to know that the position of each symbol in a particular group or period provides important information about each atom's electron structure and chemical properties.

Figure 11 below shows the positioning of Chemistry knowledge on the semantic plane. The diagram also attempts to show that the forms of knowledge vary in terms of abstraction and how, at different stages of learning, there are variations in the strength or weakness of semantic gravity or semantic density, depending on how it is taught and whether it is represented at the macroscopic, microscopic, or at the symbolic level.

Using the diagram below, Blackie (2014) presents an example of the degrees of variation of meaning through a chemical equation of sodium chloride in a solution form, and sodium chloride in a solid form (macroscopic level) NaCl(s) → NaCl (aq) – (symbolic / representation level). This simple equation is an example that illustrates weak semantic gravity and strong semantic density as illustrated in the Figure 11 below. The equation represents the concept of dissolution which has a weaker semantic gravity and is represented in element and state symbols as depicting stronger semantic density (SG-, SD+). Blackie argues that understanding dissolution requires at least an understanding of ionic bonding, polar covalent bonding and intermolecular forces. Although the concept is abstract, it can be demonstrated by showing how salt disappears when it is dissolved in water.

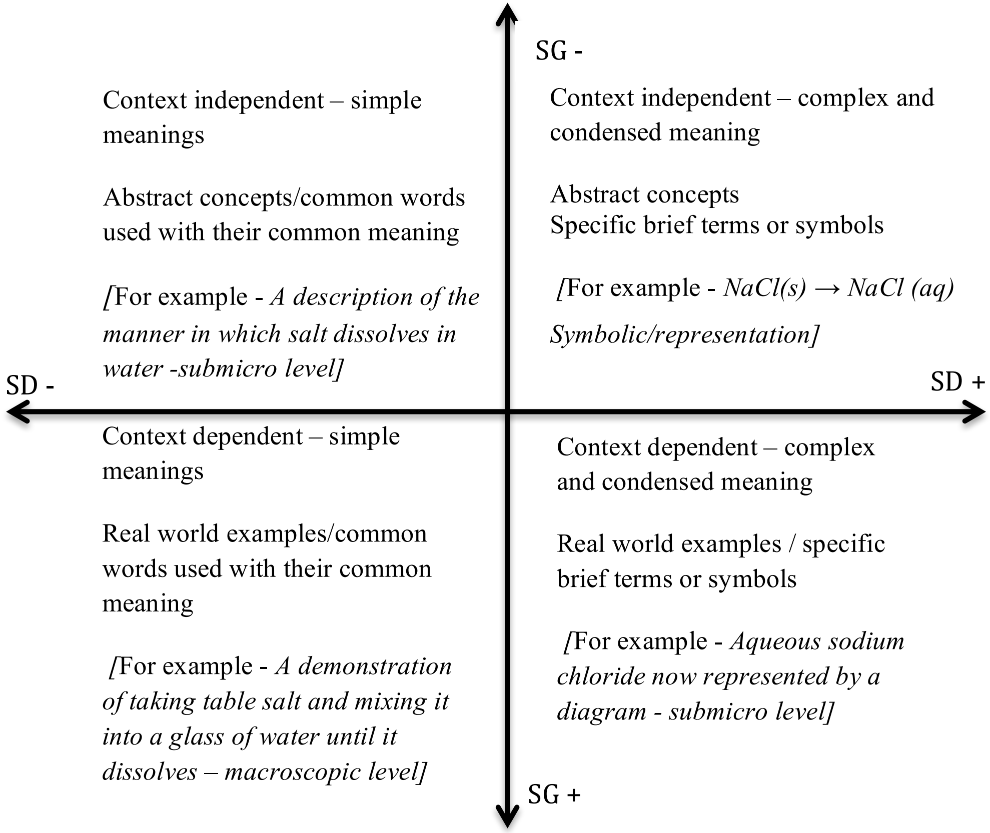

Figure 11. The relationship between semantic gravity and semantic density - Dissolution (adapted from Blackie 2014, p. 464)

It can be noted that when salt dissolves in water, changes occur in the water – it becomes a solution as a result of the presence of salt. However, understanding that the ions separate and become solvated emerges from making sense of the data, not through direct sensory observation. Full understanding of the process of dissolution is not possible through inference from simple observation since comprehension requires drawing from the macroscopic, microscopic and the symbolic nature of Chemistry knowledge (Blackie 2014). The above example clearly demonstrates that learning in Chemistry is a complex process involving the integration of knowledge from different levels, as previously mentioned in Chapter 2.

Complexity in the educational field of Chemistry is evident at multiple levels. The complexity of knowledge is reflected in the complexity of the curriculum design, including the complexity of tasks developed to scaffold student learning. To manage this complexity across the various levels of the pedagogic device requires that the rules of the disciplinary field are understood so as to make the basis of achievement in General Chemistry explicit for students. Understanding the underlying mechanisms made possible through the pedagogic device and the epistemic-pedagogic device and the two dimensions of LCT: Specialisation and Semantics is likely to make the task of designing the curriculum for optimum learning of threshold concepts in the curriculum easier for the lecturer.

LCT: Semantics can generate a semantic profile through the use of four different types of semantic codes that shed light on the nature of the educational practices and how these determine the semantic codes. Maton (2016) refers to the profiling of the organising principles as providing information on the nature of practices and dispositions and how these can change over time and basically expose "the rules of the game." He makes a distinction between *rhizomatic codes* (SG- SD+), that point to the basis of achievement consisting of context independent and complex meanings; *prosaic codes* (SG+, SD-), where legitimacy is context dependent and simpler meanings are evinced; *rarefied codes* (SG-, SD-), where achievement is based on context-independent knowledge and simpler meanings, and *worldly codes* (SG+, SD+) where legitimacy is from context-dependent knowledge with a multitude of meanings. The diagram below represents the semantic plane as developed by Maton (2016).

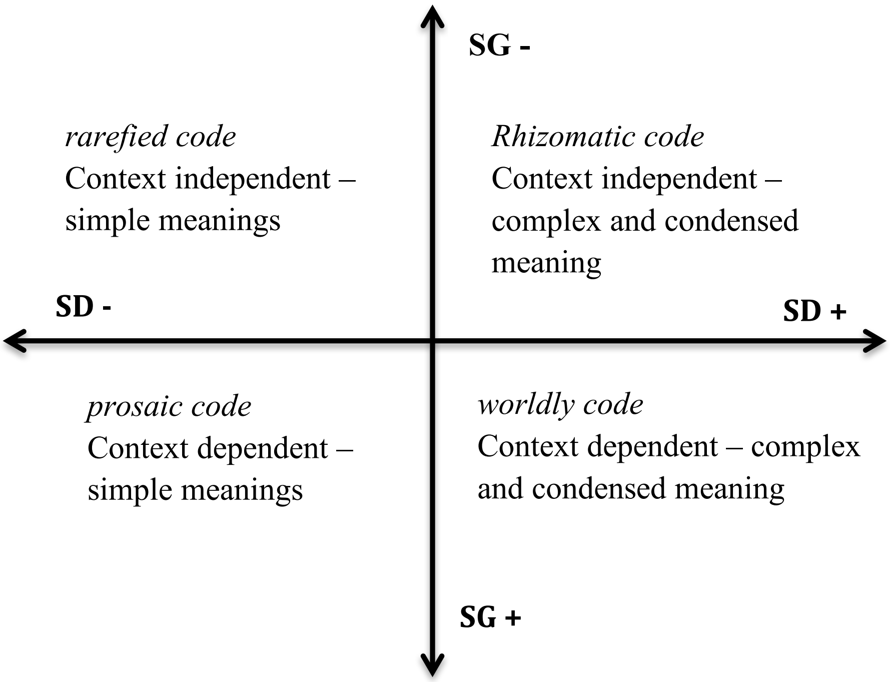

Figure 12. The semantic plane (Maton 2016, p. 16)

I have used the above-mentioned semantic codes as tools to analyse the General Chemistry curriculum specifically to understand the knowledge-building capacity of the introductory module, as required by the knowledge structure of the field.

5.11.3 Cumulative knowledge-building

The degree of context independence and the degree to which meaning is embedded within symbols is a significant indicator of the necessity for structuring the curriculum in a manner that encourages cumulative learning. Given the nature of the knowledge necessary for learning in the subject, as well as the hierarchical knowledge structure of the Chemistry field, the nature of learning should be such that it allows for progression, or what Maton refers to as cumulative learning. In terms of usefulness of LCT: Semantics for determining the capacity for cumulative learning, Maton (2013) asserts that cumulative learning is more likely to occur when there are successive waves of weakening and strengthening of both semantic gravity and semantic density. In essence, this implies that there is successive delocating and relocating of knowledge for example, during pedagogic practices, where the process of unpacking theory to simplify it and re-packing it into the disciplinary concepts to facilitate student learning, produces a particular semantic structure. Cumulative learning is dependent on the processes of weakening and strengthening of semantic gravity during a specific time span of learning. The stages or intervals at which the processes of strengthening and weakening of semantic gravity and semantic density take place indicate the cumulative or segmented learning that can occur in the pedagogic setting, depending on the nature of the knowledge and timing of these transitions.

For introductory learning in the first-year, this process of unpacking and re-packing knowledge by simplifying concepts then elaborating and relating the complexity of those concepts in different contexts is a pre-requisite for cumulative learning (Maton 2014). Maton contends that the key challenge for curriculum design is attaining iterative instances of strengthening and weakening of semantic gravity and semantic density in the teaching of the subject, that is, moving from the concrete to the abstract and back again in successive 'waves' of strengthening and weakening semantic gravity and semantic density. A further discussion on cumulative learning is presented in Chapter 8 in the data analysis.

5.12 Summary

In this chapter I have discussed the key theories and concepts that have been used as both conceptual and analytical tools in the study. Bernstein's theorisation of the transformation of knowledge through the different fields in education assisted in appropriately locating my study in the field of recontextualisation. Drawing on his conceptual tools I used the notion of knowledge structures to explain how General Chemistry is structured. For this task, I have taken into account the characteristics of hierarchical knowledge structures, verticality and grammaticality for knowledge-building in the field of practice. I have furthermore noted the need to examine the implications for cumulative learning in the discipline.

In Section 2, I explained the legitimation codes of LCT: Specialisation and LCT: Semantics and presented a case for the applicability and usefulness of these concepts for making possible a fine-grained analysis of how the knowledge of the discipline is structured. Understanding these structuring principles is central when constructing the curriculum to enable cumulative learning. Maton's (2007) assertion that the verticality of a discipline constitutes the basis for the recontextualising principle, as well as Muller's (2009) statement that "disciplinary form poses constraints on appropriate curricular form" (p. 216) provide a good basis for understanding the implications of the organising principles of disciplinary knowledge for curriculum design and development. Hence, to facilitate cumulative learning, lecturers teaching in disciplines with high levels of verticality, such as General Chemistry, need to demonstrate the application of the recontextualisation principle through appropriate sequencing, pacing, alignment, and articulation[54] when constructing the curriculum. LCT: Semantics can facilitate the examination of the structure of curricular content by showing the extent to which the selection, sequencing and pacing of disciplinary knowledge evince shifts in context dependence and abstraction. In the next chapter, I discuss the design of the research methodology of my research project.

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[54] See the discussion on grammaticality and verticality Section 5.5.3 of this chapter.

CHAPTER 6 – Research methodology

Critical realism makes the assumption that an
ontological theory presupposes an epistemological theory; and further to
this, that this meta-theory influences the way data are collected and
analysed about the social world (the strategic and methodological levels)
(Scott 2005, p. 634)

6.1 A critical realist approach to research design

This study engaged theoretical perspectives underpinned by a critical realist orientation as lenses to uncover the underlying structuring principles inscribed in the curriculum as planned for first-year General Chemistry modules at the LSAU. In this chapter, I discuss the research methodology undertaken in the study.

Critical realism proffers a depth ontology and acts as an under-labourer for an exploratory methodology. Critical realism research aims to identify, at the level of the *real,* structures, mechanisms and objects that possess causal powers which may emerge as events and practices that can be observed and experienced or that may remain un-activated or unobserved. Adopting a realist perspective of research implies searching beyond appearances for the structures and mechanisms that lie behind or beneath them in the domain of the real, thus offering the possibility of rich explanations of why phenomena are the way they are.

Scott (2000) proposes that in order to conduct research that separates ontology and epistemology, we should begin by addressing questions such as, “What is the nature of the reality which we are attempting to find out about? How can this be known? What are the implications of the answers to these questions for the choice of methods used?” (p. 16). For Burnett (2007), the overall purpose of using a critical realist approach for an inquiry into society is to bring about social change. A fundamental question that the researcher asks is, “What must the world be like for certain things or events to happen?” (Bhaskar 1998, Burnett 2007). The form of questioning adopts a retroductive process of inquiry which is a result of understanding the layered nature of reality.

Among philosophers, contestations abound regarding the notion of truth and knowledge. This quest for the truth, truthfulness and knowledge is the endeavour of (all) research activities, not only for critical realist research. As mentioned in Chapter 3, the fallibility of knowledge is a key feature of the critical realist approach, and one which offers an alternative to the extreme empiricist, positivist and relativist perspectives of the world and of how we know the world. The realist conception of fallibility addresses the issue of error in research, and it is understood that access to complete knowledge is not possible. Knowledge of the world is said to be relative (Scott 2005). From a CR perspective, this means that the knowledge attained should always be regarded as potentially fallible, and the best we can achieve, given our social and temporal context. Scott's argument on the fallibility of knowledge is that researchers should acknowledge "new ways of describing the social world as always operating and replacing old ones, even if those new ones are in a critical relationship to the old ones" (2005 p. 636).

The condition of embracing the notion of fallibility of knowledge makes the adoption of a critical realist stance most appropriate for this study since critical realists claim that the world cannot be changed rationally unless it is interpreted adequately (Bhaskar 1998, Sayer 2000). Interpretation needs to take account of the layeredness of reality and the interrelatedness of structures and agency so that an adequate explanation of causation, power and tendencies can be achieved. Distinctive to CR is the acknowledgement of ideas and meanings held by people in society in the form of concepts, beliefs, and intentions. Maxwell (2012a and 2012b) states that CR views concepts, beliefs, and intentions as being equally real and possessing causal powers in the same way as physical objects do.

6.1.1 Causation / Causality

It is worth reiterating key critical realist tenets of causation here as part of substantiating the research design. As mentioned in Chapter 3, realist research strives to develop causal explanations for phenomena that go beyond the obvious in the domains of the empirical and the actual. CR's approach is that objects in reality possess causal powers or tendencies and/or generative mechanisms.

The primary research concern that animated this study was to uncover the structuring principles of the General Chemistry curriculum and how and to what extent the structuring principles possess the tendency to influence equity of outcomes for diverse students. The key research question emanates from an interest in investigating how knowledge practices in the first-year General Chemistry curriculum can include and exclude students from disciplinary knowledge. The investigation attempted to answer the primary research question of this study, which was:

> How does the knowledge and knowledge practices privileged in the General Chemistry curriculum at the LSAU enable or constrain learning?

As indicated in the rationale for the study in Chapter 1, my interest in exploring the knowledge and curriculum practices arose from a context where a large group of students continued to experience difficulties in learning in the Introductory Chemistry module, despite a series of curriculum interventions aimed at addressing their learning needs.

In order to understand the basis of success in the modules and what is valued and highlighted through the design of the curriculum required more than saying that the curriculum structure caused some students to succeed or to fail. It was necessary to understand why that was the case. A realist orientation to the research allowed for the identification of the structures, mechanisms, and objects at the level of the *real* that possessed causal powers and tendencies which may have emerged as events and practices that could be observed and experienced or that may have remained unobserved.

The subsidiary questions which supported the inquiry into the main research question were:

a) How do curriculum discourses influence the structuring of General Chemistry?
b) How do the organising principles of the knowledge practices in the General Chemistry curriculum legitimate knowledge and knowers?

c) How does the structuring of the curriculum contribute to epistemological access and cumulative knowledge-building and learning?

6.2 Research design

6.2.1 An intensive approach

I adopted a qualitative research methodology and an intensive research approach to the study. An intensive research approach is primarily concerned with what makes things happen in specific cases (Sayer 2000). An intensive approach to research enabled me to generate causal explanations and interpret meanings in context (ibid.) and to identify the knowledge and knowledge practices occurring in this teaching and learning context. Sayer (2000) emphasises that critical realist research using the intensive approach focuses on asking "What must be the case?" rather than "What can be the case?" So, a fundamental question asked in the investigation was, *What must be the case/conditions in relation to the knowledge practices in General Chemistry to enable some groups of students to succeed while others fail?* The intensive approach provides a process for seeking out substantive connections among phenomena and situates practices within a wider context, thereby illuminating part or whole relationships (ibid.).

The study adopted a qualitative research methodology. For Denzin and Lincoln (2011), qualitative research is a situated activity that locates the observer in the world, making it more visible and thus enabling inquiries of that world in its natural setting. By so doing, the researcher is then "able to draw conclusions and make sense of and interpret phenomena in terms of the meaning people bring with them" (p. 3). Qualitative research can be referred to as an approach to enquiry that seeks to understand particular phenomena in their natural contextual setting, using descriptive, non-numerical data in the form of words to explain the phenomena. Maxwell (2012a) claims that context is intrinsic to causal explanations and any causal claims are grounded within a context. Both Maxwell (2004) and Scott (2005) highlight the contested nature of causality, especially in qualitative research, with Maxwell (2004) cautioning that it is not necessarily easy or straightforward to establish causation because of an increase in the threat to the validity of the research. It is through a systematic and rigorous process of providing evidence that supports the causal claims that the threats to validity can be reduced (Maxwell 2012a).

Through an intensive approach to this qualitative study, I attempted to illuminate the role played by the curriculum structure in enabling or constraining student learning. This I did by revealing, and then making inferences about the role played by the organising principles underpinning knowledge practices in General Chemistry. Research into knowledge practices from a social justice perspective provided an opportunity to investigate the complexity of practices. This means that not only human perceptions and experiences were evaluated, but also the deeper values, attitudes, and beliefs that advanced certain ideologies and practices in the construction of the curriculum were interrogated.

6.2.2 The case study methodology

The methodological decisions for this study were guided by a critical realist orientation and informed by the purpose of the research. Justification for the case study methodology is offered by Danermark *et al* (2002 p. 45) who argue that "it is the nature of the object that determines the possibilities we have for gaining knowledge about it" and that guides methodological choices.

Rule and John (2011) define case study research as an investigation into a particular instance or circumstance in a specific context. Although there was specificity in the context, the issue under investigation potentially has far-reaching applicability and relevance across contexts with similar characteristics.

The aim of using case studies with a critical realist approach as an under-labourer is to offer causal explanations and to identify underlying mechanisms based on direct observation, as well as through generating explanations about the presence and nature of the generative mechanisms at play in the context. Clear boundaries are drawn so that there is clarity about what does and does not constitute the case.

The case study approach makes it possible to provide an in-depth examination of the contextual and complex conditions in which the case is situated (Yin 2006, 2012; Rule and John 2011). In this instance, there was a need for a deeper understanding, within the context of General Chemistry, of how the prevailing discourses and emerging knowledge practices were enabling or constraining student learning. Rule and John (2011) propose that cases are exploratory and explanatory in nature.

The case study reported on here can be described as an intrinsic case study, meaning that the nature of the phenomenon under study was in itself an interesting issue that deserved to be understood more fully. The key question I explored related to explaining what the curriculum had to be like to enable successful learning for some students and not for others. The methodology enabled the use of multiple sources for generating knowledge (Yin 2006).

6.3 Data selection and generation

The context in which this study was undertaken was very complex and multi-layered. It therefore required an analytical process of different data sources using a staged approach and a bricolage methodology underpinned by CR. Critical realism offers a way of dealing with complexity by providing the methodology for arriving at explanations. Danermark *et al* (2002) suggest using intensive and extensive empirical methods and procedures when searching for generative mechanisms, and how they manifest in different contexts.

As part of the data selection process for this investigation, I chose a mixed sampling method to obtain different types of data from different sources. *Purposive sampling* was used to select curriculum documents given that only the study guide, online documents, and the exam papers were available. Upon reviewing the examination papers, I decided to focus on the June examination paper since it represented the actual curriculum that was assessed from the intended curriculum (the study guide I analysed was of the same period). Purposive sampling for documentary data sources makes sense when it is evident that particular sources will provide the required information (Creswell 2007). Examples of the data sources included study guides, the prescribed textbook, and support learning material such as lecture notes.

The second sampling method was the *stratified random sampling* for generating interview data from General Chemistry lecturers. Stratified sampling is a modified version of random sampling that aims to achieve a more representative sample by grouping or clustering the population into smaller subsets that are in some ways homogenous, but inherently heterogeneous (Babbie 2007). The sampling strategy took into account the stratified composition of the academic staff members who formed part of the teaching teams. For example, since the lecturers were at different levels of seniority in the department, they had different levels of responsibility and participation at various departmental teaching and learning committees where curriculum matters were discussed. A sample of seven lecturers involved in the teaching of General Chemistry and who were also part of management of the module were selected. The stratified random sampling technique enabled me to examine the complexity of the context in which curriculum design and development occurred, as well as to explore the prevailing instructional and regulative discourses of the curriculum. The complexity of the case was characterised by the nature and composition of the physical, human and social variables that impacted on the context (White 1985).

6.3.1 The case in context

A case is shaped by its context. Rule and John (2011) define a context as a particular set of circumstances surrounding a situation. Contexts have features that are significant for understanding the case under investigation. Each context has spatial, temporal and depth dimensions and features that make it unique and differentiate one context from another. The spatial dimension refers to the space within which the case as a unit of study is located. The temporal dimension refers to the sense of time and historical relevance of the phenomenon. Depth refers to what underlying practices underpin the case that require excavation (p. 40). This approach to compiling a contextual profile aligns with the depth ontology of a stratified reality. Therefore, in terms of the case, the various dimensions imply that the sourced and generated data provide evidence of the conditions at a certain point in time when the research was undertaken. As such, the findings emanating from the study are influenced by the unique features of the case at a particular time.

The case comprised the first-year General Chemistry curriculum offered by the Department of Chemistry at the LSAU. From a critical realist perspective, the data sources were present in the domains of the empirical and the actual. Through the research, the aim was to excavate the structures and mechanisms from which the documents and the experiences of the curriculum emerged.

The unit of analysis was the intended knowledge and associated knowledge practices. The knowledge practices were evidenced through the structuring principles of the curriculum which from a CR perspective were located in the real domain. Of interest was the planned General Chemistry curriculum (including the assessment plan) which had the potential to influence student learning and student identity. Both the first and second semester modules constituted the case because they were first-year modules, although the specific focus of each was different (see Table 4 below).

Modules	Semester	Staff Members [55]
General Chemistry (GCM 101)	1 – Inorganic Chemistry and Physical Chemistry	4
General Chemistry (GCM 102)	2 – Organic Chemistry	3

Table 4. The case of General Chemistry

6.3.2 The significance of context

First-year modules are often characterised by high student numbers. This was also the case with General Chemistry, particularly since the module serves as a service module for other programmes. There was thus an increased probability for the presence of at-risk students and higher failure rates.[56] As part of the inquiry into knowledge practices, the context in which the curriculum was designed was deemed central. The conception of context in this study is significant because it acknowledges the relational aspect of context. As a concept context acknowledges the connectedness of things and events that are socially situated and historically embedded. This relational notion of context focuses on social products arising from practices. Seddon (1993) explains that context constitutes the "discursive setting within which practices occur' (p. 6). Seddon further asserts that contexts can be regarded as a social product which is constructed and reconstituted through practices within a social formation understood relationally" (Seddon 1993, p. 47). The act of defining the context involves "a positioning of meaning that

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[55] Based on 2014 records.

[56] See the discussion in Chapter 1, Section 1.7 on the rationale for the study.

establishes boundaries between the significant event and its context but also obscures from view and designifies everything beyond that frame" (ibid.).

For Maxwell (2012a), context is intrinsic to causal explanations. The overall concern of the research was to understand and explain the nature of the pedagogic discourse and the knowledge and curriculum practices found in the curriculum produced in the field of recontextualisation in order to make inferences about student learning.

Through the interviews with academics, I gained insight into their understanding of how they may or may not have influenced curriculum decision-making or may have structured pedagogic discourse. The lecturers who designed and taught the modules held certain views about knowledge, the curriculum and its construction, and the knowledge it aimed to teach. The interviews with these recontextualising agents enabled me to examine the ways in which they understood and represented the complexity of the discursive setting within which General Chemistry curriculum practices occur. Lecturers were privy to the complexity of the discursive setting within which General Chemistry curriculum design happened. I hoped that the interview data would make it possible for me to explain the context of the Pedagogic Recontextualisation Field and the prevailing discourse regulating first-year learning of General Chemistry. The discourse can be regarded as representing another aspect of the knowledge and curriculum practices in the subject. In the following section, I present the context that formed the backdrop for the data analysed in the study.

6.3.3 The module structure

Both the first and second semester Introductory General Chemistry modules were taken by the majority of BSc students, who were required to complete one year of Chemistry. Students from the faculties of Engineering and Health Sciences were required to take different first-year Chemistry modules.

According to the curriculum design model discussed in Chapter 4[57], a product of the curriculum design process was the study guide. The General Chemistry modules were composed of a theory component, practical laboratory work, and tutorial sessions. The theory component was delivered during the lectures and tutorials as indicated in Table 5 below. Practical work was undertaken in the laboratories.

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[57] See Section 4.6.2 of Chapter 4 on the curriculum design framework in the module.

The first semester GCM 101 had 56 lectures, while the second semester GCM 102 had 53 lectures. The first semester module was composed of Inorganic Chemistry and Physical Chemistry, while in the second semester the modules were divided into two sections. Section A of the second semester was a continuation of Inorganic Chemistry from the first semester, and Section B comprised the study of Organic Chemistry offered over six weeks towards the end of the year.

<table>
<tr><td colspan="2" rowspan="4"></td><td colspan="5">LEARNING</td></tr>
<tr><td>Theory</td><td>Type of knowledge</td><td>Practical</td><td>Type of knowledge</td><td>Tutorials</td></tr>
<tr><td rowspan="2">Lectures</td><td rowspan="2">Conceptual Knowledge</td><td rowspan="2">Laboratory</td><td>Procedural knowledge</td><td>Student support</td></tr>
<tr><td>Conceptual Knowledge</td><td>Prescribed exercises</td></tr>
<tr><td rowspan="2">ASSESSMENT</td><td>Continuous assessment (graded)</td><td>Self-assessment exercises (non-graded)</td><td>Formal semester tests</td><td colspan="2">Informal class tests
Pre-practical assessment: Online quizzes</td><td>Post tutorial test (Non-graded)</td></tr>
<tr><td>Summative assessment (graded)</td><td colspan="5">Written examination</td></tr>
</table>

Table 5. Module teaching and learning structure

In terms of assessment, each module had two formal semester tests that comprised 30% of the final mark, and the summative assessment in the form of a formal, three-hour examination. The content of the summative assessments constituted another data source for exploring the evaluative criteria of the course which influenced decisions made about the curriculum structure and the practices.

6.3.4 The teaching and learning environment as part of context

General Chemistry at the LSAU utilises team teaching at first-year level. Team teaching is defined as where multiple teachers teach in a single module (Wenger and Hornyak 1999, Leavitt 2006, Hanusch, Obijiofor, and Volcic 2009). This approach is gradually gaining popularity in higher education (Hanusch *et al* 2009). General Chemistry modules are taught by a group of four to ten lecturers, depending on the student intake for that year. Team teaching occurs mainly in two forms: first, a group of lecturers teach the same content to different groups of students, in parallel sessions held in different venues, in different languages[58] at different times throughout the day and week. Second, each consecutive unit or theme in one module is taught by a different lecturer. The same lecturer would then teach the unit or theme of the module to different sets of students at different times. This means that students would be taught by 3 – 5 lecturers over the course of a semester. Both models of team teaching are implemented in the General Chemistry course. Generally, the first semester classes are very large, consisting of about 1700 students. Because of the service nature of the General Chemistry module, in the second semester the classes are usually drastically reduced, thus allowing lecturers to adopt the second model of team teaching.

Team teaching represented a significant characteristic of the context within which curriculum decisions occurred. In a team-teaching context, and as previously discussed, it was expected that each lecturer brought to the teaching and learning context, and the curriculum construction process, their disciplinary and pedagogic knowledge, interests, beliefs and values. In Bernstein's terms, these factors underpinned the recontextualising rules that operated in the educational setting. The teaching and learning environment was acknowledged as a relevant aspect of curriculum practice in this setting; however, it did not form the primary object of study. The inclusion of the academics as part of the context where curriculum design decisions were made, was secondary in the study. The research was an attempt to uncover the underlying mechanisms that resulted in some students being successful and others unsuccessful in learning in a diversified and changing higher education landscape. As such, it was deemed necessary to briefly mention team teaching as an element of the context. Moreover, the lecturers that were interviewed were all involved in offering the modules.

6.4 Data collection process

6.4.1. Accessing the data – curriculum documents

In critical realist research, data collection is an opportunity to collect evidence of real phenomena (Maxwell 2012a, 2012b). Different data collection methods were used for generating sufficient information to explain the 'what' and 'why' of curriculum decisions of the first-year curriculum. I requested permission from the relevant structures at the institution to access and analyse the curriculum documents, and teaching and learning materials for the study.

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[58] LSAU Language Policy says that first-year modules can be offered in English and Afrikaans.

The primary data sources for the study comprised the curriculum documents, as they offered evidence of pedagogic discourse. The documents included the study guides, lecture notes and assessment documents. Initially, I requested permission from the Head of Department and the module coordinator to use the first-year General Chemistry curriculum documents for the years 2011, 2012 and 2013. Very early on in the study when I looked at the study guides, I realised that the documents were identical. The study guides included the module outlines, the study notes, thematic exercises for continuous assessment and tutorials. I also acquired the assessment material in the form of the summative examination papers for the year 2013, the year when all the data analysed in the study were collected.

The secondary sources of data consisted of the interviews with General Chemistry lecturers and academics who were part of the management teams of the department and the faculty.

In the following section I discuss each of the data sources analysed in the research.

6.4.1.1 The study guide

The study guide was given to all students at the beginning of each semester and was structured according to the institution's standard guidelines for the development of teaching and learning materials. The study guide comprised an *organisational component* and a *learning component*. The organisational component contained information necessary for navigating learning and learning materials in the module, such as the prescribed textbooks, as well as the contact details of lecturers teaching in the module.

The *learning component* of the study guide outlined all the knowledge content, including the module objectives and a brief synopsis of the knowledge areas (knowledge content in the form of topics), the practical laboratory work required, along with associated time frames for the duration of the module.

The study guide was an enactment of the pedagogic device of the General Chemistry curriculum and was structured according to the rules that regulate and mediate access to knowledge - its production, appropriation, acquisition and evaluation (Bernstein 2000). The document formed an integral aspect of conveying various discourses or messages about teaching and learning. A large percentage of the study guide contained notes and instructions about how to learn, rules of conduct in relation to class attendance and extensive procedures for theory and practical work, and assessment rules (regulative discourse).

6.4.1.2 Lecture notes

The lecture notes supplemented the information that was provided to the students on the module website on the institutional Learning Management System (LMS). These notes, as well as learning activities contained in the study guide, were placed on the websites and could be accessed by students as and when specific topics were being taught. This website was used extensively for facilitating online learning and for formative assessment. Online learning served as an extension of the teaching and learning environment for both modules analysed in this study.

6.4.1.3 Assessment documents

A significant aspect of this inquiry related to developing an understanding of how the curriculum influenced student achievement or lack thereof. According to Porter (2006), how students are assessed provides vital clues about what lecturers value as part of the intended curriculum. He states that "knowing the content of the assessed curriculum is important because student achievement is measured only for the content assessed" (ibid, p. 141). Measuring students' achievement through tests and exams is still a widely accepted practice in education, and higher education specifically. Assessments represent the actual curriculum (Ramsden 2003) and "the knowledge principle". Kilpert and Shay (2012) describe the knowledge principle as the 'what' and 'how' of student learning from the curriculum. As the recontextualising agents, lecturers have views and expectations about what students should know and how they should know it. Therefore, the inclusion of assessment documents as data sources contributed to answering the question of what mattered in the curriculum and how this information was made visible to the students through the assessments.

The assessment documents that were examined included the continuous self-assessment exercises in the textbook, as well as the summative assessment, i.e. the examination papers. However, student responses to these assessments were not analysed.

Each learning theme contained a set of prescribed exercises based on specific sections in the textbook. The students were advised to do the self-assessment exercises before attending tutorials. They were also informed that these exercises would not be assessed formally.

Twelve themes or topics were covered in the first semester. An analysis of the examination paper showed that, given the hierarchical nature of the discipline it was necessary for the curriculum to provide the foundational building blocks essential for higher levels of learning. The interconnectedness of GCM 101 knowledge was evidenced through the four broad areas that were examined in the paper: stoichiometry, precipitation and concentrations; bonding and molecular structures, equilibrium; acids and bases; properties of salts and buffers, and titrations. Collectively, these themes highlighted the building blocks and conceptual development required for learning GCM 101. Knowledge of chemical reactions, the principles that govern the application of the laws of definite proportions, and of the conservation of mass and energy to chemical activity constitute important foundational GCM 101 knowledge.

The summative examination paper was in the form of a three-hour written examination and constituted 50% of the final mark. The examination paper contained two sections: Section A consisted of four problem-based, long, open-ended questions that included calculations. Each question had an average of four sub-questions. Section B included multiple-choice questions drawn from various knowledge areas in the curriculum. Both sections had an equal weighting of 50 marks.

In sum, the assessment documents were analysed since they provided evidence of the evaluative criteria for General Chemistry, including what knowledge was valued. I was interested in whether assessment expectations were made explicit, and at which points messages about the knowledge principle were conveyed to students, and how. The analysis of the assessment questions also provided an indication of the semantic structure of the assessment questions and tasks. As discussed in Chapter 5 (see Section 5.11), the semantic structure refers to the degree of complexity and abstraction, and the extent to which assessment tasks related or alluded to contexts of application.

6.4.2. The interviews

The first step in planning for the interviews involved identifying the lecturers who taught the modules and requesting an interview with each of them. I interviewed those involved in teaching theory as well as those who taught the laboratory classes. The interviews lasted between forty minutes to an hour and were conducted in lecturers' offices. I requested permission to use a voice recorder as a way of capturing the data. Before I began the interviews, I informed each lecturer about the purpose of the research as well as the key questions I aimed to investigate. I also informed them about the permissions received to conduct the research at LSAU. I observed that in some interviews the use of the recorder made the participant self-conscious but as the interview progressed, they eased into the conversation and became more comfortable with talking about the module. I also observed that some lecturers, despite having agreed to be interviewed, seemed somewhat reluctant during the interview process. I assured them that I would not use any names in the reporting of the data. As part of protecting the identities of this small group of lecturers, I assigned a number to identify each respondent, instead of using participants' names. When reporting on the interviews, I used the designation Respondent 1 (1, 2, 3, etc.) to refer to specific participants in the study. I have kept a separate record of details identifying all the respondents.

The interview schedule consisted of four open-ended questions and was handed to the lecturer at the start of the interview. The choice for an open-ended interview schedule was influenced by the nature of the information that was required. I wanted to know what the lecturers thought were the purposes of the first-year modules, and how the curriculum satisfied these purposes.

Finally, I asked each lecturer to talk about how decisions were made about what constituted the curriculum, and their participation in curriculum design processes. I asked follow-up questions in order to clarify responses that were unclear or when I wanted research participants to elaborate on their responses.

I found the use of open-ended questions very useful for probing, although in one case, the lecturer tended to veer from the topic and constantly had to be reminded of what the initial question was about. The use of open-ended questions in qualitative research is a common data collection method that allows for probing and acquiring deeper understanding of the context. Schudel, Le Roux, Lotz-Sisitka, Loubser, O'Donoghue and Shallcross (2008) support the use of open-ended questions for the purpose of constructing a profile of the research context.

Maton (2000, 2001) argues that it is crucial to identify and understand the dominant discourses in the context which may have an effect on educational practices. The information gathered from the interviews served to facilitate my understanding of the nature of the environment in which the knowledge practices in the curriculum were fashioned and enacted.

6.5 The data analysis

The real domain consists of structures and mechanisms that can bring about events and experiences. In this study, the organising principles of the curriculum were regarded as generative mechanisms that structured knowledge practices at the level of the real. In order to access the knowledge practices, I had to analyse the curriculum and supporting curriculum documents. To achieve this, I had to develop a means of relating the data to the theory. Below I discuss how I developed an organising framework to generate and analyse data.

6.5.1 An organising framework for data generation and analysis

I used the research questions to identify a framework that I thought was most appropriate for the initial analysis of the intended curriculum as evident in the curriculum documents. I was always guided in the analytical process by my research questions, and by the nature of the data and what I could read into the data, that is, what I thought the data pointed to or signified. As a way of organising the data I developed an organising framework that could be used to identify and conceptualise the data analysis process. The framework also assisted in organising my thinking about where and how the different parts of the data were connected. Given the nature of the object of study, the organising framework also had to provide a means for understanding the complexity of Chemistry knowledge as espoused by the intended curriculum.

Below (Figure 13) is the illustration of the organisational framework for the classification, collection, and analysis of data in the study. The data analysis comprised two phases – I first analysed the curriculum documents (Phase 1) and then analysed the interviews (Phase 2). The focus of Phase 1 was the excavation of the organising principles of the curriculum, while I examined the prevailing pedagogic discourses in Phase 2.

The analysis was underpinned by the theoretical and conceptual tools of Bernstein's pedagogic discourse, and the conceptual and analytical tools offered by Maton's LCT: Specialisation and LCT: Semantics. The main reason for considering pedagogic discourse was to understand the relationship between the regulative and instructional discourses underpinning the curriculum design and development at the LSAU. The CR tools of retroduction and abduction which are discussed in Section 6.5.2. formed the basis for the lines of inquiry throughout the data collection and generation process.

As indicated in Figure 13 below, and drawing from the theoretical framework, I decided on the categories for analysing the pedagogic discourses in the recontextualisation context of the General Chemistry curriculum. In particular, I focused on the extent of classification and framing of the curriculum.

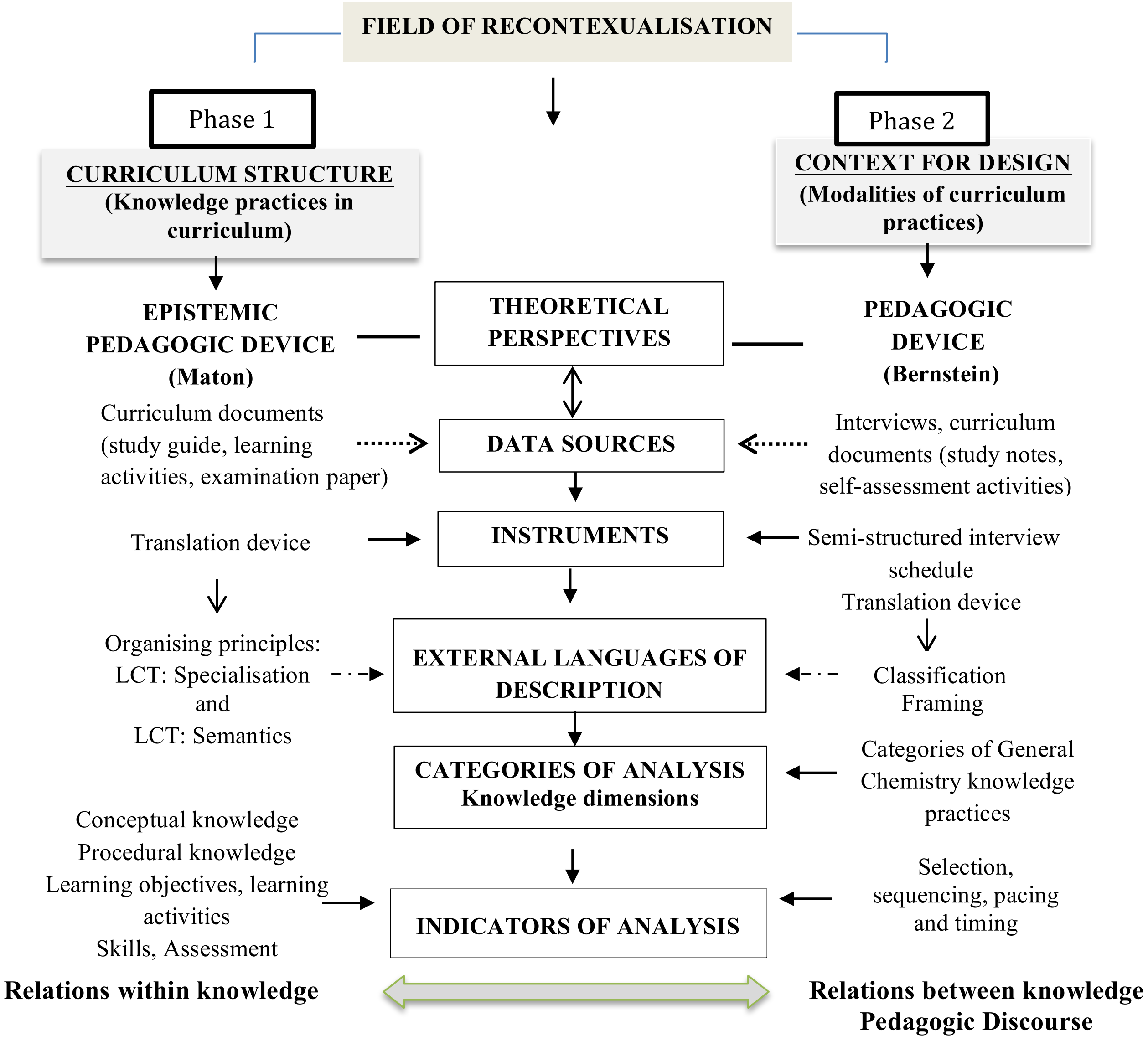

Figure 13. Organisational framework for data generation and analysis (adapted from Morais and Neves 2010)

In a CR study the context as mentioned above (see Section 6.2 of this chapter) is intrinsic to generating causal explanations that shape knowledge practices. Therefore, this analysis started with the profiling of the context in which pedagogic discourse was used / emerged. The interviews and the study guide were the main sources of data for the analysis of the pedagogic discourse.

6.5.2. Data analysis tools – retroduction and abduction

The CR tools of abduction and retroduction were used to analyse the curriculum and the interview data. Abduction and retroduction were used as analytical tools that enabled me to make inferences with the intention of arriving at plausible explanations of causation in the domain of the real.

Danermark *et al* (2002) explain inference as the "descriptions of various procedures, ways of reasoning and arguing applied in science (to) relate the particular to the general" (p. 75).

I used *abduction* in the initial stages of organising the data and in the formation of analytic categories. This process involved interpreting, re-describing and classifying the data. The strength of abduction is that, through the analysis, the data that do not easily align with the theory become evident. This type of data can be missed or disregarded as being irrelevant, but critical realists argue that this very data may be vital for explaining why something might be the way that it is. The appearance of data as different and not fitting well with the object of study is what gives abduction its strength. Meyer and Lunnay (2013) see abduction as "a means of forming associations that enable the researcher to discern relations and connections that are not otherwise evident or obvious" (p. 2). The ability to form associations is especially relevant for understanding relations to the context of curriculum design and development.

In this study, some of the interview data presented an account that did not fit with the theories adopted in the research. An example of how I applied abduction is when I asked a lecturer about the focus of the curriculum, the lecturer expressed a sense of displeasure with the context in which curriculum design and development occurred. The respondent noted that, *"The thing is people like us won't be given the curriculum. We don't even know what it is, they just give us the study guide"* (Respondent 1). This response was not in any way connected to the question that was asked, nevertheless it was a noteworthy response that pointed to the lecturer's feelings and attitude about the functioning / non-functioning of the team-teaching approach. What did this remark mean? Could the respondent's remark be indicative of other issues in the curriculum design and development environment? Critical realism acknowledges emotions as real; however, for the purposes of this study, the concept of emotions was not explored further since, it was not linked to understanding the relevance of knowledge practices in this context.

Retroduction as a mode of inference enables enquiry about the conditions / circumstances without which something cannot exist (Danermark *et al* 2002, Meyer and Lunnay 2013). Scott (2005) argues that research with a realist orientation has explanatory potential and allows for generalisation and descriptions of the social structures and explanations of change through emergence by means of retroduction. Bhaskar advocates the use of retroductive thinking processes for the identification, understanding and explanation of phenomena. Retroduction enables the researcher to pose a myriad of questions as part of the process of inquiry to identify causal structures and mechanisms. Retroduction enabled me to ask questions addressing the nature of the circumstances that had to exist for the specific knowledge practices to be possible in the context of the study I conducted. This form of inquiry provides room for in-depth exploration of a matter using a variety of interpretive approaches (Meyer and Lunnay 2013). Central to the inquiry is the constant question of why something is the way it is and not otherwise? What mechanisms could account for it being this way and not otherwise? For example, a retroductive question in the study was, what must the lecturer be thinking or believing about how first-year students learn General Chemistry for him or her to construct (an aspect of) the curriculum in the way that they did? Another retroductive question that proved useful in analysing the data was premised on my understanding of how knowledge was structured in General Chemistry and what that structuring meant for student learning. Thus, the transcendental question I asked was, "What then must the curriculum be like to enable successful learning for the majority of the students?" The ability to answer this question through using retroductive reasoning was key to uncovering the underlying mechanisms structuring the knowledge practices in the General Chemistry curriculum.

Through abduction and retroduction the researcher can uncover structures and mechanisms at play in a particular context. Therefore, as CR tools they afford deeper explanatory capacity that goes beyond the empirical and actual domains of what is observable, to the domain of the real, that is, the domain inhabited by structures and generative mechanisms. Depth of analysis was reached through the iterative asking of the question what the world must be like for something to exist. Questions were asked to understand what conditions had to prevail in the curriculum design practices to enable or constrain the success of student learning in first-year Chemistry. Therefore, the use of retroduction and abduction in the preliminary stages of analysis proved beneficial as I attempted to understand the context and the pedagogic discourse structuring curriculum design.

6.5.2.1 Phase 1 – Analysis of curriculum documents

To analyse the relations within knowledge, the conceptual and analytical tools offered by LCT: Specialisation and LCT: Semantics were used to generate insight into the underlying organising principles of knowledge practices evidenced in the learning materials. Below is a description of the steps I took in Phase 1 of the organisational framework. All the curriculum and assessment documents were analysed at this stage. The analysis was divided into a preliminary stage and the secondary stage. The preliminary level involved developing the external language of description, where the tools of retroduction and abduction were used as lines of inquiry. A translation device was developed for translating between the data and the theory for each level of analysis for the learning objectives, learning activities, and the assessments. The information gathered from these forms of data analysis had to be integrated to form a comprehensive conclusion about the structures and the mechanisms shaping the knowledge practices.

6.5.2.1.1 Preliminary analysis for curriculum documents

The first level of analysis for the curriculum documents, which I refer to as the preliminary level, involved describing the data as presented in the curriculum documents. This proved to be an arduous and complex task since I had three different types of data: the study guides, the assessment documents, and the notes to students**.** I received the different curriculum documents as individual files saved in PDF format. I organised and compiled all these separate documents into one composite document using the timetable and the learning themes as a guide for ordering them logically. I followed the outline of the study guide to collate and sequence the documents as they related to each of the topics, including all the relevant exercises and self-assessment activities.

6.5.2.1.3 Analysis of the discourses in the study guide

6.5.2.1.3.1 Analysis of the lecture notes and self-assessment activities

One of the sub-questions for the research was concerned with exploring how the prevailing discourses in the curriculum influenced the structuring of General Chemistry. To analyse the discourses in the lecture notes given to students as instructions and the self-assessment activities, I used Bernstein's pedagogic codes of classification and framing (Bernstein 2000).

As indicated by Bernstein, the instructional discourse is embedded in the regulative discourse that underpins the curriculum. I was of the view that analysing the notes and instructions included with the different learning activities across the different themes would be most valuable for determining the instructional and regulative discourse in the curriculum. The purpose of these notes was to inform, instruct and guide students in their learning of content knowledge. An example of notes that demonstrate stronger instructional discourse can be seen below where the message of what is expected of students is clear,

- When doing the exercises, focus on how a problem is approached and solved. Do not just do or try to memorise them, but place the emphasis on understanding them (Student notes, p. 1).

An analysis of the notes and the instructions can be found in Chapter 7.

6.5.2.1.3.2 Analysis of the knowledge content in the study guide

Since I wanted to understand the messages the curriculum documents were conveying (Bernstein 2000) through the study guide and its key components, I brainstormed questions about what I observed in the documents, using a concept map which I later changed into a table (see Table 6 below) to highlight the relationship between the different types of data and key questions to be asked.

As part of my brainstorming of the different ideas related to curriculum design (and implications for student learning), the lines of inquiry were facilitated by asking questions such as: What are students expected to know? What type of knowledge is privileged through the tasks and the assessments? What do the questions ask of the student from a knowledge perspective? What must the curriculum be like for the majority of students to succeed? Such questions proved a helpful starting point for the analysis. At this stage of the analysis, Maton and Chen (2014) suggest using question maps for organising the questions emanating from the brainstorming process. By so doing, the key issues are highlighted, along with the possible lines of inquiry that could be used for facilitating the data analysis.

Other brainstorming questions were concerned with the alignment of the intended and the assessed curriculum, the nature of the tasks, and whether what was required had been made explicit or not: What is the basis of achievement in this module? What is being privileged in the curriculum and in the assessments? How is the student made aware of what is significant and what counts as being important for success? To give structure to my thought processes I developed a table as an organising structure. Below is a summary of the lines of inquiry that I considered using for the analysis of curriculum and assessment documents.

Knowledge practices	Data source	Areas of enquiry using LCT
Curriculum	Curriculum documents: study guide and exercises	- What is being privileged in the curriculum and verified through assessment? - What do the questions ask of the student from a knowledge perspective? - Is the knowledge required made explicit? - How is attainment realised in the module? - What relations do the task embody? - Which relations are predominant and how does this align with the espoused learning that is valued in the module? - What student *gaze* is being assumed and cultivated?
Assessment	Self-assessment task Exam papers	
		- What form does ER and SR take in the objectives, task, and assessment? - Which instances in the exercises represent strengthening or weakening of ER or SR, and SG or SD? - What semantic profiles do the task exhibit?

Table 6. Examples of question guiding the analysis of the curriculum documents

When I initially examined the curriculum documents, my first instinct was to reach for the theory to try and identify examples that resembled what the theory said. Maton and Chen (2014) caution against the urge to start using the theory too early on in the data analysis process. They suggest total immersion in the data before relating the data to theory. I immersed myself in the data by reading the curriculum documents repeatedly and asking myself questions about what I was seeing in the curriculum documents and only describing what I was seeing from the study guide document without clouding the ideas with curriculum theory.

At some point, I alternated reading the curriculum documents with reading the theory, with the intention of trying to concretise my initial analysis of the data. This process took much longer than anticipated. While interrogating the General Chemistry curriculum, I had to keep in mind what the literature said about knowledge in Chemistry as an intellectual field and what I had come to know about what learning General Chemistry in the first year involved. Broadly speaking, I was concerned with how the Chemistry disciplinary knowledge was transformed into General Chemistry curriculum knowledge, and what knowledge practices were privileged in the transformation, as well as the effects the structuring of this knowledge may have on student success.

For this purpose, several translation devices were developed. The next section (Section 6.6) describes the development of the translation device for examining the inner logic of the curriculum through the organising principles of LCT: Specialisation and LCT: Semantics. However, before an elaboration on the translation device, it is necessary to describe the analysis of Phase 2, the interviews.

6.5.2.2 Phase 2 – Analysis of interviews

The purpose for the interviews was twofold, firstly it was to understand the prevailing pedagogic discourses shaping the curriculum and that could shed light on the conditioning context for student learning created by the curriculum. Secondly, the purpose of the interviews was to uncover the organising principles of the knowledge practices in the General Chemistry curriculum that could have enabling or constraining effects on student learning. Yin (2006) suggests that an essential feature of case study methodology is that the analysis of data begins almost as soon as the data is collected.

Soon after I conducted each interview, I began the process of analysing the recorded conversations by transcribing all the interviews verbatim. I moved constantly between the notes and the recording to verify the accuracy of what I had captured. Although the exercise of transcribing was time consuming and exhausting, it was ultimately a beneficial activity for familiarising myself with the data. The process of writing out the notes from the interview data very unnerving at times since it was a painstaking activity.

After transcribing, I was confronted with a challenge with regard to knowing what I was supposed to do in order to analyse the data. I read up on analysis methods for qualitative interviews in general, then focused on CR approaches to look at the data. Most of the methods recommended in literature suggested formulating a coding framework and defining the concepts or key components used in the coding. This method aligned with the recommendation by Maxwell (2012a, 2012b) for using the analytical narrative strategy to write the summaries of each interview. He describes narrative strategy as concerned with extracting the meaning of the text for the respondent making the statements.

Through reading and rereading the interview transcripts, I became aware of some similarities in the responses, some salient points in the data, some of which I had missed in the notes that I had made while conducting the interview. I noted these points as central ideas held by the respondents. More probing was done to find out what the lecturer possibly meant by the statement. What else was there in what they were saying?[59] Such inquiry into the data was guided by the methods of abduction and retroduction which are the data analysis tools that were used to identify the indicators for analysis in the development of the external language of description.

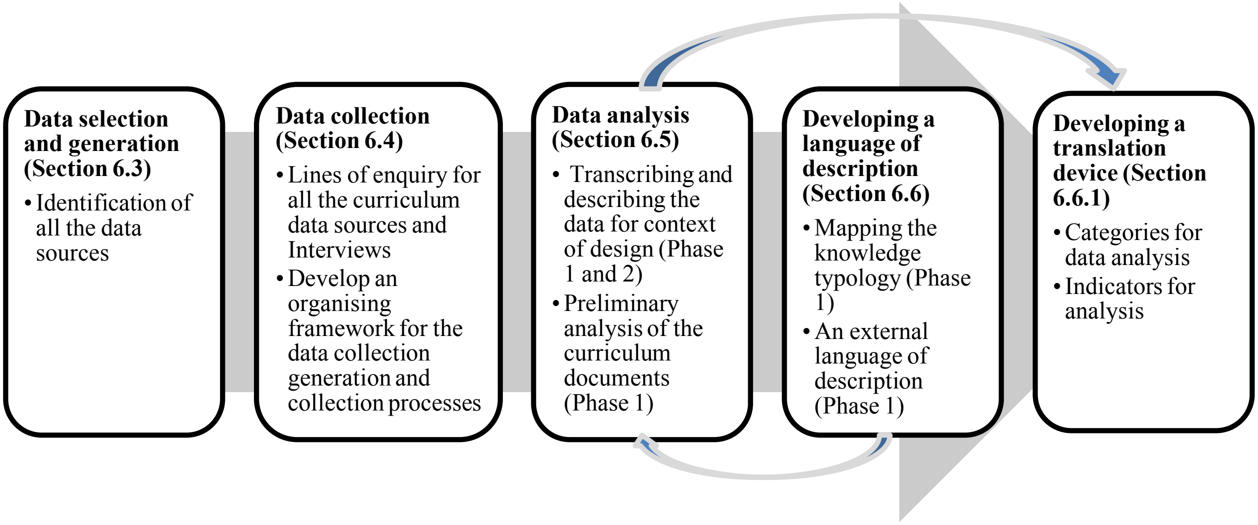

Figure 14. Overview of the data analysis process

The diagram above (Figure 14) provides a pictorial representation of the flow of the analysis process undertaken. However, because of the complexity of the case and the different sources of data that were handled, the analysis process was not a linear process as indicated in the diagram.

6.6 Developing an external language of description

The second stage of the data analysis process involved developing a language of description for translating between theory and empirical data in the process of data analysis. Bernstein (2000) makes a distinction between internal and external languages of description. The internal language of description refers to the conceptual language that frames or underpins the study (ibid: p. 132). He describes an external language of description as a language where the syntax describes something other than itself; in other words, it describes an empirical reality. The language of description that was developed acted as a translation or coding device for the exploration of the relations between theoretical concepts and empirical data. The language of description becomes a means of translating between concepts and data, and enables the researcher to read from theory to data and vice versa (Maton 2014).

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[59] See questionnaire – Appendix 1.

For analytical purposes, I developed an external language of description (ELoD) as a translation tool to allow the data to speak to the theory and the theory to speak to the data. The process of developing this ELoD was an iterative process of constantly moving between theory and data and vice versa.

6.6.1 The translation devices

The analysis of the curriculum documents focused on the module objectives, learning activities, and assessments. I developed a translation device for analysing the knowledge practices in the curriculum documents using LCT: Specialisation as discussed in Chapter 5, Section 5.10. LCT: Specialisation explores the basis of achievement required by knowledge practices, dispositions and contexts, i.e. whether the emphasis or legitimacy of achievement is about something (the object of knowledge) or about who the person (the knower) is (ER+/-, SR+/- Maton 2014). I first identified the dominant relations of the knowledge practices of the curriculum after which I identified the type of epistemic relations exhibited in the curriculum documents to shed light on the underlying structuring mechanisms of the insights privileged by the intended curriculum.

The following discussion explains the analysis process for the different data sources.

Maton (2012)[60] suggests that, when analysing curriculum documents, it is useful to write descriptions of the curriculum and thereafter to link concepts to the descriptions of the data. This method of initially formulating themes from what is observed in the data in the preliminary stages of analysis is further highlighted in Maton and Chen's work about organising the data (2015). Figure 15 below indicates the reciprocal relationship between the empirical data and the languages of description (L1 and L2) in the translation device.

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[60] October 2012, Private communication. Rhodes University PhD doctoral week.

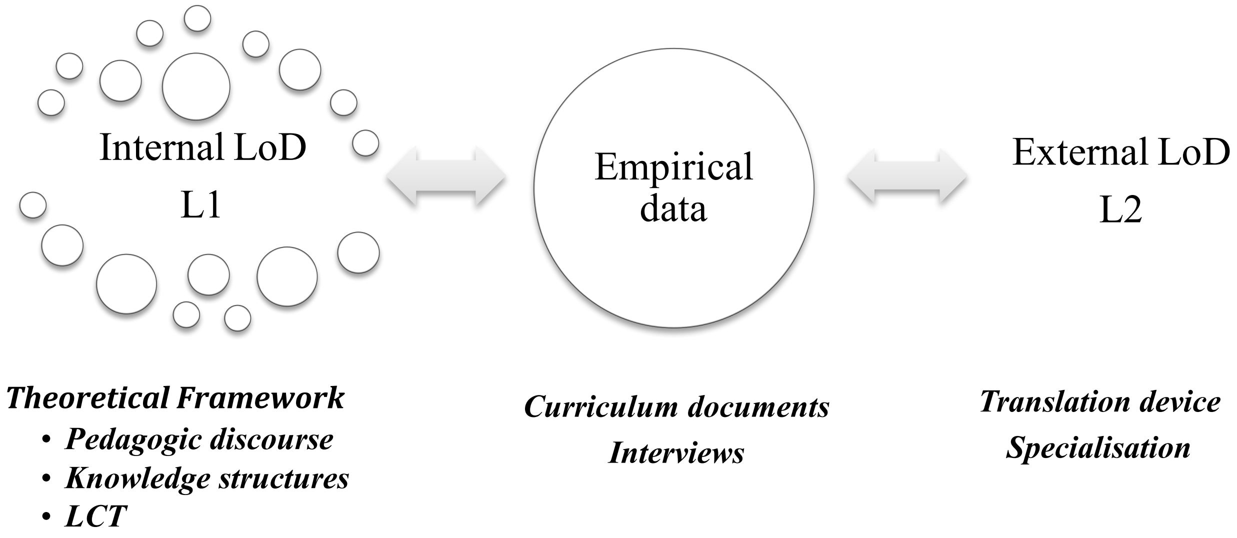

Figure 15. The relationship between the languages of description and the data

The translation devices were developed through immersing myself in the data until they became so familiar that it was possible to make connections between the data and the preferred theoretical framework, in this case LCT: Specialisation. Maton and Chen (2015) provide guidelines for developing an ELoD. They emphasise that the steps mentioned below only serve as a guide since the development and refinement of translation devices depend on the research problem. They propose that when a suitable theoretical and conceptual framework has been decided upon, and the researcher has spent time becoming familiar with the data, it is possible to begin to develop indicators for how the concepts can be related to or are realised in the empirical data. Some of the areas of inquiry that were facilitated by the development of the ELoD related to what form epistemic and social relations took in the curriculum documents, how the specialisation code is realised in the data, and the forms taken by weaker or stronger ER and SR.

6.6.1.1 LCT: Specialisation – Epistemic relations

As part of the process of developing an ELoD for all the curriculum documents, I considered the theoretical concepts that were relevant for the analysis. A review of the literature revealed different themes from which the categories and subsequent indicators for analysis were identified. Identification of the categories was in the form of concepts to foreground the key issues to be addressed in developing greater understanding of what was shaping the basis of achievement and the attainment of success in the module. The content knowledge mentioned in the literature on curriculum design (see Ornstein and Hunkins 2004) represented theoretical categories, and since knowledge was the object of investigation, it appeared appropriate to decide on conceptual (theoretical) and procedural knowledge as categories for analysis as shown in Tables 7–10.

After identifying the theoretical concept, I developed the indicators that would describe how the relations between the data and the theory could be realised empirically both for the epistemic relations and the social relations. This is elaborated with the use of examples from the data. The ELoD process was developed to analyse the learning objectives in the study guide, the learning activities, and assessment. The following is an example of how the indicators were defined for epistemic relations.

6.6.1.1.1. Content knowledge: Conceptual (theoretical) knowledge

The notions of theoretical knowledge and conceptual learning[61] featured prominently in the literature on learning in the field of Chemistry. For analysing the intended curriculum content knowledge, I used two indicators to determine the relative strength of the epistemic relation of theoretical and procedural knowledge in the curriculum. Porter (2006) defines content knowledge not only as topics to be taught and tested, but also as including the cognitive demand required in a subject. Cognitive demand entails "the extent of difficulty inherent in different activities such as memorising, performing procedures, communicating understanding, and solving problems" (ibid, p: 142).

Given the nature of Chemistry knowledge, I divided the curriculum content knowledge into conceptual knowledge (propositional knowledge – knowing that), and the theory related to skills and competencies (procedural knowledge – knowing how). The propositional content knowledge in a learning theme consisted of conceptual chemical knowledge. According to Potgieter (2010), there are contradictions in what the outcomes for first-year General Chemistry learning should be. Nevertheless, she and other researchers of Chemical education regard conceptual understanding as essential for student learning in General Chemistry.

The following is an example taken from the study guide of a learning objective indicating the need to acquire theoretical knowledge:

> Understand the physical meaning of the information given on the Periodic Table for each element (Theme 2- Atoms, Molecules and Ions; GCM 101 lecture notes)

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[61] See Chapter 2 for a discussion on the notion of conceptual learning as an outcome of effective learning in the field of Chemistry.

Procedural knowledge comprised content knowledge involving *algorithms* and requiring *mathematical skills* for doing calculations, and *procedures* for problem solving. An example of a learning objective indicating procedural knowledge taken from the study guide is:

> Apply the rules for the handling of significant figures in calculations (Theme 1- Matter and Measurement; GCM 101 lecture notes)

Possession of particular content knowledge is a basis of legitimate achievement in Chemistry and is categorised as stronger epistemic relations (ER+). For weaker epistemic relations (ER-), the possession of content knowledge is downplayed as less important in defining legitimate Chemistry knowledge. Table 7 below shows the theoretical knowledge aspect of the translation device:

Theoretical concept Curriculum Content		**Indicators: Degree of emphasis on:**	**Example from the data**
Conceptual (theoretical) learning - Theory knowledge in a study unit in the form of principles and generalisations, theories, models and structures	ER +	Content knowledge is emphasised as a necessary basis for achievement in General Chemistry	Understand the physical meaning of the information given on the Periodic Table for each element (Theme 2 – Atoms, Molecules and Ions)
	ER -	Content knowledge is downplayed as less important in defining legitimate Chemistry knowledge	No examples from the data[62]

Table 7. Example of ELoD for analysing epistemic relations in the theoretical knowledge

Therefore, for theoretical knowledge, stronger epistemic relations (ER+) denote an emphasis on content knowledge in the curriculum as significant for acquiring knowledge in the subject, while weaker epistemic relations (ER-) downplay the specificity of knowledge and allow other knowledge content. The example in the table above shows stronger epistemic relations as evidenced in the learning objectives related to knowing the Periodic Table.

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[62] See Section 10.5 for a note on the limitations of the study, including of the external languages of description.

6.6.1.1.2 Content knowledge (procedural knowledge)

The second aspect that constitutes curriculum content knowledge is procedural knowledge, that is, the skills and procedures necessary to participate in legitimate inquiry in Chemistry. An example of a field-specific competency is knowledge about and the ability to handle chemical substances, and to execute procedures in the laboratory. Although theoretical knowledge is embedded in procedural knowledge, the emphasis in the latter is on the application of knowledge, in the form of skills, techniques, methodology and specific operational processes.

One of the respondents in the study explained procedural knowledge by giving the following example:

> The principles like kinetics, speed of reactions, you can calculate and predict it but you can also measure it and because there are always little differences between the theory and the lab, how to explain that? So also, important in the practical is to be able to explain why does it sometimes not react exactly in the way that you expect it to be. So, **it's to confirm the theory**[63]. Sometimes it's the other way around where you **discover something** in the lab, where you have to **explain the theoretical reactions** or whatever, so it's mostly one of those two. But, of course, its **skills in terms of handling apparatus**, that a basic skill that has to be practised. They also (must) **be aware of reactants and how that powerful it can be.** We also make them aware of what you are working with, how should you take care of your health, getting rid of the waste, practical handling of chemicals. (Respondent 4)

The epistemic relations are stronger (ER+) where skills and procedures are emphasised and made explicit to students whereas they are weaker (ER-) when the skills and procedures are implicit and not stated as a significant aspect of subject knowledge. Table 8 displays an example of the content knowledge requiring procedural knowledge taken from the translation device that exhibits strong epistemic relations:

Content knowledge: Procedural learning		**Indicators: Degree of emphasis on:**	**Examples from the data**
Subject specific skills and algorithms, techniques and methods, criteria for determining usage of appropriate procedures	ER +	Skills and procedures are emphasised and explicit guidance is given on the steps for solving problems	Distinguish between initial concentrations and equilibrium concentrations. Note that only equilibrium concentrations can be used when working with K. When non-equilibrium concentrations are used in

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[63] Own emphasis indicating the expected outcomes of learning

			the equilibrium expression, Q results
	ER -	Skills and procedures are implicit and indications are given that the knowledge is less significant than other areas of knowledge	No example from the data

Table 8. Example of ELoD for analysing epistemic relations in relation to procedural knowledge

6.6.1.1.3 Learning activities

Another category of data that I identified to analyse the organising principles of the knowledge represented in the curriculum documents is that of the learning activities. In examining the strength of epistemic relations evinced in the learning activities, I considered the extent to which procedures for learning content knowledge and processes for learning the material are emphasised and made explicit to students.

The indicators that were chosen had to denote the extent of explicitness and specificity of skills and procedures students would be required to perform when doing the tasks or exercises. Stronger epistemic relations (ER+) were indicated when it was made clear to students that the skill or procedure was a necessary component of the content of General Chemistry. Weaker epistemic relations (ER-) were indicated when the significance of procedures in shaping learning in General Chemistry were implicit and downplayed. See Table 9 below for examples.

Theoretical concept		**Indicators: Degree of emphasis on:**	**Examples from the data**
Learning activities The design of learning activities	ER +	Procedures for demonstrating and applying disciplinary knowledge are made explicit	The aluminium in a package containing 75 ft2 of kitchen foil has a mass of 12 oz. Aluminium has a density of 2.70 g/cm^3. What is the thickness of the aluminium foil in millimetres? Given: 1 oz. = 28.4 g 1ft = 12 inches, 1 inch = 2.54 cm Interpret all conversion factors as definitions, that is, as exact numbers. The density, area and mass are measured quantities; thus, they contain uncertainty. Answer: 0.018 mm (Theme 1– Matter and Measurement)
	ER -	Procedures for learning content knowledge are implicit or downplayed as not significant	No example from the data

Table 9. Example of ELoD for analysing epistemic relations in the learning activities

Notes and comments are included with the different learning activities across the different themes. The purpose of these notes was to inform, instruct, and guide students in their learning of content knowledge.

6.6.1.1.4 Assessment activities

In my analysis of the epistemic relations underpinning the summative assessment papers for General Chemistry, I considered whether or not the extent to which the evaluative criteria had been made explicit. For stronger epistemic relations (ER+) in assessment, the evaluative criteria for judging student performances against content knowledge are made explicit. Weaker epistemic relations (ER-) are indicated where the evaluation of legitimacy of student performances are downplayed and judged against criteria external to content knowledge. The evaluation criteria refer to the "evaluation rules that are implemented for making judgements about student achievement in relation to a particular task or content knowledge" (Shalem and Slonimsky 2010, p. 762). Table 10 offers an example from the translation device for assessment.

Theoretical concept		**Indicators: Degree of emphasis on:**	**Example from the data**
Assessment Explicit evaluative criteria on content knowledge	ER +	Evaluative criteria for judging performances are explicitly provided	Draw the Lewis structure of **XeF_2**. Use different symbols for the valence electrons of the different atoms. Show all lone pairs and bonding electrons but **do not** [64]use dashes for bonds. Is this XeF_2 molecule polar or non-polar?
	ER -	Evaluative criteria not explicitly stated and are not significant in judging student performances	No example from the data

Table 10. Example of ELoD for analysing epistemic relations in the assessment documents

The question taken from the examination paper is an example of stronger epistemic relations (ER+). The instructions give a message which emphasises the importance of responding to the question in a particular manner.

In sum, I have elaborated on the indicators for recognising the epistemic relations in the curriculum as contained in the formulation of learning objectives, learning activities, and formative and summative assessments. Tables 7 – 10 show the indicators I devised for identifying epistemic relations. A further discussion on the analysis of the epistemic relations as exhibited in the data can be found in Chapter 8.

In the following section I discuss the development of indicators for analysing the social relations evident in the curriculum.

6.6.1.2 LCT: Specialisation – Social relations

To define the indicators for social relations I embarked on a process similar to the one I described above for establishing criteria for identifying epistemic relations. For curriculum content knowledge, I used two indicators to determine the relative strength of the social relations in the curriculum. The social relations are stronger where personal experience and opinions are regarded

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[64] Emphasis is from the data source.

as legitimate knowledge, while social relations are weaker where personal experience and opinions are downplayed and distinguished from legitimate knowledge.

6.6.1.2.1 Theoretical knowledge

In demonstrating theoretical knowledge, stronger social relations (SR+) indicate an emphasis on personal experience; student dispositions, attributes, and opinions are viewed as legitimate in expressing Chemistry knowledge. When student dispositions, attributes, and opinions are downplayed and distinguished from legitimate Chemistry knowledge, social relations are weaker.

Theoretical concept – emphasis on Curriculum Content		**Degree of emphasis on**	**Example from the data**
Theoretical learning – Theoretical knowledge and theory knowledge	SR+	Emphasis placed on personal experience and opinions, and / or on student dispositions in demonstrating legitimate Chemistry knowledge	No examples from the data
	SR-	Personal experience and opinions, and /or student dispositions are downplayed and distinguished from legitimate Chemistry knowledge	When doing the exercises[65], focus on how a problem is approached and solved. Do not just do or try to memorise them, but place the emphasis on understanding them

Table 11. Example of ELoD for analysing social relations in the theoretical knowledge

6.6.1.2.2 Procedural knowledge

Where procedural knowledge is referred to in the objectives, stronger social relations (SR+) are identified when emphasis is placed on personal experience and / or student dispositions and opinions are viewed as legitimate Chemistry knowledge for the development of skills for problem solving. Weak social relations in demonstrating procedural learning are evinced when personal experience, student dispositions and opinions are downplayed and distinguished from legitimate Chemistry knowledge.

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[65] Exercises in this instance refer to the learning activities provided for practising problem solving and the application of the theory for problem-solving purposes.

Theoretical concept		Degree of emphasis on	Example from the data
Content knowledge Procedural knowledge and skills relating to performing a task based on theoretical knowledge	SR+	Emphasis is placed on personal experience, student dispositions and opinions when demonstrating skills for solving problems in General Chemistry	No examples from the data
	SR-	Personal experience, student dispositions and opinions are downplayed and distinguished from legitimate Chemistry knowledge	No examples from the data

Table 12. Example of ELoD for analysing social relations in the procedural knowledge

6.6.1.2.2.1 Learning activities

For the learning activities or exercises, indicators were chosen to denote examples of strong social relations (SR+) where the individual students' preferences were explicitly emphasised as legitimate in General Chemistry learning. Where the individual students' preferences or the attributes/qualities essential to learning Chemistry were downplayed as not significant in shaping the curriculum for effective learning, the social relations were identified as weaker (SR-).

Theoretical concept		Degree of emphasis on:	Example from the data
Learning activities The design of learning or context of the learning process facilitates and supports learning	SR+	Individual students' preferences or interpretation of content knowledge are explicitly emphasised as determining learning	No examples from the data
	SR-	Individual students' preferences or interpretation of content knowledge are downplayed as not significant for learning	No examples from the data

Table 13. Example of ELoD for analysing Social Relations in the learning activities

6.6.1.2.2.2 Assessment activities

A similar exercise was conducted for the summative assessment papers. When the evaluative criteria indicated that the legitimacy of content knowledge and the basis of achievement was based on the student's personal attributes and dispositions, this was seen as an indicator of stronger social relations (SR+). Weaker relations (SR-) were signified in the examination papers where the basis of achievement based on content knowledge was downplayed and the personal attributes of the student were judged against shared criteria that are external to content knowledge. Table 14 below gives examples from the different data sources of the social relations evident in the curriculum.

Theoretical concept		**Degree of emphasis on:**	**Example from the data**
Assessment Evaluative criteria on content knowledge	SR+	Evaluation of legitimacy of content knowledge and the basis of achievement based on personal attributes and dispositions	No examples from the data
	SR-	Evaluation of legitimacy of content knowledge downplayed and judged against shared criteria external to content knowledge	No examples from the data

Table 14. Example of ELoD for analysing social relations in the assessment documents

Table 14 above shows examples of the social relations from the different data sources as evidenced in the curriculum. Tables 11–14 show the indicators I devised for identifying social relations evinced in the data. Above, I have presented the design of the processes of data analysis using LCT: Specialisation for the learning objectives, learning activities, and the assessment.

In sum, in the analysis of the intended curriculum content knowledge, I have outlined the indicators of theoretical and procedural knowledge for content knowledge for determining the relative strength of the epistemic relations in the curriculum. Examples taken from the data have also shed light on how I constructed the relationship in the translation device between theory and the data in order to establish the organising principles underlying the curriculum practices. The different forms taken by the epistemic relations and the social relations as displayed in the data shed light on the dominant organising principles in the curriculum documents. I elaborate on the presentation of the data and analysis in Chapter 8 where I demonstrate how the analysis of the organising principles of the General Chemistry curriculum generates a knowledge code.

6.6.1.3 LCT: Semantics

The second phase of the curriculum document analysis involved analysing the learning activities by using LCT: Semantics. The purpose for using LCT: Semantics was to analyse how the learning activities contributed to knowledge-building in the curriculum. I analysed the learning activities using LCT: Semantics. According to Maton (2013), each object of study deserves its own translation device; thus, for the analysis of the learning activities I developed an ELoD in order to analyse the nature of cumulative learning in General Chemistry. By doing so, I was able to create the semantic plane and the semantic profiles of the learning objectives and to create a visual map of how these changed over time. Analysis of the learning activities enabled me to generate semantic profiles for the activities. This form of analysis allowed me to explicate the degree of context dependence or independence of meaning in the learning activities. For cumulative learning to occur, knowledge practices should exhibit a capacity for strengthening and weakening semantic gravity at different intervals.

6.6.1.3.1 Developing the semantic plane of learning activities

As mentioned in Chapter 5, LCT: Semantics can generate a semantic profile through the use of four different types of semantic codes in the form of *rhizomatic codes* (SG-, SD+), that point to the basis of achievement consisting of context-independent and complex meanings; *prosaic codes* (SG+, SD-), where legitimacy is context dependent and based on simpler meanings; *rarefied codes* (SG-, SD-), where the basis of achievements is based on context-independent knowledge and simpler meanings and *worldly codes* (SG+, SD+) where legitimacy is from context-dependent knowledge with a multitude of meanings.

The different semantic codes can be plotted on a semantic plane that sheds light on the nature of the educational practices and how these determine the semantic codes. Since the analysis of the curriculum was mainly on the first semester General Chemistry module, a decision was made to analyse learning activities of the exercises offered in the first term of the first semester, from Week 1 to Week 6. Below is an example of the semantic plane upon which the data was plotted to indicate the varying strengths of semantic density and semantic gravity evinced in the learning activities.

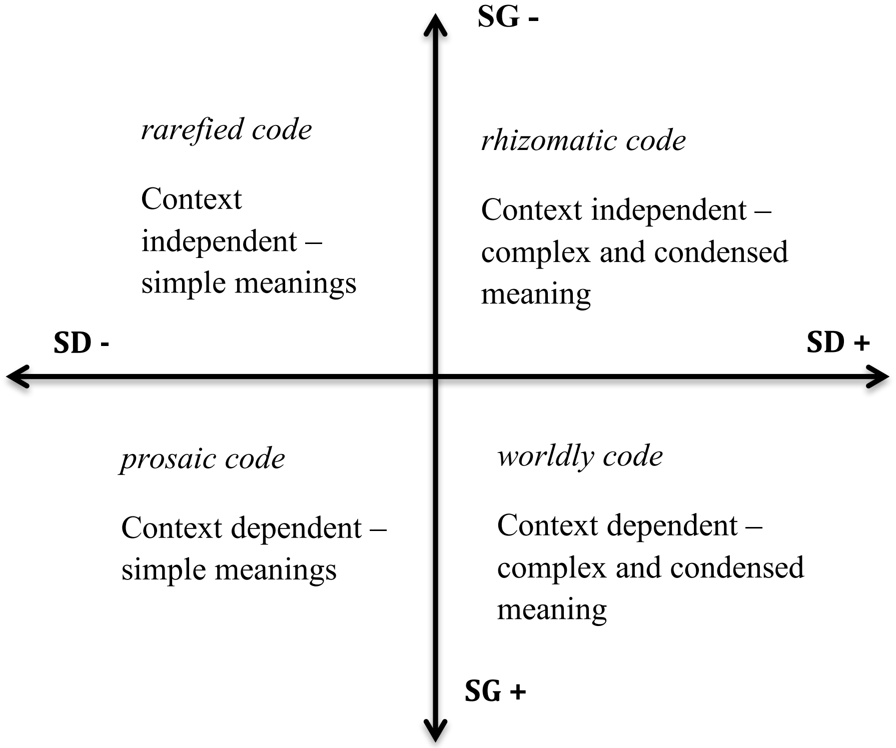

Figure 16. The semantic plane (Maton 2016, p. 16)

6.6.1.3.2 Developing the semantic profile of learning activities

In using LCT: Semantics to analyse data, Maton suggests the 7-Gs rule-of-thumb for generating semantic profiles. As illustrated in the diagram below (Figure 17), the first step is **going in** (semantic entry e.g.1. beginning on the semantic scale), followed by **going up** and **going down** (semantic shifts, upward shifts or downward shifts, e.g. 2 and 3), followed by **gamut** (semantic range, e.g. 4), then **going along** (semantic flow, e.g. 5), followed by **going out** (semantic exit, where the profile ends, e.g. 6), and **getting it right** (semantic threshold, the extent to which accuracy or epistemology matters; 7) (Maton 2016).

According to Maton, for analysis purposes, the rule-of-thumb is to ask at all times of the inquiry whether each of these stages matters, and if so, how do they matter?

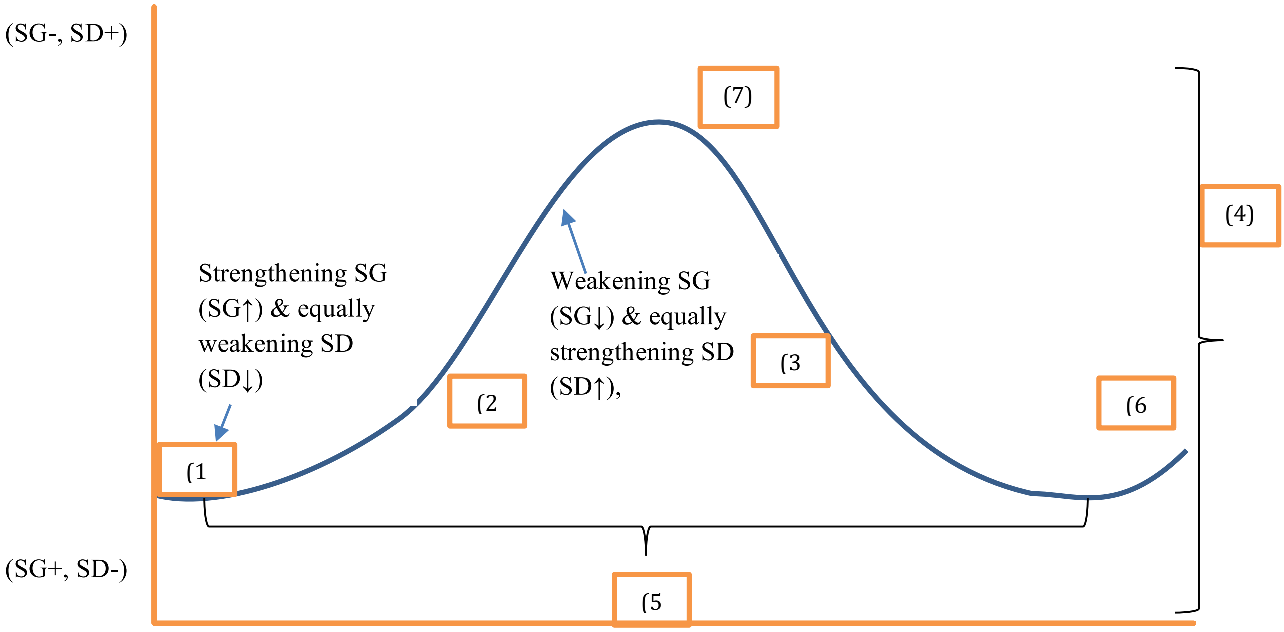

Figure 17. Semantic profile of practices with semantic waves (adapted from Maton 2014)

Figure 17 depicts a so-called semantic wave where the variation in strengthening and weakening of semantic gravity and semantic density appears to be evenly distributed, thus producing a semantic profile. Semantic waves are created through the process of varying the range between strengthening and weakening of gravity / density as illustrated in the figure above. They represent the pulses of knowledge-building (Maton 2013; p. 8). The process of strengthening and weakening of semantic gravity and semantic density can be displayed on a semantic plane, which can be represented as a semantic profile of practices.

The semantic profile takes the form of a series of repeated upward and downward movements indicating the strengthening and weakening of semantic gravity and density of knowledge in what is plotted as semantic waves. These upward and downward movements represented on the semantic profile can indicate how concepts are made more complex and abstract in the curriculum or in a pedagogic setting (weakening semantic gravity and strengthening of semantic density), and simpler (strengthening semantic gravity and weakening of semantic density) in a learning setting.

In a field like General Chemistry, the entry point is higher on the scale because of the abstractness of the concepts and complexity of meanings; but, through the teaching and learning activities, the concepts and theories are simplified and unpacked to facilitate understanding, as is also the case in exercises requiring the application of knowledge. After the unpacking of the theory, the learning should return to the abstractness which signifies the exit points on the semantic scales.

In designing a curriculum aimed at facilitating cumulative knowledge-building, it is necessary to be cognisant of the variations of the strength of semantic gravity and semantic density as the knowledge undergoes recontextualisation, packing, and unpacking. In Chapter 9, I present data on the learning activities and a discussion on the curriculum's ability for cumulative knowledge-building.

In summary, I have described the data analysis tools that were used in the study to identify the generative mechanisms that influence the structuring of the curriculum for enabling or constraining student learning. The data analysis tools and processes described are underpinned by a critical realist orientation. Since critical realist research is anti-positivist, the conventional understanding of validity in studies investigating causal relationships is challenged. The next section discusses validity, reliability and generalisability in the study.

6.7 Addressing validity

The processes of ensuring validity in qualitative studies using procedural criteria is rejected by the choice of CR (Maxwell 2012a). A realist position on validity focuses on the conclusions reached by using particular methods in a particular context for a particular purpose. The focus is not the method itself (ibid: p. 130). The design of the critical realist research needs to evince a clear relationship between the selection of data sources and the processes of data generation. In addition, the interpretation and analysis of the data indicates validity when the evidence supports the conclusions reached in the study.

Maxwell (2012b) further proposes that critical realist research should focus on descriptive, interpretive, and theoretical validity. Descriptive validity is concerned with the accuracy of transcribing and reporting interview data. Interpretive validity refers to the adoption of an approach that seeks to understand the phenomena from the respondents' perspectives and not from the researcher's perspective. Theoretical validity considers the validity of concepts as they are applied and the manner in which the relationships among the concepts are presented. In this study, I have endeavoured to satisfy all three forms of validity. The processes engaged in the data identification, selection, generation, and analysis ensured a proper representation of the phenomenon that I was studying, thus ensuring validity of the findings. By developing different translation devices for analysing different types of curriculum data, I also ensure the credibility of the claims and contribution to knowledge that I have made in the study.

Credibility and trustworthiness are alternative ways of conceptualising validity. Tobin and Begley (2004) suggest that internal validity and reliability are requirements in qualitative research. Data generated from various sources in qualitative studies should, in addition to being valid and reliable, also demonstrate other qualities like rigour, trustworthiness, and credibility (Seale 1999, Golafshani 2003).

Tobin and Begley (2004) acknowledged that establishing agreement on criteria for assessing quality in qualitative research is a challenge. They propose the use of the process of crystallisation as an alternative to triangulation, where a phenomenon can be viewed from multiple angles using different approaches. They describe the process of crystallisation as "a means for enabling viewing something from a fixed, rigid, two-dimensional object towards a concept of the crystal which allows for the infinite variety of shape, substance, transmutations, multi-dimensionalities and angles of approach" (p. 393). Ellingson (2009) argues that crystallisation combines multiple forms of analysis and multiple genres of representation into a coherent text, or series of related texts, by building a rich and openly partial account of a phenomenon that problematizes its own construction. Crystallisation "eschews positivist claims to objectivity and a singular discoverable truth, embraces, reveals, and even celebrates knowledge as inevitably situated, partial, constructed, multiple and embodied" (Ellingson 2011: p. 605). The complex context in which this study was conducted required sourcing multiple sources of data and using a variety of tools for analysis. By approaching the research questions through the analysis of the different sources of data as discussed in this chapter, crystallisation served as a form of improving rigour in the study. These strategies facilitated reaching conclusions that had richness, depth, and variance.

Reflexivity, vulnerability, and positionality are some of the principles underpinning crystallisation in the research process, as suggested by Ellingson (2011). Below I discuss how I maintained a reflexive stance throughout this study, and discuss my positionality and vulnerability in relation to this research project.

6.8 My role as researcher

The critical realist approach adopted in this study enabled me to be flexible as a researcher and to accept and respond to changes that occurred during the research process. During the research process, I experienced changes that required adapting the research design and methodology. In the following section, I explain the main changes in my circumstances and the main challenges that I confronted in the research process.

On a personal level, the main challenge for me as a researcher was to reframe my ontological stance towards a critical realist philosophy. Researching knowledge and knower structures and curriculum design practices in Chemistry education as a non-chemist was one of the major challenges that I encountered. As a researcher, I was an outsider from two perspectives: in relation to the discipline of Chemistry, and in relation to the institution that was the site for my study. My own experience with Chemistry education is very limited. When I began the research, I was comforted by the fact that I had undergone a year of studying Chemistry in my undergraduate degree programme. Confronting Chemistry at this stage as the object of my investigation in my PhD resulted in reservations about my ability to handle the subject again. Feelings of vulnerability and *naivety* in the field of Chemistry were eventually overcome by the fact that the study was first and foremost focused on education practice. Therefore, approaching Chemistry knowledge practices from a sociology of education perspective strengthened motivation for a different approach to understanding the workings of the discipline of General Chemistry. This outsider perspective provided the vantage point of being unbiased and being able to pursue the cause of improving education practices.

The critical realist orientation adopted for this study initially contradicted my positivist academic training. The notion that knowledge is fallible was unsettling since it was my first encounter with such a view. Getting to a proper grounding in the philosophy was an education in itself that took several years to develop. Nevertheless, embracing the realist lens for looking at reality opened up a whole new world of possibilities for explaining phenomena and everyday social reality.

6.9 Possible threats to the causal explanation, and limitations to the study

There are two major changes that occurred during the research process that affected the design of the research. When the study began, I worked extensively in teaching and learning development within the area in which the investigation was conducted. As an academic development practitioner, I engaged constantly with different stakeholders in the institution about the curriculum aimed at improving student learning by enhancing the teaching and learning environment in the faculty, especially at first-year level. A change in employment status initially affected the ease of access to the data. Securing time for interviews and accessing curriculum documents at times was also not easy. However, through the relationships that I established while working at the institution, I was able to get permission for the study and access to the necessary documents.

As part of the data analysis process, I had intended to use the web-based curriculum mapping software owned by the university. The mapping process involved developing a matrix for categorising the content of study guides so that clearer course descriptions using the software could be generated and made widely available to relevant stakeholders. The project that used this software was discontinued, thus making it difficult to access the computer-based programme. Without access to this software, I had to analyse the entire study guide and supporting learning materials manually through a paper-based process. The absence of the technology as an analysis tool did not adversely affect the quality of the descriptions that I was able to generate from the data. The main advantage of using the technology would have been to reduce the time spent on developing the instrument for analysis, and manually plotting curriculum data onto a table. Although this exercise of plotting the data on the translation device was time consuming, I now value the experience because I engaged with the data at a greater depth, even at the early stages of data generation.

In terms of the methodology adopted, generalisability is a potential issue in case study research because of the context-dependent nature of the research. Easton (2010) is of the view that representativeness of the case methodology should not be seen as problematic. Although scientific knowledge and the curriculum content is said to be constant, what might change in each case would be how it is presented. Therefore, even though the case study methodology is not recognised for its ability to support generalisations, the lessons learnt from this study can shed light on the phenomenon of curriculum design for cumulative learning in the first year of Chemistry in other contexts, in other universities. The use of the case methodology is not regarded as a limitation in this instance, but is viewed as an opportunity for offering in-depth exploration of a phenomenon that can shed light on knowledge and curriculum practices enabling or constraining student learning. As mentioned in the introductory chapter, part of the motivation for conducting the investigation was to provide insight into curriculum design practices necessary for useful implementation in other, similar contexts.

6.10 Ethical considerations

Ethical considerations had to be taken into account in relation to handling the data, the personal information of the respondents, and in reporting the findings. Approval for the PhD proposal was sought and granted at the meeting of the Higher Degrees Committee of the Faculty of Education of Rhodes University on 25 October 2012. I also needed permission from the LSAU to conduct the research and thus had to undergo an ethical clearance process. As part of the process of securing permission from the management of the faculty to conduct this inquiry, I held meetings with the Dean of the Faculty of Science, and the Head of the Department of Chemistry to inform them about the study. Additional permission to conduct an investigation into the Introductory Chemistry modules was sought from the faculty's Ethical Clearance Committee at LSAU. Clearance was granted on the 27 March 2013. I had two meetings with the Head of Department prior to conducting the research and was granted permission to work with the curriculum documents and to interview the lecturers.

Written consent to participate in this project and permission to use a recorder during the interviews was sought from each participant. Participants were informed about the purpose of the research and its significance in understanding curriculum design for improving student success.

I had to agree to handle curriculum documents and store all interview transcripts according to the LSAU's policy on storage of research documents; this means that the data must be kept in a safe place for at least fifteen years from the point of data collection. As a former employee of the university and as an ethical researcher, I have a duty to act responsibly with regard to the information collected, the reporting and publication of findings, together with managing information so as to prevent risk to the participants. I am aware that maintaining anonymity and confidentiality when reporting on this study will be a challenge, especially since lecturers teaching the modules examined in the study are well known. A commitment to ethical conduct has been demonstrated in the way the research was written up. Reporting and publication will be handled with care and respect for all concerned. In reporting the research findings, the focus is placed on explaining practices and not on whose practices is presented. Further dissemination of the research will be through publications in peer-reviewed journals and through conference presentations.

6.11 Summary

The chapter began by positioning the study as a critical realist investigation into knowledge practices in General Chemistry by reviewing the two concepts of causation and emergence as relevant to this research, and for supporting the choices made for the research design and methodology adopted. The unit of analysis was the knowledge practices found in the curriculum which constituted the case for this study. The case study as a design and methodology is in keeping with the qualitative nature of the study where in-depth investigation was conducted with the intention of explaining a phenomenon. I explained my use of retroduction and abduction as tools of inquiry for developing the organisational framework for data analysis to uncover the mechanisms at play in the knowledge practices of the General Chemistry curriculum. I described an organisational framework that was developed for the data analysis process and I outlined the data analysis process which began with the collection of data in the form of curriculum documents and conducted interviews with staff members involved with the General Chemistry modules. The conceptual and analytical tools for the analysis of the curriculum documents, along with the development of the ELoD, were explained. For the analysis of interview data, I used analytical descriptions in conjunction with retroduction. Lastly, I discussed aspects of validity, my role as a researcher, and the ethical consideration that were implemented.

CHAPTER 7 – Analysis of the curriculum discourses

> Science or the production of any kind of knowledge, is a social practice
> (Sayer 1992, p. 5)

7.1 Introduction

I argued in Chapter 2 that the nature and characteristics of disciplinary Chemistry knowledge have an influence on student learning in first-year General Chemistry[66]. I discussed how the curriculum of General Chemistry is constituted. The approach to curriculum design implemented at the LSAU for General Chemistry, the site of my study, was also explored (Chapter 2, Section 2.4.2).

To recap, the primary research question for this study was to explore how the knowledge or knowledge practices in the General Chemistry curriculum at LSAU enabled or constrained student learning. The secondary questions were aimed at understanding the basis of achievement inscribed in the General Chemistry curriculum plan by uncovering the organising principles underlying the knowledge practices therein. However, an initial inquiry into the curriculum discourses that influenced the structuring of General Chemistry was necessary for understanding the prevailing pedagogic discourse in the Pedagogic Recontextualisation Field (PRF). Through analysis of the pedagogic codes and the instructional and regulative discourses, the intention was to provide recommendations for how the design of the General Chemistry curriculum could best facilitate student learning. It should be noted that the construct of epistemic access includes access to powerful forms of knowledge and cumulative learning,[67] as a requirement to knowledge acquisition in a discipline with a hierarchical knowledge structure. Epistemic access is the central concern that underpinned my examination of the curriculum of the General Chemistry course.

I discussed the processes of analysing the relations between discourses underpinning knowledge and curriculum practices, that is, the *what* and *how* of the pedagogic discourse. This was done from the perspective of the lecturers interviewed for this research (referred to as *respondents* hereafter) as the recontextualisers, and also using the notes and instructions given to students as

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[66] See Chapter 2 Section 2.2 on Chemistry knowledge and Section 2.3.2 on the approaches to learning in the field.

[67] The analysis on the knowledge-building and cumulative learning capabilities in the curriculum are discussed in Chapter 9.

further data sources. The aim of the analysis was to uncover how the curriculum discourses structured the General Chemistry curriculum.

7.2 The data generation process revisited

As part of the data generation exercise, I used three data sources to understand the construction of the curriculum as a knowledge practice and to examine the possible effects of the curriculum on the inclusion or exclusion of students from accessing General Chemistry knowledge.

As discussed in Chapter 6 Section 6.5.1, an organising framework for analysing the data was developed based on Bernstein's pedagogic device. The focus of the analytical exercise was the PRF. It should be noted that although this study was firmly located in the PRF, reference to the field of reproduction and to pedagogic practice is unavoidable for the purpose of shedding more light on the knowledge and curriculum practices. Figure 18 below is a diagrammatic representation of the steps I followed in analysing the curriculum discourses influencing the structuring of General Chemistry. The data for this analysis were the curriculum documents and the interview culminating in this chapter.

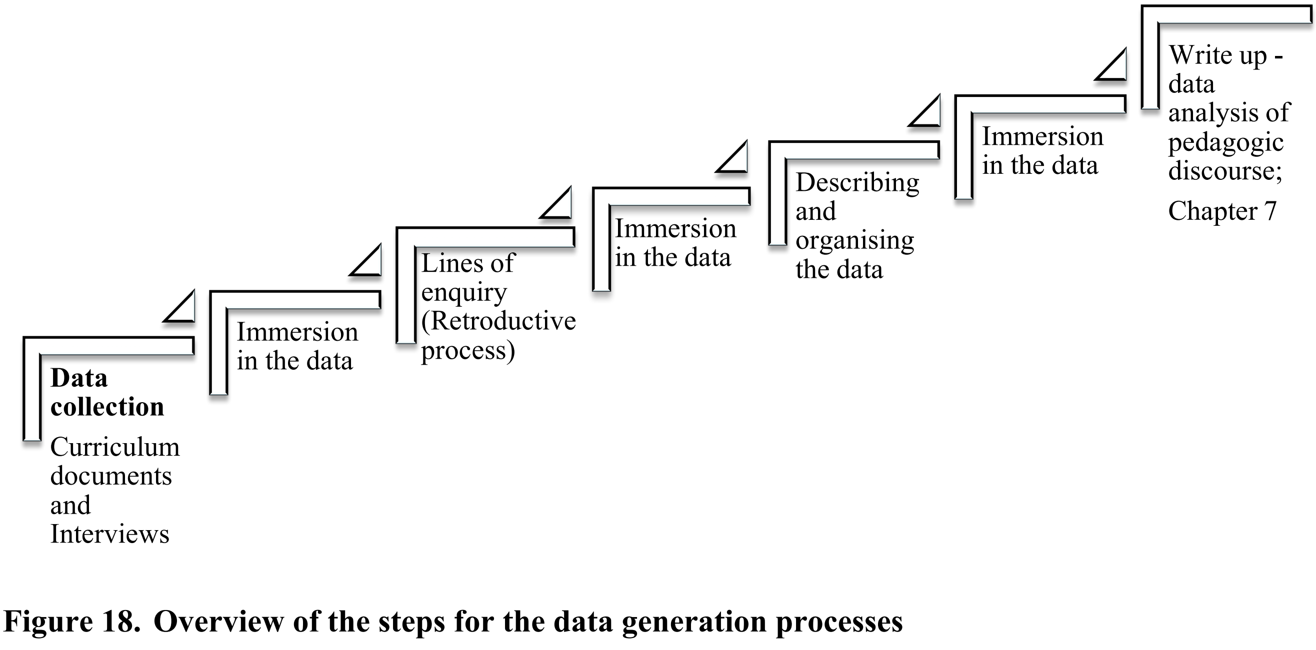

Figure 18. Overview of the steps for the data generation processes

From early on in this study, understanding the context within which curriculum design and development occurred has been vital to appreciate the dominant relations and the discourses underlying the curriculum. As noted in Chapter 6 (Section 6.3.2), I endorse a relational conception of context. For Seddon (1993), context is the "discursive setting within which practices occur" (p. 6). Context acknowledges the connectedness of things and events that are socially situated and historically embedded. Such a relational conception understands context as a "social product which is constructed and reconstituted through practices within a social formation understood relationally" (p. 47). This relational conception of context highlights the sociality of the context where social products arise from practices. In addition, such an account of context considers the inherent connections between the different elements that constitute curriculum design. I now discuss how, through the pedagogic discourse, curriculum practices have been influenced at the LSAU by the triad conceptualisation of the characteristics of Chemistry knowledge.

7.3 The pedagogic discourse in the curriculum

In the first instance, the process of recontextualisation involves delocating knowledge from the field of knowledge production and relocating it in the field of recontextualisation (curriculum), followed by a further process of delocation and relocation to the field of reproduction (pedagogy). In order to understand and explain the nature of the pedagogic discourse and the practices embedded in the espoused curriculum, I talked to the recontextualisers of the knowledge, i.e. the Chemistry lecturers. I conducted interviews with six staff members using open-ended questions. As discussed in Chapter 6, the intention with the interviews was to explore lecturers' understanding of the implications for the choices made in relation the selection, sequencing, pacing, and evaluation of curriculum knowledge. These choices also point to the regulative and instructional discourses of General Chemistry in this context.

7.3.1 Classification in the curriculum

Bernstein's concepts of classification and framing were used to analyse relations between discourses in General Chemistry and to explain aspects of the context of recontextualisation of knowledge into the curriculum. Bernstein (2000) asserted that the construction of the curriculum is influenced by the knowledge structure and the pedagogic codes of classification and framing (ibid). These pedagogic codes make it possible to distinguish between the nature, structuring or organisation of the knowledge between and within disciplines. Classification refers to the strength of relations between contexts (in this case, the degree of difference between the respective knowledge content areas, for example, between Chemistry and Statistics), and framing denotes the extent of control over the curriculum, for example the different design practices. As previously mentioned, it should be noted that although this study is firmly located in the field of recontextualisation, reference to the field of reproduction and to pedagogic practice is unavoidable due to the intertwined nature of the curriculum and pedagogy.

At the LSAU, as at many other universities in the country, the General Chemistry curriculum follows the standard division into Inorganic Chemistry, Physical Chemistry and Organic Chemistry. Four of the six respondents I interviewed noted that General Chemistry was closely related to Physics, Biology and Mathematics. According to Respondent 3, for instance:

> We say Chemistry always is the central science … with the living systems and the non-living systems (material, energy). … Material and energy on that side, what goes on in the cell in the Biochemistry and Biology. We are central. There is no other science that positions itself like that. If we talk to medical people we talk … about Organic Chemistry. We talk about the materials science (Respondent 3).

The view that Chemistry is a central science has implications for the strength of its boundaries with other science subjects and the degree of insulation *between the knowledge of* General Chemistry and that of Physics, Biology, and Mathematics. According to the interviewees, the fact that General Chemistry is a central science is regarded as possibly the biggest hurdle that students have to master. Chemistry as a field of study is a ‘central’ or ‘fundamental’ science, important in its own right and, as noted by Respondent 5:

> It provides the building blocks for knowledge in the material world and for building a model for matter. (Respondent 5)

When explaining the connection of Chemistry to other subjects, Respondent 1 pointed out why some students could possibly be struggling with drawing clear boundaries between the science subjects:

> I am telling you, they (students) will tell you that Physics is much better than Chemistry because in Physics this much has to be remembered (makes a gesture of something small). A lot you just have to think about, like in Mathematics. And you see, if you ask any student which part of Chemistry is more difficult they will tell you that its Physical Chemistry because you have to take your Maths, combine it with your Physics and a bit of Chemistry and you are going to form Physical Chemistry. (Respondent 1)

Mathematics and Physics, form a central component of the knowledge base of General Chemistry. Taber (2001) explaining the relationship between Chemistry and Physics states that “no matter which aspects of Chemistry are considered, a fundamental reliance on aspects of Physics is implicitly present” (p. 125). The General Chemistry student is expected to appreciate the physical basis for the ideas used in Chemistry as expressed by this respondent:

> If you are a medical doctor and if you would speak with a biochemist, there is something like concentration, mass balance, there something like kinetics, something like thermodynamics, concepts must be there for conversing. The vocabulary must be there for conversing. (Respondent 5)

In terms of Bernstein's knowledge structures, Chemistry as a science has a clear identity, a unique voice and its own rules of internal relations. On a continuum of strengths, when compared to other disciplines, the field is thus strongly classified (2000). As an Introductory Chemistry module, the General Chemistry curriculum is recontextualised knowledge from the intellectual field of Chemistry. On a continuum of strengths of classification of disciplines in the natural sciences, and considering the above excerpt from the interviews, it can be argued that General Chemistry as a knowledge base is less strongly classified than the discipline of Chemistry. My argument is that General Chemistry exhibits weaker classification on a continuum of strengths because of its relations with Physics, Biology and Mathematics. The boundaries between these fields are semi-permeable. Knowledge of these disciplines is also required since the other disciplines are necessary for building Chemistry knowledge. Physics, Biology, and Mathematics knowledge from high school form essential pre-requisite knowledge for General Chemistry, as well as requisite knowledge for studying General Chemistry at university level. In most instances, students need to have done these subjects at high school level to be admitted into studying science disciplines at university.

According to Muller (2013), strong disciplinary identities are generated through the possession of specialised knowledge and a specialised disposition to certain forms of conduct regarding disciplinary matters. It therefore follows that the degree of insulation of the curriculum between the different subjects such as Physics and Mathematics is porous, thus making the formation of the identity with General Chemistry weaker. From a curriculum design perspective, the relative weakness in the classification of General Chemistry has implications for epistemological access to the knowledge and for the formation of appropriate student identities. The student's inability to see the connections with the other subjects might provide opportunities for struggling with the content, thus excluding some students from accessing the knowledge. Therefore, the curriculum should be designed in a manner that signals the integration of the different subjects that are necessary for understanding Chemistry knowledge.

Lastly, the nature of the General Chemistry curriculum itself is composed of different, but related topics. Seviana and Talanquer (2014) point out that dominant approaches to teaching the subject in many countries tend to present the discipline as a collection of somewhat isolated topics: atomic structure, chemical reactions, chemical bonding, thermodynamics, kinetics, etc. Although these topics form essential knowledge in the field of Chemistry, organising and sequencing the topics into a coherent curriculum can be a challenge for the sub-field of General Chemistry. It is for this reason that analysing the framing of the content in the curriculum has been included in the following discussion. I now turn to a discussion on framing the different elements of the curriculum design and consider the possible implications of the framing for enabling or constraining student learning.

7.3.2 Framing in the curriculum

In the following section I describe the selection, sequencing, pacing, and evaluation of the learning objectives and learning tasks.

7.3.2.1 Selection of curriculum content knowledge

In the interviews, I asked lecturers why specific content was included in the curriculum. There is consensus in the literature that General Chemistry consists of certain fundamental topics that form the foundation for introductory tertiary-level Chemistry. This means that there is little debate about the selection and sequencing of topics in the modules. In this regard, Respondent 2 stated:

> It is cumulative wisdom and knowledge worldwide that say these are the topics required in a typical first-year Chemistry course, so I think we are largely guided by collective wisdom of Chemistry practitioners worldwide and it is also reflected in the content of the vast majority (of) Chemistry textbooks. (Respondent 2)

Respondent 3 also argued that the knowledge of what constituted the General Chemistry curriculum was a given since there was a universality to Chemistry and that the selection of content knowledge was thus a *fait accompli*:

> We say this is a worldwide game. We are not different, so it is easy for us not to take the full responsibility *(for designing a curriculum)* ourselves and to decide on what we are going to teach. And we take a typical textbook, so it would be silly to reinvent the wheel to say we are more clever (sic) than others. We look at the first-year textbook and say, okay, does it *(the textbook and content)* apply to us in SA? There may be some reasons why we may deviate – how is our school preparation? So, there are some little contextual things that we have to keep in mind, but in general, if you think we have to end with these students in mind there is only one league not two leagues; not like the Olympic games. So, we have to all move in that direction. (Respondent 3)

Similarly, Respondent 6 commented that, “a normal self-respecting university must address these topics. When the student leaves first-year level they must know these concepts”. These comments indicate that the selection of content knowledge was aligned to what was being taught in other institutions and was comparable with choices made at Chemistry departments elsewhere, thus making the selection of the content a given.

However, Young (2008a) asserts that the practice of taking knowledge as a given is a twofold fallacy. He distinguishes between internal fallacy and external fallacy. *Internal fallacy* regards knowledge as an a-social given and "something that has to be acquired by anyone who wants to see themselves educated" (ibid; p. 95), whereas *external fallacy* happens when regarding knowledge as a given signifies the tendency to overlook how knowledge shapes educational outcomes such as social inclusion and widening participation. In terms of curriculum design models, external fallacy is comparable to Moore and Young's (2001) account of a technical-instrumentalist ideology of curriculum, and knowledge acquisition and production, and internal fallacy can be associated with conservative neo-traditionalist approaches. Contrary to these fallacious perspectives, a social realist perspective of knowledge and the curriculum rejects the view that knowledge is a certainty. Realists recognise that knowledge is an independent entity with properties, effects, and powers, and as such, an investigation into the structuring of the curriculum by uncovering the generative mechanisms in the curriculum can offer an understanding of what enables or constrains learning.

As noted earlier, for some students General Chemistry is a pre-requisite if they are enrolled in programmes that require them to have the foundational knowledge in that course. It is a major for students who will graduate in Chemistry, whereas other students take the module as a non-major subject. The lecturers I interviewed agreed that the curriculum should be the same for both student groups:

> Over here there are students who carry on and they do the same first-year Chemistry as students who don't carry on; so, they have the same content. We have to … at a level that allows the student to continue. So, it has to be at a level that prepares the student to continue as a major. We don't have a watered-down Chemistry for students who don't intend to carry on with Chemistry. (Respondent 5)
>
> In our set-up here, there is a small percentage, of course, of first-year students that go to second year. But we have an understanding with Microbiology, Genetics and Biochemistry that we give the student the same basic knowledge. We can argue about why is the curriculum the curriculum…The end product in the first year must meet these criteria,[68] students must know. And above that also, they must be able to go on to all these other courses. (Respondent 6).

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[68] Reference is made to the international Union of Pure and Applied Chemistry (UIPAC), an international body that oversees teaching, learning and research in Chemistry, and the Royal Society in Britain.

Although Respondent 6 acknowledges that the majority of students will not continue with Chemistry as a major, the level of the selected content and the level at which the subject is taught should allow students to progress and enrol in the second year of the Bachelor of Science degree.

Accordingly, for Respondent 5, the bigger aim of the first-year is to serve the needs of those students who will major in Chemistry. This is in spite of the fact that these students form the minority group in the class. This begs the question about what the curriculum might look like if its focus was to cater for the majority of the students who need Chemistry as a foundation for further studies in other science majors, rather than the focus being on the minority who intend to pursue Chemistry as a major subject, as is currently the case.

As noted earlier, the selection and structuring of curriculum knowledge and learning materials is largely based on the textbook (see also Talanquer and Pollard (2010) and Duit and Talanquer 2009).[69] Some respondents noted that, although the textbook was used religiously, there was room for slight deviation from the textbook structure to accommodate the needs of incoming students, "there are some little contextual things that we have to keep in mind, but in general, if you think we have to end with these students in mind" (Respondent 3). Although the textbook is used extensively in the module, material is not necessarily presented by working through the textbook in a linear fashion.

Respondent 5 expressed the view that the textbook content needed to be contextualised to make it relevant to the South African context. He noted:

> The thing is, we use an American text book … Many people say these are international textbooks. There is a reason why it is written in this order. But their reason is based on ***their*** intake of students, what *they* know…. so, eh … it's not exactly the same for our students. (Respondent 5)

The current selection process, although strongly influenced by the logic and structure of the textbook, also points to a need for an approach aimed at filling the gaps in student knowledge, given the problems in South Africa with teaching and learning at school level. This process may involve working through earlier chapters first instead of interspersing later chapters with the earlier ones when there was clear evidence that students had notable gaps in their prior knowledge. The messages about the *what* and *how* that is chosen or not chosen from the textbook, and what forms of knowing are valued, can be confusing to the student in a discipline where the logic of the sequence of knowledge matters. There may need to be more careful movement between topics

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[69] I discussed this matter in Chapter 2 Section 2.2.2

to ensure coherence and progression and to enable students to make connections between the topics. The sequencing of topics in the curriculum has implications for coherence and is based on the assumption that students would be able to follow the logic of the sequencing.

In sum, it was evident from the data that the selection of the content knowledge for the curriculum exhibited strong framing (F^+). In terms of the selection of topics, the curriculum was largely influenced by the knowledge base of the discipline intellectual field; however, within the context of General Chemistry at LSAU, lecturers had strong control over the decisions about the selection of content and topics.

7.3.2.2 Sequencing of curriculum content

The above discussion on selection is closely linked to the issue of sequencing of the content knowledge. Sequencing is a key dimension of curriculum design. Sequencing is about the organisation of topics and the ordering of knowledge in the curriculum. This process is informed by the nature of the knowledge, the amount of time available to teach the content, as well as meeting the varied needs of students in the class.

Bernstein claims that hierarchical knowledge structures display greater internal logic. A hierarchical knowledge structure requires careful sequencing to ensure that foundational concepts, theories and principles are grasped before exposing students to more complex knowledge. Careful sequencing thus ensures greater coherence (see also Chapter 5 Section 5.5). Furthermore, hierarchical knowledge structures make stronger epistemic claims about the relationship between concepts and empirical phenomena (Shalem and Slowinsky 2010). Hoadley and Muller (2009) indicate that "the richness of these concepts requires that learning is sequential and acquired under the guidance of a specialist" (p. 75). They argue that enabling learning in hierarchical knowledge structures requires that students do not get stuck at any stage of their learning. If a student gets stuck at any stage of the sequence, conceptual learning is interrupted, thus posing a problem for the student's capacity to build knowledge cumulatively. According to Respondent 6,

> Chemistry is a pyramid that we build and if a certain layer is not there the whole thing will topple in. Yes, we can change some things, certain things, certain aspects, but in essence it's really a set thing. You must know certain things and understand certain aspects before you can go on. All the concepts must be addressed in a specific order from the easy to the complex.

The intention of curriculum design and the resultant teaching and learning processes in first-year General Chemistry are to induct the student into the discipline and provide a basis for cumulative learning. Respondent 5, for example, noted that students needed to follow "the golden thread of Chemistry":

> There is a golden thread that runs through it (the curriculum). If the thread is broken you can work as hard as you wish, but you know you lack that previous knowledge so you have to work consistently from the start, otherwise you're not going to know this. As you said, how do they know this is a sequence of doing things, because if you don't work consistently you're gonna (sic) miss a building block and nothing is gonna make sense. (Respondent 5)

Respondent 5 here noted the importance of students working consistently so that they keep up with learning the content. However, he also suggested that if students did not recognise when they had gaps in their knowledge, and if they were not able to learn from their earlier experiences of learning, i.e. if they did not have the requisite metacognition, they would struggle. However, Respondent 5 further noted that lecturers did have the choice to include more relevant content when necessary:

> So, we're not shy to deviate from the order in which it is done in the textbook. For our students that has come basically from dovetailing the school curriculum with what we are doing.

Even though there was general agreement among the team of respondents that certain content knowledge had to be included in the curriculum, there was an understanding that there was room for some deviation from the textbook. Some themes did not follow the logic of the textbook and were not aligned with specific chapters in the textbook. However, in some cases, various sections from across a number of chapters in the textbook were brought together under a single theme in the study guide; for example, from Theme 4 in the study guide, the topic of which is Chemical Reactions, Equations and Stoichiometry combines sections from Chapter 3: *(Chemical Reactions)* Sections 3.1 and 3.2, and Chapter 4: *(Stoichiometry Quantitative information about Chemical Reactions)*. Students are also instructed to learn Sections 4.1 to 4.4. Similarly, Theme 5, on *Aqueous Solutions,* takes its content from three different chapters, i.e. Chapter 3, Sections 3.4 to 3.9, Chapter 4: *(Principles of chemical reactivity: Electron transfer reactions)* Sections 4.5 and 4.7, and Chapter 20: Section 20.1 of the textbook. One of the reasons for changing the sequence of topics in this way was to align the content of the course more logically with students' prior knowledge, based on the high school Chemistry curriculum.

Bernstein (2000) asserts that sequencing rules mean that the curriculum needs to be arranged in ways that support learning progression. In the quotation below, it appears that the respondent had a sense that the sequencing rules may not be explicit to the novice student, and that students needed background knowledge as a foundation to deal with General Chemistry. The issue of background information is emphasised throughout the interviews. One respondent was of the view that the challenges experienced at first-year level had their roots in high school education:

> Look at what is happening in the beginning. In Grade 8 they must know the 20 elements, in Grade 9 - 36 elements, Grade 10;... When they come to the university they (students) must know everything, only to find that when they come to university they don't even know the first 20 elements nor the first five elements. This is what makes the students to fail horribly because they don't have the foundation. Because, if you don't know that (*pointing to the Periodic Table*) you are not going to succeed. (Respondent 1)

According to this respondent, there are significant gaps in students' prior knowledge. This is problematic, given the structure of knowledge of the discipline[70]. Sequencing in General Chemistry is understood as linking the knowledge in ways that cohere logically. Sequencing also needs to take into account the different dimensions of Chemistry knowledge as discussed in Chapter 2, viz. the descriptive (macroscopic), the interpretational (microscopic) and the representational (symbolism) levels of Chemistry knowledge. However, one respondent indicated how the sequencing of content knowledge could sometimes be problematic if the arrangement of selected topics did not progress logically:

> The logical order, the logical progression of the themes …We (lecturers) have felt for a number of years that the order is not always logical. You find that sometimes you introduce a topic and before you can teach it you have to say, "We have not done Chapter 5, but in the first half of the lecture let me quickly give you the basics." And it makes no sense. Why do that, re-organise it and do it, you know? (Respondent 2)

Respondent 2 also noted that each of the three related levels of Chemistry knowledge required learning progression which was not always achieved because the structuring of the information in the textbook did not follow an order consistent with the manner in which knowledge is applied in the field of Chemistry. According to Respondent 2:

> It's basically these things that I have highlighted, it's called physical properties, … what we call Physical Chemistry. They were done in the second semester. …We are not introducing anything new, but literally moving topics based on

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[70] The role played by prior knowledge in Chemistry will be further discussed in Chapter 9 (Section 9.4 and 9.5) as part of the discussion on cumulative knowledge-building.

> sequencing and logical progression or complexity plus what are the topics we know traditionally give lots of problems. Put them in. I guess you can call it the safer spaces. The start of a new semester, the students should be refreshed, there is more time for going into this in depth and that is basically what is informing (some of our curriculum decisions). (Respondent 2)

Muller (2009) states that in an intellectual field where conceptual coherence is fundamental, sequence in the design matters. He also points out that conceptual coherence is important in a vertical knowledge field. The more conceptual coherence matters, the clearer the knowledge signposts should be, in terms of the examples and explanations and in relation to assessment.

Among the respondents there was a strong sense that the sequencing of the modules could be improved although there did not seem to be agreement about the order in which the content knowledge should be taught. One respondent felt strongly that the sequencing of the module had to be reviewed so that student learning could be facilitated better:

> I don't think students always know at every point, understand, why we are doing it in a certain sequence. And as I indicated earlier, we're busy changing the sequencing because we feel we need to reconsider what we assume they know and what we now know they struggle with. (Respondent 2)

In sum, the respondents concurred with Bodner (1986) about the challenges of explaining the logical order of content in Chemistry that exists in the mind of the expert, but which is not always the best order of presentation for the novice student. For an expert, the sequencing is logical while for the student, the order may be confusing.

Based on my reading of the literature on Chemistry education, there appears to be a general understanding of what should be in the Chemistry curriculum. Although there was general consensus on the selection of the content for the first-year curriculum, there was less agreement on how progression, sequencing and pacing could aid student learning of foundational knowledge. The sequencing of knowledge content exhibited moderately strong framing (F^{++}), even though the knowledge base is strongly influenced by the field.

7.3.2.3 Pacing and timing of curriculum content

Closely linked to sequencing in the curriculum is the pacing and timing of the content knowledge. Pacing denotes the rate at which the content is taught to the students, as indicated in the timetables found in the study guide, as well as the rate at which students are meant to learn the material. Pacing and timing are made clear in the information provided to students in the study guide which includes a timetable indicating lecture periods (theory) and practical laboratory sessions for each semester. The timetable reflects the pacing of teaching and is based on lecturers' judgement about the amount of time it would take to teach and learn certain topics. Certain topics, such as aqueous solutions, chemical bonding, and molecular structure were given more lecture time than others, and these topics were also covered to a greater extent in the final examination papers.

One lecturer noted that, no matter how much time a student was given to learn particular topics, the time never seemed to be enough. For this lecturer, the amount of time was not necessarily an issue; it was instead the conceptual complexity of the work as noted in the following excerpt from my interview with Respondent 2:

> Interestingly enough we have in General Chemistry 101, we normally plan five lectures,… for each of the three topics.[71] So it's approximately 15 lectures altogether. Sometimes it works out to 12. So, let's say 12 … Then the sister programme[72], you know about the four-year programme, runs the Chemistry 1 over three semesters. So, you find that there obviously is more time … The number of lectures is almost double what we have available for General Chemistry101. And yet, even there, the same phenomenon – students struggle. That's just a basic fact. (Respondent 2)

According to this respondent, the work was so complex that no amount of additional time spent on the hard topics seemed to make a difference to the success rate of students in the subject:

> It's complicated because it's very complex it goes slightly deeper than just introducing a topic. And traditionally, because it's at the end of the year, students do not get an opportunity to be tested on it more than once. So, (they need to count on) their own perception of do I understand this work - yes or no. You know, there is no feedback. I think that plays a role. The fact that it's complicated, very intertwined, and to some extent it's done at the end of the semester. Some factors like student fatigue, pressures of other subject deadlines for things that have to be submitted. I don't think the students themselves find a large space to say, okay no, let me focus on this, they do it among many other things. (Respondent 2)

In the extended curriculum programme where the first semester was extended over a period of eighteen months, these topics were still a great challenge to students. Similarly, mainstream students seemed to struggle with this content. The complexity of the knowledge required breaking through a number of conceptual and representational understandings, especially in relation to the triplet relationship of Chemistry knowledge.

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[71] Respondent 2 is here referring to the first three topics of Physical Chemistry.

[72] The Extended Foundation Programme is an alternative access route for students entering the BSc degree where the first-year curriculum is spread over 18 months, that is, over three semesters.

Respondent 4 expressed concern about the pace, but these concerns were superseded by the necessity of including specific topics in the curriculum – not just for the sake of student learning, but in order to remain competitive with other universities:

> I think the pace is fast; they experience the pace to be fast. I don't know if we can do anything about it – the course. That is, the pace. The amount of work should be covered and is also covered in other universities. (Respondent 4)

Changing the pace was beyond this respondent's control. This issue was not mentioned by other respondents as a challenge.

In sum, there is stronger framing (F^{++}) over pacing and timing as evidenced through the timetable for both theory and practical laboratory sessions. There is weaker framing (F^{-}) in relation to self-study activities, such as problem-solving exercises; students are thus granted greater flexibility in control over their self-study programme.

Additional learning opportunities existed in the form of compulsory practical laboratory sessions and optional tutorials. Students attended tutorials as additional opportunities to have their concerns and questions regarding theory addressed. Accordingly, students had greater control over the pacing of their learning outside of lectures and practicals, however student responses from the self-study activities did not form part of the analysis.

7.3.2.4 Self-assessment as evaluation in the curriculum

As part of the process of judging the extent to which students have understood the work, it was expected that they would engage in self-assessment activities. The self-assessment activities provided strong clues about what lecturers and the curriculum privileged through the self-assessment exercises they selected from the textbook.

The following instruction was given under the heading, Theme 2, in the study guide.

> The following numbers refer to exercises from the prescribed textbook. The answers are given in Appendix R of the textbook. Textbook pp. 98 to 106. (Theme_2 –_Atoms, Molecules and Ions: GCM 101 study guide)

This instruction was followed by a list of the numbers of the exercises (selected from the end of the chapter in the textbook, and included in the study guide) that students were encouraged to attempt in order to assess their understanding of the content:

> 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 35 37 39 41 43 45 47 49 51 53 57 59 97 101 103 111 126 127 128 141 (Theme 1- Matter and Measurement: GCM 101 study guide)

The set of numbers referred to the numbers of the exercises as they appeared in the textbook that students were supposed to attempt. Similar instructions were given for each of the themes covered in the curriculum. On examining the exercises, I observed that most of the numbers were odd numbers. Students were able to check the answers to the exercises at the back of the textbook; however, they were encouraged to work out the examples before finding the answers in the textbook. When asked about this practice, one respondent mentioned:

> The authors of the textbook provide the answers to the problems with the odd numbers at the back of the book. At the end of the textbook there is a glossary and there's answers. We believe that students must be in a position to assess themselves. For the even number questions, the students have to see me and I have to look at the work and tell them yes, you're right. (Respondent 6)

According to Respondent 6, having the self-assessment exercises and the answers were useful for the purpose of student self-assessment. The need for students to develop confidence, as suggested by Respondent 6, as an attribute developed from self-assessment however, is not carried through in the practices supporting student learning. Many students were unlikely to attempt the additional exercises for which answers were not provided at the back of the textbook. Even if they attempted the even-numbered exercises, most would not have taken the opportunity to consult the lecturer if they happened to experience difficulties with those exercises, as Respondent 6 suggested. There are numerous plausible explanations for the students not attempting the exercises that do not have answers, and also not consulting with the lecturer for further assistance. Reasons could include the students' workload, lack of confidence to attempt the work, or lack of interest and motivation due to studying in a programme that was not their first choice, as mentioned by Respondent 6:

> If one is interested in something you will be motivated to learn more, to read more, to know more, but many students are not interested; they want to do something else, for instance, if they are not selected for medicine (the last selection is in the middle of the year after the first semester) then there is no purpose, they have to continue with the BSc. (Respondent 6)

Furthermore, there seemed to be evidence, according to one respondent, that students did not attempt the exercises for which no answers were provided in the textbook.

For Respondents 2 and 5 the reason why students were less likely to tackle the self-assessment exercises without answers at the back of the textbook was because of a lack of confidence and a need for instant feedback, which was not available.

> You know, there is no feedback. I think that plays a role. The fact that it's complicated, very intertwined and to some extent its done at the end of the semester. I think that plays a role. (Respondents 2)
>
> I find that the students are scared of discovering that they don't have that confidence or they don't give themselves a chance to feel confident. The answer at the back is immediate feedback, so maybe it's more better *(sic)* for them and less anxiety-causing to be able to get instant feedback. (Respondent 5)

According to Davila and Talanquer (2010), the use of end-of-chapter[73] assessment exercises is a widespread practice in General Chemistry. They found that the questions did not require students to translate or interpret particular representations of matter. They noted a paucity of questions "that require students to apply what they have learnt in new contexts and to use their knowledge and understanding to make hypotheses, create models, design experiments, generalise ideas and make judgements" (p. 101). In order to get more engagement with the end-of-chapter questions in General Chemistry at the LSAU, the incorporation of these exercises into the formal work that is graded should be considered. I would argue that the message that students did not have to submit the self-assessment tasks, even though the tutorial test would be based on these exercises, demonstrated inconsistent practice and assumed that the students would take the initiative and that they would be self-directed in their learning. Given that feedback was a major aspect of the learning process, not putting in place more structured opportunities for feedback seemed to be a missed opportunity to scaffold and provide support for student learning. It is necessary to cultivate opportunities for offering support to students that is non-threatening. Students should know what counts as a good answer (Muller 2009).

Respondents held diverse opinions about the availability of the answers in the textbook. One respondent thought that the current practice of using textbooks with answers at the back constituted a serious challenge to student learning because s/he believed that students would not make the effort to work through the problems; they would just check for the answer at the back of the book. One respondent said the following about the usefulness of the self-assessment tasks in the subject for student learning:

> You are not supposed to learn the answer. You are supposed to learn the method of answering the question to get to the answer. And I think to be successful, you must teach yourself as a student that confidence by answering questions and knowing that you're right. (Respondent 5).

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[73] The end-of-chapter questions are exercises mainly used for revision and for self-assessment purposes.

Respondent 5 valued the development of procedural knowledge and problem-solving skills and the attribute of confidence for learning the subject. Being able to verify the correct answer served as instant feedback. However, arriving at the correct answer without using the proper problem-solving approach limited learning. Respondent 5 believed that showing the method of arriving at the answer had greater value since the process demonstrated the thinking practices that were necessary for solving a particular problem. Learning the procedures for problem solving was paramount for success in General Chemistry for Respondent 5. Similarly, Mbajiorgu and Reid (2006) noted that the discipline privileged content knowledge that developed algorithmic skills.

A student's ability to show how a problem was solved was an indication of the extent to which theoretical and procedural knowledge was understood. Therefore, the inclusion of ready-made answers in the textbook did not model the process of problem solving, thus not making explicit the recognition and realisation rules. In addition, scaffolding to guide problem-solving processes or procedures was not provided, and thus, the realisation rules were not made explicit (Davidowitz and Chittleborough 2009).

The following instruction taken from the study guide seemed contradictory. The self-assessment exercises were regarded as "indispensable" even though they were not to be formally assessed:

> You do not have to hand in this work. However, the tutorial test is based on these exercises. You should not expect to get exactly the same questions, but these exercises are indispensable for your preparation and understanding (Notes from Theme 3: Chemical Formulas and Related Calculations - GCM 101)

As noted earlier (Chapter 6, Section 6.4.1.3), from a student's perspective, assessment constitutes the actual curriculum (Ramsden 2003). Thus, what is assessed is regarded as what is valued knowledge in the module. Even though the statement in the note above may have been meant to motivate students to work independently, it would, in all likelihood, have had the effect of signifying to many students that it was not really necessary to do the exercises.

Although the work was not meant to be submitted, the recognition rules were made explicit by the notes. The **recognition rules** refer to what is acknowledged as legitimate knowledge and is recognised as the basis of achievement (Bernstein 2000). Bernstein (2000) advocates making explicit the rules of the game in the form of both **recognition and the realisation rules**. This means that what counts in texts should be made transparent to students as part of the transmission of knowledge through the curriculum. The realisation rules which relate to how students are required to put meanings together to produce legitimate texts are also not specified in the self-assessment activities. It seems, however, as if some students are not able to decode the messages contained in the notes, as suggested by one of the lecturers:

> I think you could say that to a certain extent, because we tell them, make no mistake, learn this. We don't have to understand. Learn this, memorise. But it doesn't seem to happen. (Respondent 2)

By implication then some students fail to develop the recognition and realisation rules even if lecturers consider these to be explicitly stated in the notes and in the tasks. Although the message in the notes clearly indicated that students were required to do the exercises there were limited measures of control to ensure that the work was done and understood.

In sum, the evaluation of the curriculum knowledge through the self-evaluation exercises exhibited weaker framing because the locus of control for the assessment was with the student. In addition, the assessments were not graded and students did not receive feedback. Although emphasis was placed on the development of knowledge (epistemic relations), the self-assessment tasks also encouraged the development of the disposition of approaching problem solving with confidence (social relations). Despite attempts to encourage students to consult with lecturers when they experienced problems with the curriculum, new students were unlikely to take up the invitation. In the next section I present the analysis of the relative strength of framing of the instructional discourse through the notes given to students to guide their learning.

7.4. Framing of the discourses in the curriculum

As noted in the discussion in Chapter 5 on pedagogic discourse, Bernstein's (2000) contention that curriculum texts act as message systems for pedagogic discourse is relevant because curriculum texts contain both the discourse of skills and competence (instructional rules) required, and the discourse of rules governing the discipline (regulative rules). The regulative discourse refers to the value or moral order underpinning the curriculum. Singh (2002) expanded Bernstein's concepts and described the regulative discourse as the "moral regulation of the social relations of transmission and acquisition of rules of appropriate conduct, character and manner in the classroom" (p. 567). Since instructional discourse refers to knowledge and cognitive competencies that students need to acquire, the discourse is always embedded in the regulative discourse which defines the parameters of transmission and acquisition in the pedagogic context. In the context of curriculum practices, the instructional discourse is a reflection of the regulative discourse. Both discourses should be evident in the intended and assessed curriculum as demonstrated in the notes and instructions for students.

The remarks that introduce each module in the study guide alert students to what they should expect in the module. What is emphasised or highlighted in communicating with students about the module signifies to students what is important. The introduction to first-year General Chemistry in the first semester module begins with a reference to the focus of the modules in the following manner:

> In this course, the emphasis is mainly on general chemical concepts and principles that serve as a basis for more advanced concepts in Chemistry, as well as in other disciplines" (GCM 101 study guide, p. 1).

The intention of the above excerpt is to alert the student to the purpose and intentions of the module, the nature of the knowledge, its structuring and the purpose of the learning. From the outset, the student is made aware of what s/he is supposed to learn in this module, that is, the concepts and principles of Chemistry. The student is also made aware of the foundational nature of the module and its relationship to other knowledge areas.

Similarly, the introduction to the second semester General Chemistry module places greater emphasis on the knowledge claims made in the discipline. Again, the kind of knowledge that will be engaged with is noted as follows:

> In this course, the emphasis is on physical and organic chemical concepts and principles. Some of the concepts the student encountered at school are revisited, but with greater depth and detail (GCM 102 study guide, p. 1).

A range of learning activities and tasks are presented in the study guide and students are pointed to where additional exercises can be found in their prescribed textbook. The number and types of exercises are carefully selected. In the study guide some elements or components of the curriculum have been strongly framed, while others have been less strongly framed. The learning activities students are required to do, point to what matters in the curriculum. The sequencing and pacing of exercises as well as the evaluation criteria are frequently strongly framed, but in some cases, students are given mixed or unclear messages about what is valued.

To examine the strength of relations of the discourses evident in the notes provided to students in the learning material, I considered how the instructions for learning content knowledge were conveyed to students. In this section I discuss the analysis of the curriculum documents, beginning with the notes, for the purpose of showing the framing evident the General Chemistry curriculum. The decision to include the notes as a data source was because almost all the themes were accompanied by notes. Throughout the different curriculum documents notes for the students' attention were placed on the module webpage on the LMS. These notes provided valuable information and instructions on what students needed to focus on in a particular section and how they were required to respond to questions. In the analysis that follows, the data on the notes are interspersed with the views expressed by respondents in the interviews. These excerpts provide evidence of how they understood the intention of the messages about the curriculum and knowledge practice of General Chemistry as communicated through the notes.

First-year Chemistry is one of the first modules that new students in the Science Faculty encounter. Of the 12 themes in the General Chemistry 101 module, only nine themes included notes related to the learning of the content knowledge and the different topics in the theme. The purpose of the notes was to provide students with guidelines on the procedural knowledge they needed to acquire. The procedures for learning and solving problems were made explicit in the notes, thus making the learning requirement clear. The following are examples of the notes for students:

> The correct number of significant figures in the answers of all calculations in this course must always be given (Note from Theme 1: Matter and Measurement).
>
> In this course, Avogadro's number is always used to 4 significant figures: 6.022 x 1023 mol−1. Note that this is a measured quantity and therefore it contains inherent uncertainty. It is known to a very high precision, but it will always be given to 4 significant figures. (Note from Theme 3: Chemical Formulas and Related Calculations).

The notes contained instructions on what the student needed to pay attention to and also signalled what was important in terms of conceptual and procedural knowledge, the *what* and the *how* of knowing in the subject. In a sense, the notes exposed the rules of the game to the student:

> The conversion factors will always be given when units of the British System (Imperial System) are involved. However, the conversion factors between the SI units must definitely be memorised. (Note from Theme 3: Chemical Formulas and Related Calculations)
>
> IMPORTANT 1. The integrated rate equations for zero, first second order reactions will be given in tests and exams. However, you must understand the meanings and uses of these equations, and the rest of Table 15.1 on p. 686. 2. The Arrhenius equation will also be given (equation 15.7 on p. 694). Focus on its application. (Note from Theme 9: Chemical Kinetics)

The basic messages from the notes provided instructions on what to look out for in a general way (as in the example above) or sometimes the notes were more specific about the knowledge content to be acquired, as demonstrated in the extracts from notes below taken from different themes:

> Acids and bases are covered in much more detail in a following theme. At this stage, a table of reduction potentials will not be given. Thus, it will not be possible to read redox reaction simply from a table (Theme 5: Aqueous Solutions - GCM 101 study guide).
>
> Study the guidelines for the writing of reaction mechanisms provided on page 5 of this document (Theme 4: Chemical Reactions, Equations and Stoichiometry - GCM 102 study guide).

In the above examples, no words or phrases were written in bold or underlined to emphasise the importance of any activity or instruction. However, the notes communicated the focus on knowledge and drew students' attention to which procedures were valued in the process of acquiring the knowledge. The notes indicated strong framing (F^+) as they provided guidance on how students were required to approach the tasks and what was viewed as important.

In this section I have presented the notes as a form of instruction given to students via the LMS. These notes were in addition to the notes and instructions that were given in the study guide. It is evident that the inclusion of the notes as part of the instructional discourse highlights the extent of control of what is learnt and how the content should be learnt. Ramsden (2003) argues that such communication to students is written by the lecturer from the lecturer's perspective and does not necessarily capture the students' perspective, thus presenting an epistemic gap. The message the students could be receiving could contradict the message intended by the respondents (the lecturers), especially if these messages were not mediated. As such, the analysis of the notes asked the retroductive question: What kind of knower was being developed, what student *gaze* is being assumed and cultivated?

7.5 Prior knowledge and articulation of curriculum design

The acknowledgement of prior knowledge is a central feature of constructivist pedagogy. The introduction to the module points to links between this module and the high school Chemistry curriculum and the importance of students building on the knowledge they acquired in high school.

The General Chemistry study guide states:

> The course follows closely on the school syllabus and many of the concepts the student encountered at school are revisited, but this time in greater depth and detail (GCM 101 study guide, pg.1).

As discussed in Chapter 2, constructivist approaches to learning dominate the field of Chemistry and it is particularly prominent in writing about General Chemistry education. A constructivist approach to learning is premised on the idea that learning occurs when students construct their own meaning and understanding of the world. Cognitive approaches to learning also highlight the centrality of existing schemata for accommodating and assimilating new information. Prior knowledge thus plays a major role in the constructivist paradigm of learning[74]. It makes sense that curriculum design should reflect the importance of prior knowledge.

A study conducted by Sedumedi (2008) on the role of prior learning in the acquisition of scientific concepts in first-year General Chemistry, showed that there were significant gaps in many students' prior knowledge and that this had an effect on the student's ability to learn new knowledge. One of the respondents noted that some students' problems with General Chemistry stemmed from them not having been taught or not having learnt the Periodic Table. This view was expressed as follows:

> The problem is at school, should you uproot this at school and make a point that should the student come to the university (they) must know the Periodic Table. You see whatever question paper you get, it has a Periodic Table at the end, and you know why the student does not finish the question paper, they have to have the table at the end (Respondent 1).

In the General Chemistry curriculum, the Periodic Table is taught in Theme 2. One of the learning outcomes of the theme is that students should understand the general layout of the Periodic Table. When and how the Periodic Table is taught is significant for General Chemistry. According to Respondent 1, students are aware that assessments do not require them to have memorised the Periodic Table since it is always supplied with the assessment papers:

> They say the Periodic Table is given to us at the exam. Okay, they (sic) are given to them in the exam. Now you talk about Rubidium, you find that the student looks for Rubidium here (pointing on the Periodic Table). They don't know which side of the Periodic Table they are going to get that Rubidium and then what is the sign representing the element. (Respondent 1).

In the above extract, the respondent highlighted what they viewed as significant knowledge but which they think is not appropriately emphasised in the curriculum. A common thread exists about what students are expected to know about the field when they begin tertiary education and that gradually builds in complexity as the semester progresses. As mentioned previously, several studies conducted at other universities in the country all concluded that students' prior knowledge

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[74] See Chapter 2, Section 2.3.2 for a discussion on the approaches to learning in the field of Chemistry education.

had been compromised due to changes in the high school science curricula (Sedumedi 2008, Potgieter *et al* 2008, and Potgieter 2010).

The absence, or lack, of knowledge noted in various studies refers to the very pronounced articulation gap between high school education and higher education, especially in relation to the sciences. The proposal for a new structure for the undergraduate curriculum (CHE 2013) acknowledges the complexity of the articulation gap in the sciences. The proposal points to the gap being, in part, a result of the focus at high school level on "algorithms, standard forms and procedural knowledge, and not sufficiently on developing reasoning, conceptual and theoretical knowledge that is the basis of higher education" (ibid, p. 58). One respondent thought that one way of addressing the articulation gap would be to devote more time to the Periodic Table which they regarded as the source of most of students' problems with General Chemistry. The respondent remarked that:

> When you start with the Periodic Table you won't finish the syllabus; however, when you finish the syllabus, you leave the students behind. They fail horribly. (Respondent 1)

One of the reasons that contributed to the articulation problem was the introduction into the high school Chemistry curriculum of 'relevant' knowledge. These more socially relevant topics included Chemical Systems and Global Cycles in Grade 10; resources of the lithosphere (mining and mineral processing); the atmosphere in Grade 11 and chemical industries in Grade 12 (petrochemical, fertiliser, chloralkali and battery industries) (Curriculum Assessment Policy Statement - CAPS 2011). Potgieter (2010) points out that the Organic Chemistry content now included amines, amides, ketones and arenes. The introduction of the topics shifted the high school curriculum towards a focus on a contextual application of Chemistry knowledge rather than conceptual development of Chemistry knowledge.

Moreover, there appeared to be a stronger focus in the NCS curriculum on the links between the chemical and physical properties of compounds, as well as types of reactions. However, Potgieter noted that the changes were bound to have a greater impact on the quality and status of the prior Chemistry knowledge of students entering the university. The changes in the high school curriculum were likely to result in pedagogical and basic epistemological challenges for the General Chemistry curriculum, including:

- The fact that acid-base is no longer examined, and therefore no longer taught in depth is a source of concern. Apart from its practical relevance to everyday life, it is a fundamental concept, not only for Chemistry, but also for the Biological Sciences.
- Stoichiometry is another fundamental concept that is poorly mastered. Together with the Mole Concept, it underpins many other topics in basic Chemistry, such as Chemical Equilibrium and Chemical Reactions.
- The inability to handle numbers with exponents is a concern since this is the format of scientific notation. It will impact on students' ability to handle Avogadro's number and Planck's constant, to calculate pH and equilibrium concentration, or to apply the Nernst equation.
- The inability to carry out unit conversions will negatively affect the solving of quantitative problems in topics such as Gas Laws, Solution Chemistry and Stoichiometry (Potgieter 2010).

The above concerns regarding the high school curriculum are major since the first-year General Chemistry curriculum is meant to be an extension and more in-depth exposition of the same concepts dealt with in high school. When referring to high school Chemistry and the changes to the curriculum, Respondent 5 thought that Chemistry might not be getting the attention that it deserved at high school level because teacher knowledge of Physics tended to be stronger than Chemistry knowledge:

> The school syllabus is misleading and they should cruise through this[75]. Either the Chemistry is not done at school because it's a combined subject[76] and I know the teachers are strong in Physics. In one school the Chemistry might be strong and in another it might not be the case (Respondent 5).

The changes in the high school curriculum had implications for the pedagogical content knowledge of teachers and concomitantly the quality and nature of pedagogy, and as a result, the quality of student learning. Such a shift in the high school curriculum is aligned to the debates on the vocationalisation and skills agenda of higher education as noted by Barnett (2009) as a global trend in the provision of higher education. Muller (2005) argues that restructuring curriculum

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[75] The first-year modules.

[76] It should be noted that at high school the science subject of Physical Science is the name given to the combination of Physics and Chemistry taught in schools. Each subject is taught over the course of one semester in any one year.

towards relevance mandated by national policy directives (the White Paper 1997)[77] was not well researched and does not take account of the developmental needs of society.

Since 2009 the National Senior Certificate (NSC) curricula in Physical Science have undergone some significant changes. These changes and their implications for students' transition from learning Chemistry at school to learning Chemistry in higher education have been closely studied by researchers at the universities of Pretoria and Cape Town (Potgieter and Davidowitz 2010). These studies have identified knowledge areas that were absent or not adequately covered in the NSC. The changes thus have a bearing on the scope of students' prior knowledge in General Chemistry at university (Sedumedi 2008).

In line with Sedumedi's findings on prior knowledge in Introductory Chemistry, one can conclude that if the student's prior knowledge is insufficient s/he is bound to experience some challenges with the curriculum since the foundations on which to build new knowledge will be weak or inadequate. The assumption noted in the introduction to the study guide that students have certain prior knowledge has implications for curriculum design and decisions about knowledge selection, organisation and pacing. It is imperative that curriculum designers also take into account the nature of students' prior knowledge. In addition, the misconceptions or alternate conceptions that students hold also constitute a barrier to learning[78]. If the articulation gap is not addressed in the curriculum students are placed at a disadvantage. The gap requires that alternate conceptions and misconceptions of knowledge are diagnosed, identified and addressed or counteracted early in the semester. Currently, there is no evidence in the data that any diagnostic activities are being conducted for informing curriculum design practices.

7.6 Summary

In this chapter I presented the relations evident in and strength of the discourses through an analysis of interviews with lecturers. I also presented my preliminary analysis of curriculum documents, namely the study guide and the notes that were placed on the institution's LMS. Instructional discourse represents the different elements that constitute the curriculum, including pedagogic practice. The instructional discourse comprises the content that is selected, its sequencing, pacing, and the evaluative criteria for judging the attainment of learning.

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[77] Education White Paper 3: A programme for the transformation of higher education in South Africa policy document outlines a comprehensive set of initiatives for transforming the higher education sector after the advent of democracy.

[78] See Gabel 1999.

In the above discussion of the instructional discourse I demonstrated that, due to the nature of the knowledge structure of General Chemistry, there is relatively stronger classification (C^{++}) of content knowledge (both theoretical and procedural knowledge) as expressed in the notes and instructions given to students. The data indicated that there was also relatively strong framing (F^{++}) of the selection of content, as well as of sequencing, pacing, and timing of topics. The stronger framing values in General Chemistry were congruent with the nature of the strong internal coherence of the knowledge field. The strong framing was also a result of the strong organisation necessary to deal administratively with the large student numbers in these modules. Based on the analysis, I concluded that the curriculum was structured in a manner that was bound to exclude many students from accessing General Chemistry knowledge. This finding was confirmed by a recent study conducted by Ellery (2016). Although Ellery's study focused on epistemological access to scientific knowledge in an academic development programme, the findings suggest that a curriculum with strong framing of discourses is not beneficial for epistemological access in introductory courses. Ellery suggests that weaker framing of instructional discourse would be more beneficial to enable independence, autonomy and critical thinking.

Concerning the framing of the evaluation in the curriculum in relation to the self-assessment exercises, there was little or no formal control on the part of the lecturers over students' engagement with the self-assessment and practice exercises. However, expectations about and guidance in relation to what should be learnt and how it should be learnt was provided in the notes and instructions, but there was no system for ensuring feedback to facilitate student learning from these exercises. I therefore contend that the inclusion of the self-assessment activities, although meant to stimulate self-directed learning, require much more formal and systematic mediation in the assessment plan of the module.

It is evident that assumptions exist about the type of student enrolled in General Chemistry. There are also assumptions about what students know and what they do not know based on the school curriculum. The need to take account of the realities of first-year students' prior knowledge in the design of the General Chemistry curriculum was discussed. There appeared to be consensus among respondents about what knowledge should be included in the General Chemistry curriculum, and the need to address the articulation gap between matric and first-year Chemistry was acknowledged. As noted by Potgieter (2010), if the deficiencies in the curriculum knowledge at first-year level are not addressed, then successful student learning in the subject could be threatened, thus excluding many students. More should be done in selecting the knowledge content to address the missing knowledge. Current processes of selection, sequencing, pacing, timing, and assessment point to a greater need to consider how the General Chemistry curriculum can contribute more appropriately to the transformative agenda of higher education for all in the South African context.

CHAPTER 8 – Analysis of the organising principles – LCT: Specialisation

All experience carries a pedagogic potential but not all experiences are
pedagogically generated (Bernstein 2000, p. 199)

8.1 Introduction

In a realist depth ontology, the actual domain is where observable events and occurrences are actualised. These processes are brought about by generative mechanisms in the domain of the real. Maton (2014: p. 31) states that, in order to understand the *basis* and *focus*[79] of knowledge claims, one must uncover the organising principles of practices by examining the forms of relations that are emphasised in an intellectual field. In this chapter I present an analysis of the learning outcomes for General Chemistry as stated in the curriculum documents. I also offer my analysis of the examination questions. For this analysis, I used Maton's LCT: Specialisation tools to analyse the messages conveyed about the basis of achievement in General Chemistry.

Analysing the curriculum design practices using legitimation codes is an approach to curriculum inquiry that focuses on knowledge as the object of study. The reason for identifying the organising principles of the curriculum is an attempt to explain the nature of relations that legitimate knowledge claims in this context. Curriculum choices signify the *what* of legitimate knowledge in this context. The curriculum also embodies messages about the *how,* that is, the forms of knowing that are regarded as legitimate for the cultivation of the ideal knower in General Chemistry at LSAU.

To recap: LCT: Specialisation comprises two sets of relations, namely, epistemic relations and social relations. These relations characterise what knowledge claims can be made (epistemic relations) and who can claim to be the legitimate knower (social relations). The relations are organising principles of knowledge practices. These relations exhibit varying degrees of strength and can be represented on a continuum from stronger to weaker relations. Epistemic relations are depicted as ER+/- and social relations as SR+/-. Stronger epistemic relations and weaker social relations exhibit a knowledge code (ER+, SR-), whereas weaker epistemic relations and stronger social relations represent a knower code (ER-, SR+). The following analysis further explores the organising principles that shape the basis of achievement for learning activities and the

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[79] See the discussion in Chapter 5, Section 5.10 on LCT: Specialisation.

assessment of the curriculum. The analysis provides a further exposition of the underlying organising principles of the knowledge practices in the General Chemistry curriculum.

8.2 The external language of description: The translation device

The ELoD[80] is a device that enabled me to establish a way of deciphering meaning from the empirical data through a process of translation between data and theory. As mentioned in Chapter 4, the development of a translation device required the identification of categories related to student learning of the curriculum content, and to assessment. Chemistry knowledge is abstract knowledge and includes both conceptual (theoretical) knowledge and procedural knowledge. A major objective for learning the discipline of Chemistry is that students will achieve conceptual learning (Posner *et al* 1982, Anderson and Schonborn 2008, Duit and Treagust 2010).

8.3 The nature of specialisation in the intended curriculum

In the following section I discuss the basis of achievement in General Chemistry. I analysed the learning objectives stated in the intended curriculum as well as the assessed curriculum, using the ELoD I devised. I present the data using the categories and indicators for the categories that I identified, along with examples from the data.

8.3.1 Realising epistemic relations – learning objectives

I analysed the epistemic relations evident in the learning objectives of the General Chemistry curriculum as stated in the study guide. The learning objectives stipulated the principles and theory (theoretical knowledge), as well as specific or more general skills and procedures (procedural knowledge), that students needed to acquire. In addition, they also signified whether students were expected to develop a particular *gaze* or set of values through studying General Chemistry.

8.3.1.1 Theoretical knowledge

The indicator for strong epistemic relations (ER+) was the degree to which the attainment of specific knowledge was emphasised as necessary for legitimate achievement in the module. Strong epistemic relations refer to knowledge that is strongly classified and strongly framed. For example, the following are examples of learning objectives in the first semester module aiming at the development of theoretical knowledge:

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[80] ELoD – External Language of Description.

a. Learning objectives in relation to theoretical knowledge

- Know and understand the classification of matter (Theme 1: Matter and Measurement)
- Understand the difference between physical and chemical changes (Theme 1: Matter and Measurement)
- Understand the physical meaning of the information given on the Periodic Table for each element (Theme 2: Atoms, Molecules and Ions)
- Predict the water solubility of a given ionic compound (Theme 5: Aqueous Solutions)
- Give the four quantum numbers for any given electron in an atom (Theme 6: Electronic Structure of Atoms).

Epistemic relations would be categorised as weaker in this context (ER-) if there was evidence of the content knowledge being de-emphasised and thus regarded as less important in the achievement of the learning objectives (See Table 15 of the ELoD). I noted that there were no clear examples in the data pointing to weaker epistemic relations (ER-) as legitimate grounds for achievement in General Chemistry related to theoretical knowledge. The basis for achievement in demonstrating theoretical knowledge captured in the learning objectives of the module exhibit strong epistemic relations (ER+).

8.3.1.2 Procedural knowledge

The second form of knowledge that needed to be acquired in General Chemistry was procedural knowledge, that is, the skills and procedures necessary to participate in legitimate inquiry in General Chemistry. An example of a field-specific competency is knowledge about and the ability to handle chemical substances and to execute procedures in the laboratory. Although theoretical knowledge is embedded in procedural knowledge, the emphasis in the latter is more on the application of knowledge through applying a specific methodology and executing specific operational processes. The integration of theoretical or conceptual knowledge and practical knowledge in the application of particular procedures was noted in the objectives as the basis of achievement. The following were examples of learning objectives related to procedural knowledge in first semester module:

- **Apply** the rules for the handling of significant figures in calculations (Theme 1: Matter and Measurement)
- **Calculate** the average relative atomic mass from isotopic information (Theme 2: Atoms, Molecules and Ions)
- **Balance** given chemical reaction equations with the inspection method (Theme 4: Chemical Reactions, Equations and Stoichiometry)
- **Distinguish** between initial concentrations and equilibrium concentrations. Note that only equilibrium concentrations can be used when working with K.

> When non-equilibrium concentrations are used in the equilibrium expression, Q results (Theme10: Chemical Equilibrium)

The above are examples of objectives that referred to the application of skills and procedures from various themes (See Table 15 of the ELoD). In the case of procedural knowledge, emphasis on and explicit references to the application of specific skills and procedures was indicative of strong epistemic relations. Epistemic relations were stronger (ER+) where skills and procedures were emphasised and made explicit to students, whereas it was weaker (ER-) when the skills and procedures were implicit and not stated as a significant aspect of subject knowledge (See Table 15 for the ELoD). Most of the examples were located in the area of strong epistemic relations for procedural knowledge[81].

The above examples of the learning objectives show that the focus was on particular knowledge and procedures related to topics such as Matter and Measurement, Atoms, Molecules and Ions, and Chemical Reactions, Equations and Stoichiometry. Students were thus expected to possess both specialised knowledge and precise skills to solve problems. The examples signified possession of knowledge of the specific procedures, skills and techniques needed for using formulas and theories for learning in General Chemistry, i.e. the know-how. The objectives explicitly stated the requirements for following specific procedures in the application of General Chemistry knowledge and particular skills, thus displaying strong epistemic relations (ER+) for procedural learning.

Since both theoretical knowledge and procedural knowledge displayed strong epistemic relations in all the themes, it was clear that possession of both forms of knowledge was important for learning General Chemistry. One respondent eloquently explained the importance of the development of both forms of knowledge, the theoretical (conceptual) and the practical (procedural), as an imperative to achieving in the discipline. In highlighting the role of the practicals[82] Respondent 4 noted,

> So, ***it's to confirm the theory***. Sometimes it's the other way around where you ***discover something*** in the lab; where you have to explain the theoretical reactions or whatever. So, it's mostly one of those two. But of course, it's skills in terms of handling apparatus. That's a basic skill that has to be practised. They also should to be aware of reactants and how powerful they can be. We also make them aware of what you are working with – how should you take care of your health, getting rid of the waste, practical handling of chemicals.

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[81] See Table 15 of the ELoD.

[82] It should be noted that practical work in the laboratory was not included as part of this study.

There were no examples from the data demonstrating weaker epistemic relations for procedural knowledge.

8.3.2 Realising social relations: Learning objectives

There were no examples in the data that demonstrated social relations in the learning objectives. This means that the learning objectives did not emphasise the development of student dispositions, i.e. referring to personal experience and opinions as the basis of achievement in General Chemistry.

8.3.3 Realising epistemic relations: Learning activities

The indicators of epistemic relations as found in the learning activities explicitly required evidence of particular forms of knowledge (See Table 15 of the ELoD). For example, in the following exercise from Theme 1 on Matter and Measurement, the task required students to calculate the thickness of aluminium foil. In the design of learning activities, the application of the knowledge for problem solving was explicit. Both theoretical and procedural knowledge were necessary for successfully solving the problem:

- The aluminium in a package containing 75 ft2 of kitchen foil has a mass of 12 oz. Aluminium has a density of 2.70 g/cm^3.

  What is the thickness of the aluminium foil in millimetres?
  Given: 1 oz. = 28.4 g 1ft = 12 inches, 1 inch = 2.54 cm
  Interpret all conversion factors as definitions, that is, as exact numbers. The density, area, and mass are measured quantities; thus, they contain uncertainty.
  Answer: 0.018 mm (Theme 1: Matter and Measurement)

Another example taken from Theme 4 on Chemical Reactions, Equations and Stoichiometry, required students to apply the subject knowledge. The task also emphasised the application of knowledge:

> Aluminium hydroxide reacts with sulphuric acid in the following way:
>
> $2Al(OH)_3 + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6H_2O$
> The following quantities of the two reactants are mixed and allowed to react. For each of the cases 2.1 to 2.5, calculate:
> a. Which one is the limiting reactant?
> b. What mass of which reactant remains unreacted:
> 2.1 50.0 g $Al(OH)_3$ 50.0 g H_2SO_4 [H_2SO_4; 23.5 g $Al(OH)_3$]
> 2.2 30.0 g $Al(OH)_3$ 50.0 g H_2SO_4 [H_2SO_4; 3.5 g $Al(OH)_3$]
> 2.3 30.0 g $Al(OH)_3$ 60.0 g H_2SO_4 [$Al(OH)_3$; 3.4 g H_2SO_4]
> 2.4 156.7 g $Al(OH)_3$ 263.7 g H_2SO_4 [H_2SO_4; 16.9 g $Al(OH)_3$]

2.5 263.7 g $Al(OH)_3$ 156.7 g H_2SO_4 [H_2SO_4; 180.6 g $Al(OH)_3$]

> Note: In each of these cases the reactants are exactly enough for each other. These are called stoichiometric quantities. In such cases, nothing of the reactants themselves remains after the reaction. Each of them reacts completely. (Theme 4: Chemical Reactions, Equations and Stoichiometry)

The basis of achievement in the learning activities evinced stronger epistemic relations (ER+) because the emphasis on the procedures required abstract theoretical knowledge. The instructions for the learning activities clearly showed that the acquisition or application of knowledge of particular procedures was required. Knowledge of procedures were necessary for the problem-solving exercises and for exercises relating to balancing equations. In the above examples, the recognition and realisation rules have been made explicit.

8.3.4 Realising social relations: Learning activities

As was the case with determining the strength of epistemic relations legitimated in the General Chemistry curriculum, I developed indicators for determining different strengths of social relations valued in the curriculum. The social relations would be stronger where personal experience and opinions were regarded as legitimate in demonstrating knowledge in General Chemistry. The curriculum needed to show an emphasis on personal experience and opinions, student dispositions and attributes to signify the valuing of strong social relations (SR+).

Strong social relations in the demonstration of theoretical knowledge would require that content knowledge, and /or particular skills and procedures be de-emphasised as significant in the demonstration of learning. No such examples were present in the data. There was no evidence from the data that social relations were valued in General Chemistry (See Table 16 of the ELoD).

Social relations were weaker where personal experience and opinions were downplayed and distinguished from legitimate educational knowledge. An example of curriculum content that exhibited weaker social relations can be seen below. Students were informed that:

> When doing the exercises, focus on how a problem is approached and solved. Do not just do or try to memorise them, but place the emphasis on understanding them. (Note from Theme 3: Chemical Formulas and Related Calculations – GCM 101 study guide)

For the learning tasks or exercises, the indicators denoting stronger social relations pointed to explicit emphasis on individual students' preferences in relation to how knowledge was to be demonstrated. Weaker social relations, on the other hand, were indicated when individual preferences were downplayed as significant in demonstrating successful learning. In the following task, where the students were instructed to 'choose the best' with reference to formal charge, there seems to be *focus* on the student's ability to choose the most appropriate response but the *basis* exhibits stronger epistemic relations. The usage of the word *best* suggests that the student could use his/her discretion or opinion to make a judgement. Granted on a gradient of strength of social relations, the above example is a minimal indication that the student's view or judgement can be used to determine the response thus the task generates weaker social relations. Therefore, there were no good examples from the data to clearly demonstrate the nature of social relations in the learning tasks.

EPISTEMIC RELATIONS (GCM 101 Study Guide)			
Theoretical concept manifested		**Indicators about degree of emphasis on:**	**Example quotes from empirical data**
Curriculum content **Theoretical learning** Theory knowledge in a study unit in the form of principles and generalisations, theories, models and structures	ER +	Content knowledge is emphasised as a necessary basis for achievement in General Chemistry	Know and understand the classification of matter Understand the difference between physical and chemical changes Understand the general layout of the Periodic Table Understand the physical meaning of the information given on the Periodic Table for each element Give the name of a given ionic formula, and vice versa Use Dimensional Analysis to convert units Draw the Lewis structure of any given simple molecule. Give the approximate size of any bonding angle in any given simple molecule
	ER –	Content knowledge is downplayed as less important in defining legitimate Chemistry knowledge	No example from the data
Procedural learning Subject specific skills and algorithms, techniques and methods, criteria for determining usage of appropriate procedures	ER +	Skills and procedures are emphasised and explicit guidance is given on the steps for solving problems	Describe each the following terms and provide illustrative examples of each Convert from mass to volume using density Convert between the different temperature scales Apply the rules for the assignment of the number of significant Apply the rules for handling significant figures in calculations
			Distinguish between initial concentrations and equilibrium concentrations. Note that only equilibrium concentrations can be used when working with K. When non-equilibrium concentrations are used in the equilibrium expression, Q results
			Give the (theoretically expected) electron configuration of any given element with the Periodic Table as an aid
			The integrated rate equations for zero, first and second order reactions will be given in tests and exams. However, you must

			understand the meanings and uses of these equations, and the rest of Table 15.1 on p. 686. 2. The Arrhenius equation will also be given (equation 15.7 on p. 694). Focus on its application
	ER -	Skills and procedures are implicit and indications are given that the knowledge is less significant than other areas of knowledge	No example from the data
Learning activities The design of learning activities	ER +	Procedures for demonstrating and applying disciplinary knowledge are made explicit	Interpret all conversion factors as definitions, that is, as exact numbers When doing the exercises, focus on how a problem is approached and solved. Do not just do or try to memorise them, but place the emphasis on understanding them. All of these tutorial tests count, and contribute 20% towards your Semester Mark, as explained in the study guide. Therefore, one should be very serious about these exercises. Describe each the following terms and provide illustrative examples of each (where possible) Balance given chemical reaction equations with the inspection method
	ER -	Procedures for learning content knowledge are implicit or downplayed as not significant	No examples from the data
Assessment Explicit evaluative criteria	ER +	Explicit evaluative criteria for judging performances are explicitly provided	Calculate the mass of oxygen. Calculate the mass of water Draw the Lewis structure. Use different symbols for the valence electrons of the different atoms. Show all lone pairs and bonding electrons but **do not**[83] use dashes for bonds

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[83] Emphasis is from the original instruction

			Draw the 3-dimensional Lewis-line structure. Use lines and wedges for bonding pairs Give the **formal charge of every** atom on both the structures You should not expect to get exactly the same questions, but these exercises are indispensable for your preparation and understanding You do not have to hand in this work. However, the tutorial test is based on these exercises. 1. The activity series will always be provided 2. Acids and bases are covered in much more detail in a following theme 3. At this stage a table of reduction potentials will not be given. Thus, it will not be possible to read redox reactions simply from a table
	ER -	Evaluative criteria not explicitly stated and are not significant in judging student performances	No examples from the data

Table 15. **Translation device – ELoD: epistemic relations for curriculum documents**

SOCIAL RELATIONS (GCM 101 Study Guide)			
Theoretical concept		**Degree of emphasis on:**	**Example quotes from empirical data**
Curriculum Content - theoretical knowledge:	SR+	Emphasis placed on personal experience and opinions, and / or on student dispositions in demonstrating legitimate Chemistry knowledge	No examples found in the data
	SR-	Personal experience and opinions, and /or student dispositions are downplayed and distinguished from legitimate Chemistry knowledge	Choose the "best" of a set of resonance structures, with reference to formal charge Deduce and explain the electron pair geometry and the molecular geometry of any given simple molecule When doing the exercises, focus on how a problem is approached and solved. Do not just do or try to memorise them, but place the emphasis on understanding them
Content knowledge Procedural knowledge and skills relating to performing a task based on theoretical knowledge	SR+	Emphasis placed is on personal experience, student dispositions, and opinions when demonstrating skills for solving problems in General Chemistry	No examples found in the data
	SR-	Personal experience, student dispositions and opinions are downplayed and distinguished from legitimate Chemistry knowledge	No examples found in the data
Learning activities The design of learning or context of the learning	SR+	Individual students' preferences or interpretation of content knowledge are explicitly emphasised as determining learning	No examples found in the data

process facilitates and supports learning	SR-	Individual student’s preferences or interpretation of content knowledge are downplayed as not significant for learning	No examples found in the data
Assessment Evaluative criteria on content knowledge	SR+	Evaluation of legitimacy of content knowledge and the basis of achievement based on personal attributes and dispositions	No examples found in the data
	SR-	Evaluation of legitimacy of content knowledge downplayed and judged against shared criteria external to content knowledge	No examples found in the data

Table 16. Translation device – ELoD: Social relations for curriculum documents

8.4 Assessment practices in General Chemistry

Although assessment was not the central focus of this study, I thought it necessary to include a brief discussion on the relevance of assessment in the curriculum. I use the term ‘assessment’ to mean the evaluation of students’ understanding of knowledge practices in the intended curriculum. As part of exploring meaningful learning, Ramsden (2003) noted the importance of alignment in the curriculum design. This means that the module outcomes are aligned with the evaluative criteria and the different assessment tools used in a module. According to Ramsden, assessment signifies the actual curriculum for students. Sirhan (2007) supports the view that the nature and form of assessment should be aligned to the module’s objectives to promote meaningful learning and conceptual understanding.

The assessment materials that were analysed were both[84] the examination papers for the June examinations of 2013 since the bulk of the analysis focused on the first semester module, General Chemistry module 101. Furthermore, it is in this module where I needed to attain understanding of how the knowledge practices enabled or constrained student learning. The purpose for undertaking an enquiry on the knowledge practices in this module was largely influenced by the need to understand why learning posed a challenge for some students and to explore, what it was in the way that the curriculum was structured that enabled or constrained student learning. The key question used in the inquiry with regard to assessment concerned the explicitness of the evaluative criteria. I asked: What counts as legitimate knowledge in this module? Are the evaluative rules evident in the assessment tasks congruent with the legitimation code of the subject?

The examination papers for both modules were divided into two sections: Section A consisted of questions requiring problem solving, and the application of disciplinary knowledge; Section B was composed of multiple-choice questions requiring recall of disciplinary knowledge and simple problem-solving activities. Both sections were equally weighted. The use of multiple-choice questions as an assessment method is fairly common in first-year General Chemistry 101 for several reasons, one of them being the large student numbers. The rationale was therefore practical and not

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[84] The examination paper is composed of two parts, as explained later in this discussion.

pedagogical. Johnstone (2006) notes that this form of assessment avoids data-loaded questions; however, he questions the efficacy of multiple-choice questions for evaluating conceptual learning, which is a key intended outcome of learning in the subject.

8.4.1 The nature of specialisation in the assessed curriculum

8.4.1.1 Realising epistemic relations

The indicator that was used for identifying data reflecting stronger epistemic relations related to the explicitness of evaluative criteria for judging student attainment. For weaker epistemic relations, the indicator referred to the evaluative criteria not being explicitly stated in judging student performance. The aim of this analysis was to ascertain the coherence of practices between the intended curriculum and the assessed curriculum. The questions posed in the examination papers signified the knowledge that was valued in General Chemistry. The organising principles of knowledge valued in examination papers were identified and analysed. By so doing I was able to make inferences about the facilitation of epistemological access to this knowledge[85]. The following section provides an analysis of the assessed curriculum.

In Section A of the examination paper, the evaluative criteria were very explicit in several respects. Throughout the paper, certain words were underlined and in some instances, these words were in bold, drawing attention to what was expected as a response from the student for example:

> Give the **formal charge of every** atom on both the structures. (June examination 2013)

In analysing the assessment tasks, my focus was on the extent to which the kind of learning and knowledge that had to be displayed, i.e. the evaluative criteria, were made explicit. The evaluative criteria refer to the evaluation rules used when making judgements about student achievement in a particular task (Shalem and Slonimsky p. 762) (See Table 7). In the following example from an examination paper, the

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[85] See the discussion on the research methodology in Chapter 6 Section 6.6.1 concerning the development of the translation device for analysing the examination paper.

evaluative criteria were explicit about what would count as a valid response to this question. Note that the focus was on strong epistemic relations (ER+):

> Draw the Lewis structure. Use different symbols for the valence electrons of the different atoms. Show all lone pairs and bonding electrons but **do not** use dashes for bonds.

In a sub-question to the one above, some words were underlined, but no words were emboldened, as in the example below,

> Use lines and wedges for bonding pairs. Show all bonding pairs and all bonding angles. (June examination 2013)

The instruction from the examination paper quoted above suggests that emphasis was placed on procedures and the application of the rules. It was not clear whether there would be punitive measures if the students did indicate bonds with dashes.

The tasks embodied a knowledge code exemplified by the application of the knowledge. Students were asked to indicate the steps taken to reach the answer. The procedures for working through the calculation were important for assigning marks, as demonstrated by the excerpt from the examination paper above.

In sum, it is therefore evident from the data that the assessment privileged strong epistemic relations (ER+). The evaluative rules were made clear for students. The use of bold, underlined instructions in the examination paper was not evident in any other curriculum documents. The study guide did not provide details of the evaluative rules for General Chemistry. It was possible that relevant textual markers were included in the tutorials but, from a curriculum design perspective, I was unable to determine whether the same level of explicitness was evident in the formal assessments given during the semester. It was difficult to establish whether this practice occurred throughout the year since I was not granted permission to analyse the formal formative assessment materials.

8.4.1.2 Realising social relations

For analysing the social relations evident in the examination questions, the indicators referred to the explicit emphasis on student preferences, dispositions, attributes, and opinions or choice in relation to the form that the responses to the questions would take to demonstrate knowledge acquisition (SR+). In addition, weak social relations (SR-)

would be signified if student dispositions, attributes, and opinions or choice were downplayed as important for being a legitimate knower of Chemistry.

For weaker social relations, the indicators denoted little or no emphasis on individual students' preferences as significant in shaping the forms of knowledge. It was interesting to note that, in the examination paper, there was little evidence of strengthening of the social relations. In the example below taken from Section B of the examination paper, the student was required to motivate their responses as follows:

> 3.1.2 Which statement applies to this system at time *t*?
>
> A. The forward rate is faster than the reverse rate
>
> B. The reverse rate is faster than the forward rate
>
> C. The forward and reverse rates are equal.
>
> Motivate your answer (June examination 2013)

Although the student was asked to argue for their response to the question, the basis of the student's argument had to be grounded in theoretical knowledge and not on the student's disposition, opinion, or on the student preferences. This single example does not explicitly demonstrate emphasis on stronger social relations but shows an inclination for strengthening social relations by affording the student space to think about the answer and to respond using their knowledge. Therefore, on a continuum of strengths, the example seemingly indicated an inclination towards strengthening social relations (SR↑); however, this was not so. The requirement for the student to motivate their response had to be grounded in specific theoretical content. There were no identifiable examples in the data indicating student choice or interpretation of procedures or skills as legitimate in General Chemistry. Therefore, the assessment category exhibited weak social relations (SR-).

One respondent was of the view that the inclusion of multiple-choice questions in Section B of the examination paper was not ideal instrument for assessing student knowledge in the discipline. Moreover, the respondent regarded designing the multiple-choice questions as a challenge and s/he thought that students tended to perform poorly in this form of assessment:

> Setting multiple-choice questions (MCQs) is quite tricky. That's where we feel we hope we use our knowledge of common misconceptions and some of the distractors in the questions are always common misconceptions. Students tend to find MCQs more difficult. I don't think that we make them more difficult because they are suddenly faced with an answer. Something else, is the technique of answering (Respondent 2).

The respondent's view further strengthens the argument that multiple-choice assessment evinces strong epistemic relations in the General Chemistry. Although the students were required to motivate, deduce, and support their responses, the responses had to be based on specific theoretical knowledge.

Past examination papers were made available to students to help them prepare for the examinations. The papers usually included an answer for each question. It could be argued that this practice was contrary to a focus on getting students to develop their problem-solving abilities in the subject. The process of arriving at the answer was not shared with the students as part of feedback process. I would argue that it was important, from a curriculum design for learning perspective, that the realisation rules be made explicit, especially at the beginning of the semester. In terms of the type of questions for assessing conceptual learning, Hudson and Treagust (2013) suggest that open-ended questions were more appropriate for achieving this outcome. They explain that open-ended questions expose the process and methodology followed by the student in producing the answer, thus allowing the assessor to glean the students' thinking process for solving the problem.

8.5. The knowledge code in the curriculum

As discussed previously, Maton (2014) states that stronger epistemic relations (ER+) generate a knowledge code (ER+, SR-) where the basis of legitimation is knowledge and the procedures that are specialised to the object of study. The knowledge code makes clear distinctions between the field's object of study and other objects. The code also exhibits relatively strong classification (C+) and strong framing (F+) where there is strong control over the pacing, sequencing, and evaluation rules of content knowledge as evinced in the discussion in Chapter 7. As a knowledge field, General Chemistry exhibits a knowledge code depicted in the diagram below (Figure 19). When represented on the epistemic plane, the knowledge code is located in the upper left-hand quadrant where the epistemic relations are strong and the social relations are weak.

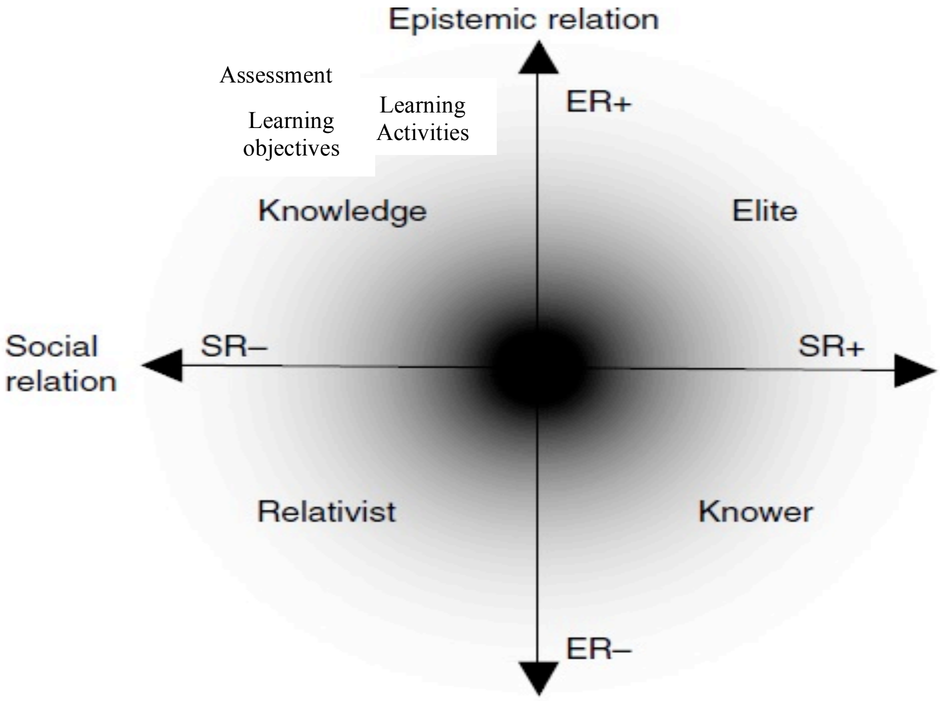

Figure 19. Knowledge code for General Chemistry

Figure 19 above is a representation of the strengths of epistemic and social relations exhibited in the learning objectives, the learning activities, and the assessment tasks for General Chemistry. Maton (2014) argues that a knowledge code is legitimated by an orientation to highly specialised knowledge that is strongly bounded and controlled. In a knowledge code, the specialised knowledge is characterised by specific rules, criteria, and procedures for performance by actors in the field. The focus and emphasis of knowledge claims is on the object of study that dictates legitimate knowledge, and ways of knowing in the field.

A knowledge code downplays the individual's dispositions, attitudes, and beliefs while privileging knowledge, principles, procedures, and practices. Therefore, knowledge practices that generate epistemic relations may be specialised by both *what* practices relate to and *how* they relate to practices (p. 175).

Explaining the type of knowledge in the subject, Respondent 3 noted:

> At first-year level, we need to integrate, for example, *algebra and some Maths*[86] with *observations in the lab – say colour changes*, *quantities, masses, and volumes of gases*, how do they relay? What happens if you heat a substance? How do I have *a model* that has to enter his mind - that the gases are on a miniature scale, are like a couple of billion balls bouncing against each other. And that is the model that has to enter his mind. He has to be convinced that this is a picture that he cannot observe with his eyes. They need to have an abstract way of thinking, seeing and getting familiar with things that they cannot see but can measure the bulk of. If you see a gas expanding if you heat it up, he's got to have it in his mind something, why does it do that?

The above extract not only provided evidence of stronger epistemic relations, but also pointed to the three levels of Chemistry knowledge, namely, the macro, sub-micro, and the symbolic levels.

Since stronger epistemic relations combined with weaker social relations generate a knowledge code (ER+, SR-) as suggested by Maton (2007, 2014), the ideal knower in General Chemistry is one who possesses specialised knowledge of the concepts, theories, principles, skills, and procedures valued as legitimate knowledge in the discipline. Mostly, a knowledge code would be demonstrated by the possession of chemical thinking which is described by Seviana and Talanquer (2014) as knowledge of and skills in disciplinary core practices of analysis, synthesis, and transformation. However, the *knower's attributes* and dispositions are not regarded as premium for knowledge acquisition within a knowledge code.

Above I have described how General Chemistry exhibited strong epistemic relations and weak social relations (ER+, SR-), thus rendering a knowledge code. However, having identified the code, more questions about the nature of the epistemic relations and the kind of knower and knowing that the curriculum is cultivating was evoked. Of interest were the implications for epistemological access for the student exposed to the curriculum with a distinct knowledge code. Maton (2013) contends that knowledge-building depends on the particular modalities of epistemic relations. He proposes the conceptualisation of the differences within epistemic relations as generating *insights,* and those from social relations generating *gazes*. Therefore, after having identified the knowledge that counts as legitimate in the curriculum I also considered it important to

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[86] Own emphasis to indicate the distinctions made between the levels of Chemistry knowledge that are required simultaneously. Refer to Chapter 2 for an outline of the nature of Chemistry knowledge.

identify *the knower* as displayed through the data. The following section is an exposition of the kind of knower privileged in this context.

8.6 Insights and the ideal knower in General Chemistry

Within the knowledge code, Maton analytically distinguishes between two forms of relations, namely, *ontic relations* (relations between practices and the part of the world to which they are oriented; that is, the focus is inward looking on the object of study) and *discursive relations* (relations between practices and other practices; that is, the focus is outward looking on the object of study). As discussed in Chapter 4, variations in epistemic relations can be represented on the epistemic plane using four main insights, namely, situational, doctrinal, purist and knower, or no insight, as illustrated below.

As the discussion above shows, the learning activities, the notes, and the examination papers all indicate strong epistemic relations and a *trained gaze.* The *trained gaze* emerges from extensive exposure usually in a formal learning setting where knower identity is developed in an intellectual field with a knowledge code. An individual is trained in specialised knowledge, principles, and procedures (Maton 2014; p. 95). The focus of the learning is always on the object of study and not on the characteristics of the knower. The analysed examples drawn from the data demonstrate how the knowledge practices bound and control both the legitimate object of study and the approaches to studying the object. Therefore, the ideal knower produced by the General Chemistry curriculum is one who should possess specialised knowledge, and the procedures for attaining and expressing legitimate knowledge. "One must use a specific approach to study a specific phenomenon" (Maton 2014: p. 176). Such insight generates a purist modality where knowledge practices privilege both the object of study and how it is studied, for example in Chemistry.

A *purist insight* (OR+, DR+) implies that the ideal General Chemistry knower should demonstrate both the *what* of knowledge and the *how* of knowledge. Great value is placed on the knowledge domain of the field, but also on the specialised procedures and skills associated with acquiring the knowledge. The message about the knower being cultivated is in evidence from the intended curriculum right to the assessed curriculum. For example, in all the learning units students are directed towards particular steps and procedures that must be followed in the problem-solving process:

> The use of your molecular model set is recommended to build models of molecules. In this way, molecular geometries are easily observed. The normal procedure is first to draw the Lewis structure of a molecule, and then to build the model (GCM 101 study guide).

> When doing the exercises, focus on how a problem is approached and solved. Do not just do or try to memorise them, but place the emphasis on understanding them (GCM 101 study guide).

The above examples indicate that the emphasis is placed on both the *what* of knowledge (theoretical knowledge) and the *how* of knowledge (procedural knowledge). Having both the knowledge of the 'know-what' and the 'know-how' is necessary as a basis for achievement in General Chemistry at the LSAU. The *purist insight* confirms that, in learning General Chemistry, both theoretical and procedural knowledge are valued.

The assessed curriculum when plotted on the epistemic plane exhibits a *purist insight* as indicated in the figure below.

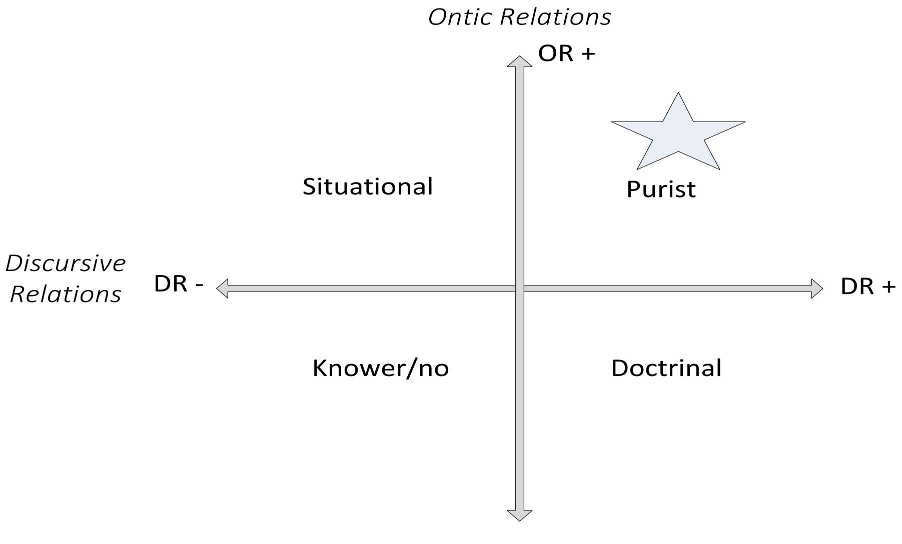

Figure 20. Insights as evidenced in the curriculum documentation

The analysis of the various notes and instructions related to the learning activities and the assessment indicate the value placed on knowing what and knowing how of the discipline. The development of a *purist insight* in General Chemistry curriculum at LSAU, as demonstrated by the data, implies that social relations are not valued.

Drawing from the literature on General Chemistry learning, there are several suggestions about the ideal knower and the form of knowledge that should be significant [87] in a Chemistry curriculum. Both conceptual (the *what* of knowledge) and the *how* of procedural knowledge are highly valued in this context. Furthermore, the epistemological orientation in General Chemistry favours constructivist approaches in the form of cognitive theories for curriculum development and student learning. Several proponents of constructivist approaches in General Chemistry argue for the development of a certain kind of knower in the field. For example, another key objective in the General Chemistry curriculum besides academic development is to guide the student towards developing particular ways of thinking and ways of practising in the discipline (Talanquer and Pollard 2010; Potgieter 2010, Johnstone 2000). Perkins (2008) contends that a mind-set is not concerned with what people *are able* to do but with what they are *inclined* to do. He suggests that a mind-set is associated with a particular way of thinking and disciplinary practice such as displaying a positive attitude. The development of a Chemistry mind-set requires the acknowledgement of the social in the acquisition of knowledge.

Given the above ideas, it can be argued that knowing and being the ideal knower in General Chemistry means adopting a certain disposition and mind-set, thus including social relations as part of knowing, and therefore, what should be explicitly valued and taught. As the data have indicated, there was a lack of evidence that certain dispositions, attitudes, and values other than those linked to epistemic growth were being developed. As such, the development of a curriculum that solely focuses on epistemic gains ignores the social relations of knowledge to be developed through learning. For epistemological access, providing education that places a premium on the epistemic relations of knowledge and does not incorporate the development of the social relations of knowledge perpetuates the conundrum of the notion that what is studied is the knowledge of the powerful instead of developing appreciation of powerful knowledge per se. A focus on the former, would have implications for social inclusion in the curriculum and students' ability to participate in and shape society's conversations

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[87] See the discussion in Chapter 2 on the approaches to learning in General Chemistry.

about itself (Wheelahan 2010). Given that one of the intentions of the study was to contribute to an understanding of social inclusion in higher education in South Africa and to inform curriculum practices for enhanced epistemological access, the lack of inclusion of social relations in the curriculum should be a concern.

8.7 Summary

In this chapter I discussed my analysis of the organising principles of the General Chemistry curriculum using the analytical tools offered by LCT: Specialisation. I discussed the implications of the knowledge code generated by the analysis of curriculum documents and the inferences that can be made from the dominant relations evident in the knowledge practices.

Generally, Chemistry knowledge is characterised by cognitively complex propositions and abstractions, and the curriculum of General Chemistry is no different. Chemistry knowledge evinces a knowledge code with a *trained gaze*. Given the need to create epistemological access for more students, a cognitively demanding field such as General Chemistry requires the development of a curriculum that, through decisions about the selection, sequencing, pacing and assessment structure create the conditions for access to the knowledge of the field. The curriculum aims to clearly point out the rules of the game, but the state at which the player finds herself is neglected, thus excluding some students. As previously mentioned in Chapter 7 (see Section 7.5), the lack of prior knowledge from high school further disadvantages the student from gaining epistemological access.

Through the conceptualisation of *gazes* and *insights* it was possible to establish that the ideal knower in this discipline possesses a *purist insight*, that is, the knower should possess knowledge of both the knowledge content that should be studied and how the knowledge should be studied. This is evidenced through the formulation of the many notes and instructions to students included in various curriculum documents. Given the difficulties that have been identified that students have in general sciences, the formation of a *purist insight* by the curriculum at an introductory level without a proper knowledge base in the discipline has the potential to exclude some.

In conclusion, I argued that there are two matters arising from the data in relation to curriculum practices. As discussed earlier in the chapter, data from the interviews with respondents suggested an expectation that the incoming student possessed certain dispositions in order to be successful in the module. When I considered the interview and the data presenting the respondents' conceptions of the student, it seemed as if legitimacy in the subject was based on both the possession of specialist knowledge and the possession of the appropriate knower attributes. Framing legitimation in the field of General Chemistry in this way points to the curriculum needing to cultivate and value the expected knower dispositions. This move was not evident in the curriculum documentation I analysed for this project. The differences in the specialisation code emanating from the curriculum documents (knowledge code) and from the interview (a strengthening of knower attributes) indicated a code clash between the recontextualising agents' expectations and the evaluative rules evident in the curriculum. The respondents demonstrated awareness of the rules for playing the General Chemistry game but these have not been made sufficiently apparent in the curriculum, except to a limited extent in the notes and instructions provided. There was limited effort to address the dispositions and attitudes required of the ideal General Chemistry knower (social relations) through the knowledge practices inhering in the intended curriculum.

The curriculum seemed to ignore the formation of the General Chemistry knower by absenting social relations. Given the design of the curriculum at the time of the study, the student who was most likely to succeed was the student that was already able to learn the highly abstract knowledge, and who was also able to apply the methods and techniques for solving problems at the micro, the sub-micro and the symbolic levels. The respondents were aware of the challenges presented by the high school Chemistry curriculum for learning first-year Chemistry. The data pointed to the need for the first-year General Chemistry curriculum to provide opportunities for strengthening social relations to facilitate students' acquisition of the *trained gaze*.

CHAPTER 9 - Analysis of the organising principles - LCT: Semantics

Cumulative knowledge-building in research, teaching and learning are at the heart of education (Maton 2013, p. 8).

9.1 Introduction

In this chapter I address how the structuring of the curriculum contributes to knowledge-building and cumulative learning by analysing the inner logic of the curriculum. Foundational modules serve as building blocks for further learning in the different science degree programmes in the LSAU, and it is therefore necessary to address how the curriculum facilitates the cumulative development of disciplinary knowledge. It is necessary to understand the organising principles of the General Chemistry curriculum that require progression in acquiring knowledge and it is also relevant for a fine-grained analysis of organising principles to uncover the properties that enable or constrain knowledge-building and cumulative learning for effective student learning. There is a need for disciplines with high levels of verticality, such as General Chemistry, to demonstrate the application of the recontextualisation principle through careful sequencing, alignment, coherence, and articulation when constructing the curriculum (Muller 2005, 2009).

As a means of conceptualising the knowledge practices inherent in the curriculum, I used LCT: Semantics since it offers an "additional level of conceptual/ analytical delicacy" (Maton 2016; p. 235) to uncover a further set of organising principles in order to explain the form taken by knowledge and the knowledge-building practices in General Chemistry. The next section provides an analysis of exercises and a discussion on the analysis process undertaken for uncovering the semantic codes. Through this analysis, I wanted to ascertain to what extent and in what ways the first semester curriculum exhibited the potential for cumulative learning, with a particular focus on some exercises given to students.

9.2 Cumulative knowledge-building

Chemistry has a hierarchical knowledge structure characterised by explicit and coherent knowledge development, therefore the curriculum structure demonstrates features of hierarchical knowledge-building over a certain period (Bernstein 2000). In Chapter 8, I demonstrated that the organising principles of LCT: Specialisation in the General

Chemistry curriculum exhibit a knowledge code. Maton (2009, 2014) asserts that the primary basis for legitimacy in an intellectual field that has a knowledge code is the possession of an explicit set of principles, skills, and procedures that enable knowledge-building. In agreement with Bernstein, Maton further contends that knowledge-building depends on the knowledge structure and the curriculum structure and the forms of learning that they make possible.

A feature of cumulative learning and knowledge-building is the ability to understand and work with knowledge that is highly abstract and theoretical, that evinces the organising (structuring) principles of degrees or variances in context dependence, and condensation of meanings into concepts and symbols. Maton argues that the knowledge structure of a discipline tends to give rise to either cumulative or segmented learning. Cumulative learning depends on knowledge that evinces weaker semantic gravity and stronger semantic density (SG-, SD+) while segmented learning where the transfer of meaning between contexts is constrained is characterised by stronger semantic gravity and weaker semantic density (SG+, SD-). In the following section I present an analysis of the data on the learning activities using the lens of LCT: Semantics to explain how the structuring of the General Chemistry curriculum may enable or constrain cumulative learning as required by the discipline. An understanding of the cumulative knowledge-building properties of learning activities, as found in the curriculum, is important for understanding how the organising principles in the exercises over time allowed or constrained epistemological access.

9.3 LCT: Semantics - analysing the learning exercises

In the first-year General Chemistry modules, the learning tasks are given to students in the form of exercises, with the majority of these being from the prescribed textbook. I analysed the learning exercises that were selected for the first semester of the Introductory General Chemistry module. The exercises represent learning activities for each theme in the curriculum, therefore representing learning over a specific time period. The number of exercises varied between the topics in the curriculum. Some exercises were also placed on the LMS and students were encouraged to work through them before seeking assistance from a tutor. The exercises derived from the prescribed textbook were not part of the analysis[88], only the exercises in the study guide were analysed.

The exercises chosen and developed by the curriculum designers shed light on what forms of knowledge were valued in General Chemistry. I thought it necessary to analyse the learning tasks because of the constant emphasis on the need to practice exercises in order to develop knowledge[89]. The intention of the analysis was to understand the level of complexity of the tasks and to examine in what ways the tasks enabled knowledge-building and cumulative learning over time. The inclusion of the exercises as part of the analysis further illuminated the 'what' of knowledge in the General Chemistry curriculum.

9.3.1 Mapping the semantic plane

I began with examples of exercises taken from Week I and followed these up with discussion of an example taken from later in the semester. Examples 1–3 below are taken from Theme 1 dealing with units of measurement (Matter and Measurement) in the GCM 101 study guide, and were some of the first given to students to solve in the first semester. The first example is an exercise that required problem solving by calculating the mass of sodium fluoride to be added to the water as follows:

> Exercise 1:
>
> The fluoridation of city water supplies has been practised for several decades. This is done by continuously adding sodium fluoride to water as it comes from a reservoir. Assume you live in a medium-sized city of 150 000 people and that 660 ℓ of water is consumed per person per day.
>
> What mass of sodium fluoride (NaF) (in kilograms) must be added to the water supply each year (365 days) to have the required fluoride concentration of 1 ppm (part per million), that is, 1 kg of fluoride (F–) per million kilograms of water? (Sodium fluoride is 45.2% fluoride, and water has a density of 1.00 g/cm^3).

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[88] See Chapter 7, Section 7.3.2.4 for a discussion of the self-evaluation exercises taken from the prescribed textbook.

[89] Practice refers to consistently working on exercises and solving problems. The practice attained from working in the laboratory is not included in this study.

The second example on Matter and Measurement taken from Theme 1 required students to calculate the mass of the acid as follows:

> Exercise 2:
> Car batteries are filled with sulphuric acid.
> What is the mass of the acid (in grams) in 500 ml of the battery acid solution if the density of the solution is 1.285 g/cm^3 and if the solution is 38.08 % sulphuric acid by mass?

The exercise used a concrete example of a battery which was assumed to be a familiar object, although some students might be more familiar with a cell phone battery than with a car battery, but the concept of a battery and what it does was known to the student. In order for the student to calculate the mass of the acid, the student was required to engage at the macroscopic level (car batteries, which is a concrete example) and also at the sub-microscopic (mass of the acid, which is an abstract concept – perceived with the aid of an instrument).

In examples 1 and 2, everyday vocabulary and knowledge were used before conceptual (theoretical) knowledge about the concepts of matter and measurement were introduced, thus indicating strengthening of semantic gravity (SG+). However, the tasks themselves were less context independent, denoting more abstract content requiring procedural knowledge and mathematical knowledge to solve the calculation (SD-). The code thus generated by these exercises was a *prosaic code* (SG+, SD-).

The calculations in the exercise involved the application of procedural knowledge represented through appropriate symbols. On the semantic plane, the procedural knowledge necessary to solve the problem thus generated a *rhizomatic code* (SG-, SD+). Basically, being able to calculate mass in examples 1 and 2 required the application of algorithmic knowledge (microscopic level) to solve the problem that was presented at the macroscopic level. However, the actual calculation required the weakening of semantic gravity and the strengthening of semantic density (SG↓, SD↑), where the student was required to apply abstract principles in the process of solving the problem.

The third example, taken from Theme 1, used an historical experiment to frame an exercise about surface Chemistry. The student was required to calculate the thickness of the film of oil in the water as follows:

> Exercise 3:
>
> About two centuries ago, Benjamin Franklin showed that 1 teaspoon of oil would cover about 0.5 acre of still water. If you know that 1.0 x 104 m^2 = 2.47 acres, and that there are approximately 5 cm^3 in a teaspoon, what is the thickness of the layer of oil? Give the answer in nanometres. How might this thickness be related to the size of the oil molecules?

For Exercise 3, both the conceptual knowledge and procedural knowledge necessary to solve the problem were less context dependent in terms of the example that was used that students may not relate to especially if they have no knowledge of American history. The calculation also requiring the application of abstract knowledge and skills. Although a real-world example was used, the terms were not common knowledge, thus displaying a combination of both weaker semantic gravity and stronger semantic density (SG-, SD+) for both conceptual (theoretical) and procedural knowledge, and generating a rarefied code for the whole exercise.

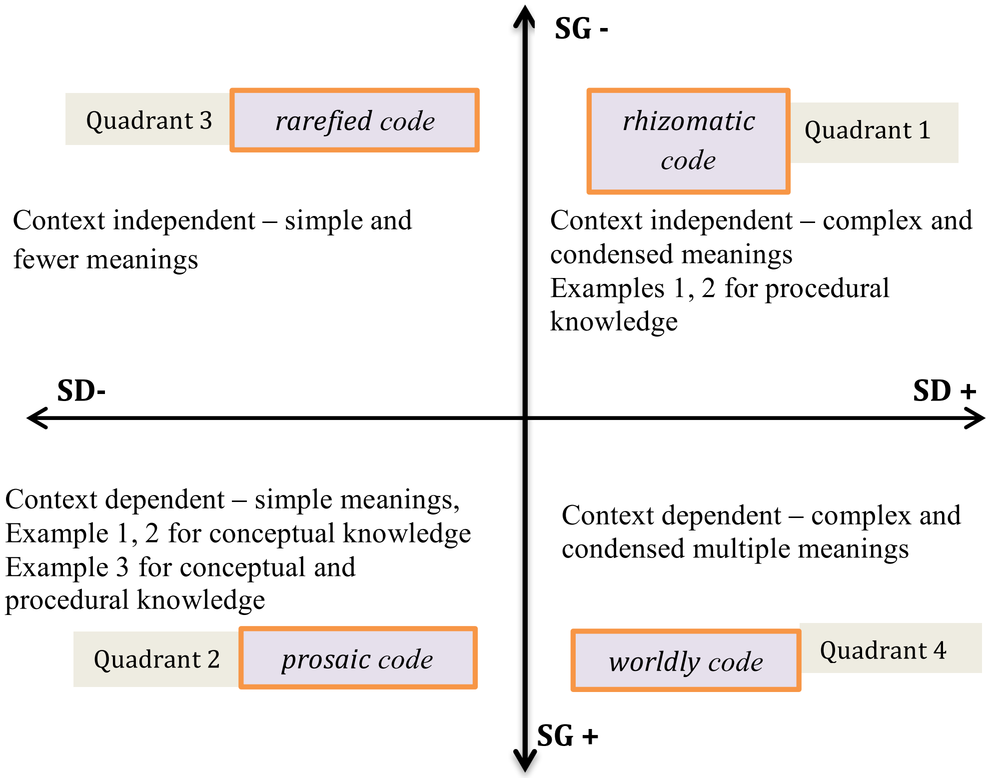

Figure 21. Plotting the learning activities on the semantic plane (See Maton 2016, p. 16)

In terms of LCT: Semantics, when the Exercises 1, 2 and 3 were plotted on the semantic plane they were placed in quadrant 2[90] as they required engagement with conceptual knowledge (Figure 21). The exercises included everyday knowledge (practical, everyday knowledge[91]) as well as procedural knowledge. This was because the exercises contained real-world examples expressed in common vocabulary, expressing everyday meaning. All three exercises used examples that were strongly related to the everyday contexts that the students had knowledge of, that is, drinking water, a car battery, and oil (macroscopic level). A common thread for General Chemistry is that these examples typically require attention to all three levels of Chemistry knowledge: the macroscopic, the microscopic and the symbolic/ representation levels.

Therefore, within the first two weeks of the semester, the exercises appear to be straddling the *prosaic code* and *rhizomatic codes,* meaning that the content of the learning activities includes conceptual knowledge blended with everyday practical knowledge *(prosaic code)* and theoretical knowledge *(rhizomatic code),* which privilege scientific concepts. The implications for learning are that, although the principles for learning and gaining knowledge are derived from practice, theoretical understanding is required for the practical application of the theory to solve the problem. Simply, in the General Chemistry curriculum there was an emphasis on content knowledge based applying theoretical knowledge in procedural applications.

The everyday words have specialised meanings in Chemistry, thus posing a barrier for learning. Language use[92] in Chemistry is regarded as a serious challenge to student learning in the field. The language in the exercises was accessible and students were likely to relate to the first two examples; however, in the third example even though the information is simple, the reference to an historical American figure used with American terminology has less meaning for the student in South Africa. The fact that Exercise 3 uses context-dependent information poses a further constraint to learning,

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[90] The numbering of the quadrants follows Maton's ordering of the descriptions of the semantic codes in Maton 2016; p. 16.

[91] Shay (2012) cites Friedson 2001 who classifies practical knowledge as "knowledge that is largely free of formal concepts and theories, learned by experience and instrumental for performing concrete tasks in concrete settings" (p. 7).

[92] See also Gabel (1999), Mbajiorgu and Reid (2006), Sirhan (2007) and Blackie (2010).

especially in the introductory stages, because the likelihood of the student knowing the information is reduced.

As the semester progresses the tasks become less context dependent and more abstract, as indicated in the following example of an exercise given in Week 4, Theme 4 on the topic: Chemical Reactions, Equations and Stoichiometry:

Exercise 4

Chromium exists as four natural isotopes with the following properties:

Natural Isotope	Relative Atomic Mass	Percent Natural Abundance
^{50}Cr u	49.9461u	?
^{52}Cr	51.9405 u	83.79%
^{53}Cr	52.9407 u	?
^{54}Cr	53.9389 u	2.36%

Calculate the natural abundances of chromium-50 and chromium-53.

Hints: Use the average relative atomic mass of chromium from the Periodic Table for the calculation. To check your answers, repeat the calculation with the abundances to get the correct average relative atomic mass of chromium.

Exercise 5

Aluminium hydroxide reacts with sulphuric acid in the following way:
$2Al(OH)_3 + 3H_2SO_4 \rightarrow Al_2(SO4)_3 + 6H_2O$
The following quantities of the two reactants are mixed and allowed to react. For each of the cases 2.1 to 2.5, calculate:
a. Which one is the limiting reactant?
b. What mass of which reactant remains unreacted:
2.1 50.0 g $Al(OH)_3$ 50.0 g H_2SO_4 [H_2SO_4; 23.5 g $Al(OH)_3$]
2.2 30.0 g $Al(OH)_3$ 50.0 g H_2SO_4 [H_2SO_4; 3.5 g $Al(OH)_3$]
2.3 30.0 g $Al(OH)_3$ 60.0 g H_2SO_4 [$Al(OH)_3$; 3.4 g $H2SO_4$]
2.4 156.7 g $Al(OH)_3$ 263.7 g H_2SO_4 [H_2SO_4; 16.9 g $Al(OH)_3$]
2.5 263.7 g $Al(OH)_3$ 156.7 g H_2SO_4 [H_2SO_4; 180.6 g $Al(OH)_3$]

Note: In each of these cases the reactants are exactly enough for each other. These are called stoichiometric quantities. In such cases, nothing of the reactants themselves remains after the reaction. Each of them reacts completely. (Theme 4: Chemical Reactions, Equations and Stoichiometry)

Here the student is expected to solve a highly abstract and complex problem with no reference to context, thus all the meanings are highly condensed. Guidance on what is expected is offered. Exercises 4 and 5 are composed of context-independent knowledge which is also represented by symbols, meaning that the Chemistry knowledge evinces weaker semantic gravity and stronger sematic density (SG-, SD+). These exercises can be located in quadrant 1 in the diagram below (Figure 22); they contain complex theoretical knowledge. Quadrant 1 generates a *rhizomatic code* as indicated in Figure 22 below.

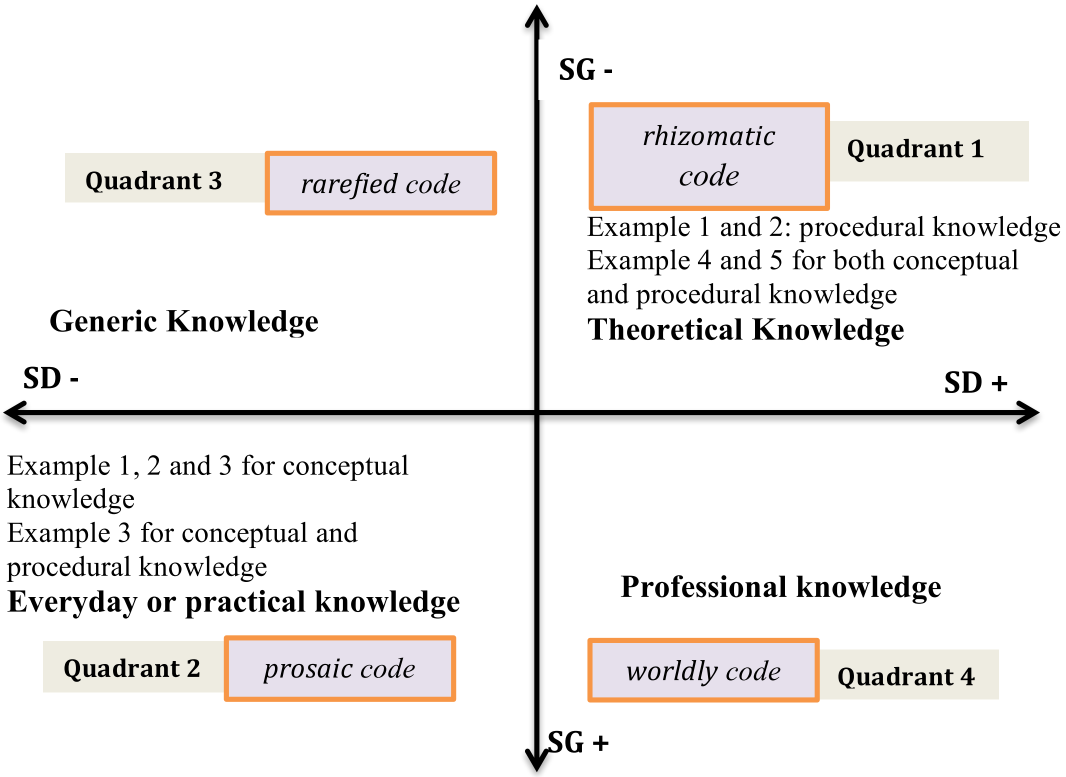

Figure 22. The semantic plane in the learning activities Maton 2016: p. 16 (Knowledge categories from Shay 2012)

In sum, the learning activities presented exhibit different codes. Exercises 1 and 2 appear to be straddling two codes: the *prosaic code* (the basis of legitimation /principles are derived from practical knowledge) and the *rhizomatic code* (the basis of legitimation /principles are derived from theoretical knowledge from the discipline). For Exercise 3 the conceptual and procedural knowledge evince the *prosaic code.* Exercises 4 and 5 are both located in quadrant 1, evincing a *rhizomatic code*. From the analysed examples 1–5, the data demonstrate that there are *code shifts* in the learning activities. A code shift implies a change in code within the semantic plane (Maton 2016) with changes from *prosaic code* to *rhizomatic code*. Such a change in the code denotes a change in the complexity of the knowledge that is required for learning over a certain time.

To recap, one of the subquestions of this study led me to examine how the structuring of the curriculum contributes to epistemological access and cumulative knowledge-building and learning. I analysed the structure of the module by plotting the exercises on the semantic plane, and in so doing identified where the initial topics in the curriculum were located and whether the timing of topics enabled or constrained learning.

I did not investigate the extent to which the variations in semantic gravity enabled or constrained cumulative learning.[93] This can be regarded as a limitation of this study.[94] My analysis shows that the examples provided are likely students to make it difficult for students to access knowledge early on in the course – not only because of the nature of the knowledge of General Chemistry but because of how the curriculum is structured. This is because for successful and meaningful learning to occur, students should have sufficient prior knowledge upon which to anchor new ideas (Anderson and Schonborn 2008).

The objective for student learning in the subject is twofold: first, the design of the learning activities should facilitate access to theoretical knowledge through the learning of abstract and complex scientific knowledge; second, facilitation of epistemological access to this knowledge. Similarly, as part of improving epistemological access in the subject, the choices of learning activities should support the gradual progression of exercises from those which are predominantly context dependent with relatively simple meanings, to exercises that are context independent with more complex meanings.

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[93] I am aware that it would be useful to undertake an analysis of the extent of variation of semantic gravity *within* each of the learning exercises. Such an analysis would require the development of an ELoD for semantic gravity. However, the focus of my analysis was the exercises *across* the learning units. My analysis shows that there is a straddling of codes across the problems and that the problems evinced the codes, SG+, SD- for conceptual knowledge and SG-, SD+ for procedural knowledge. I examined the level of complexity of the exercises and the degree to which they are context dependent or context independent. In particular, I considered what it would require to solve the problems from the perspective a new student in the field.

[94] See Section 10.5 on the limitations of the study and the development of a translation device for semantic gravity.

In principle, I would argue that the change in code is aligned with the type of knowledge-building required in the subject. However, for the purposes of student learning, it would be important to signify the points at which semantic thresholds[95], (that is, the point at which accuracy or epistemology matters) will be crossed and at which point students will need to engage with different kinds of knowledge, or knowledge that evinces a different code, in Maton's terms.

As suggested by Shay (2012), the semantic plane of learning activities elaborates on the basis of legitimation or the different logic structuring the curriculum which influences the selection, pacing, and sequencing in the curriculum. The significance of the framing of the curriculum (Section 7.3.2), sequencing, timing, and pacing of the knowledge content in terms of the difficulty of the tasks, what is introduced at which time is a significant feature for enabling epistemological access to the subject. The timing of a move between codes is important in enabling epistemological access to General Chemistry knowledge.

The curriculum structure should signify the points at which there are changes in the kinds of knowledge that students need to engage with, whether a theoretical or procedural knowledge base, and the requirements for knowing. When lecturers are explicit that students need to work with different kinds of knowledge and what that means for the kind of thinking that they need to engage in, it is likely that students will find it easier to make connections between different concepts, theories, and procedures and that they would be able to build upon previously existing knowledge. From a curriculum design perspective, signposting the code changes and the transition of complexity is recommended for exposing the rules of the game and alerting the student to what is required and when it is required.

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[95] Maton suggests the 7-Gs rule of thumb for generating semantic profiles in Chapter 6, Section 6.6.1.3.2

9.3.2 Emergent semantic profiles

In General Chemistry, there seems to be a seamless shift between conceptual knowledge (theoretical knowledge) and procedural knowledge while also incorporating symbolic/representational knowledge. Blackie (2014) argues that Chemistry knowledge predominantly resides in the domain of abstract concepts that are less context dependent.

According to Maton (2015), for analysis purposes, the rule-of-thumb is to ask at all times of the enquiry whether each of these stages matters, and if so, how do they matter? As explained in Chapter 6, (see Section 6.6.1.3.2) Maton suggests using the 7-Gs rule-of-thumb for generating semantic profiles, as illustrated in the diagram below. Figure 23 illustrates how the semantic profile of the learning activities can be represented schematically. The semantic plane indicates a semantic range where semantic entry is represented as A, and semantic exit as B on the semantic range.

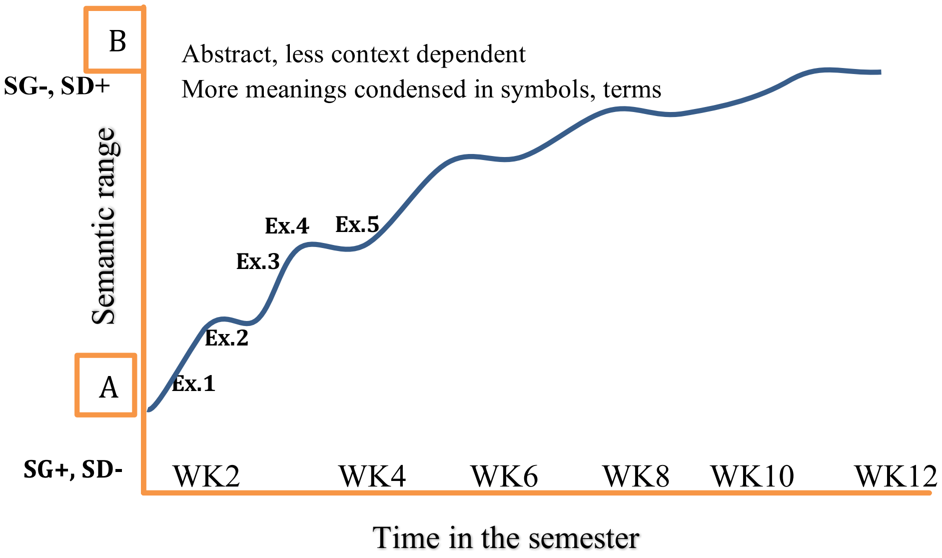

Figure 23. Semantic plane for exercises in the module

Although the semantic entry point indicated as (A) for the exercises in the first week (WK1) was initially lower on the semantic range, the exercises contained concepts that were context dependent. Common terms were used to describe an abstract concept in the theme on Matter and Measurement. As the term progressed, the exercises included more context-independent concepts with complex and condensed meanings, thus indicating an upward shift in cognitive complexity.

Semantic entry is aligned with Johnstone's (2000) suggestion that the design of the curriculum and the teaching thereof should start from the macro level (beginning with a concrete, everyday example) and build up to the micro and symbolic levels (proceeding to the abstract) at the semantic exit.

As the semester progressed, the exercises became less concrete and more abstract. Exercises 3 to 5 indicated as (B) in the diagram can be represented higher on the semantic scale and exhibit relatively weaker semantic gravity with the concepts being less context dependent. There was a sharp upward movement from exercises with stronger semantic gravity (meanings are concrete) and weaker semantic density, to exercises where semantic gravity was weaker and semantic density was stronger, thus where meanings were more abstract. The upward movement stopped when exercises showed greater abstraction and generality. An upward escalator implies that the knowledge demand increased progressively from the more contextual and simpler meanings (SG+, SD-) to the more abstract and condensed meaning (SG-, SD+) without offering students the opportunity to apply that knowledge to exercises where there was strengthening of semantic gravity and the weakening of semantic density. When students have to learn highly abstract, decontextualised knowledge, they generally find it very difficult, unless they are able to see how the knowledge relates to more concrete contexts. In Maton's terms, learning is supported with highly abstract concepts that are repackaged, and there is shift from weakening semantic gravity to strengthening semantic gravity. Maton and others (see Blackie 2014, Clarence 2014) have shown that cumulative learning is facilitated by presenting content or engaging students in exercises where there is movement up and down the semantic plane, that is, where there is strengthening and weakening semantic gravity and semantic density to create a semantic wave.

As can be seen from Exercise 3 to Exercise 5, from Week 2 to Week 4 all the exercises were of a highly abstract nature. The semantic profile of the exercises did not generate waves but generated upward escalators as indicated in the figure below. An upward escalator without complementary downward movement requires consistent engagement at an increasingly high level of abstraction and complexity, indicative of what Maton terms a high semantic flatline with no movement up or down the semantic plane as depicted in Figure 24 below.

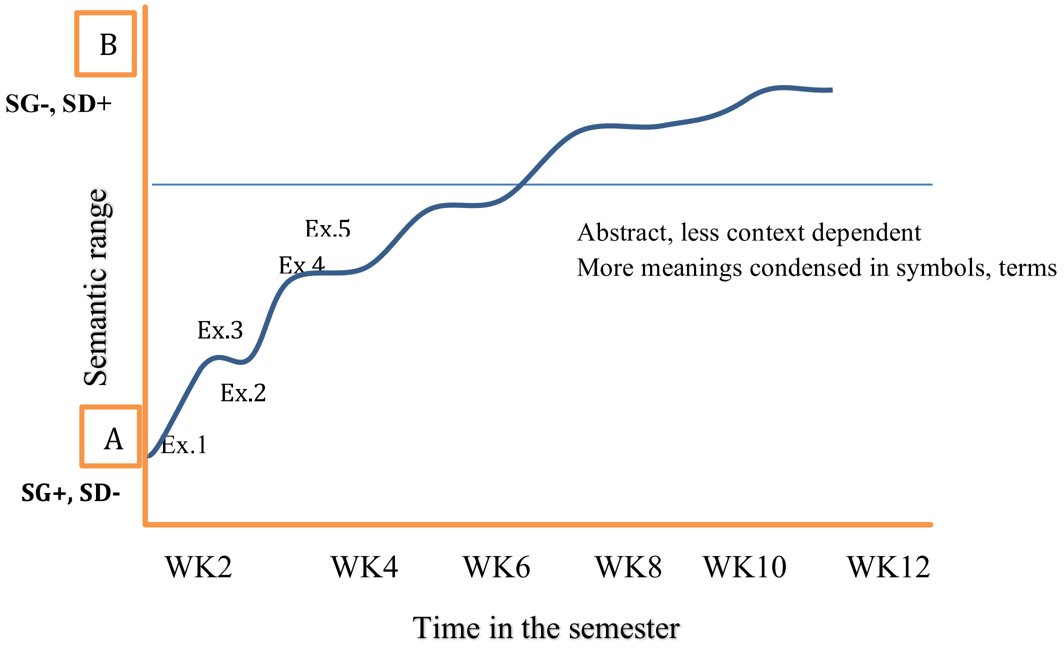

Figure 24. Semantic profile with high flatline

In a curriculum where there is a high semantic density flatline (i.e. no semantic range or movement between simple and complex, abstract and concrete knowledge) students need to acquire knowledge that is context independent and complex. It is likely that the student would find it difficult or impossible to enact or transfer this knowledge to different contexts when exposed to a continuously high flatline. A low flatline on the other hand, is indicative of learning that remains context bound with the student not being challenged or expected to integrate concept and abstract ideas in their learning. Neither of these conditions is ideal for cumulative learning.

Successive upward escalators indicate that the various exercises provided seemed to generate the same upward movement with little or no counter, downward movement where abstract ideas could be related to contexts that students may have been more familiar with. Content knowledge remained abstract at a high level of cognitive complexity. The exercises scheduled early on in the semester required engagement at a highly abstract theoretical level with context-independent examples. I would argue that the complexity of the exercises was likely to constrain access to knowledge or meaningful cumulative learning. Successive upward shifts with no opportunities for downward shifts towards examples that concretise knowledge means that the important process of linking new knowledge to prior knowledge, or knowledge that relates to students' lived experiences did not happen (McNaught, Maton, Martin and Matruglio 2013).

Studies have shown (see Blackie 2014, Clarence 2014) that student learning is supported when there is a gradual increase in the level of complexity of the knowledge they are introduced to. I would suggest that the same would be true for General Chemistry.

9.4 The model semantic profile for General Chemistry

General Chemistry at the sub-microscopic and the symbolic levels requires more abstract application of chemical knowledge with less context-dependent meaning. The resultant semantic wave of the curriculum practices would ideally be represented as a gradual building of knowledge by starting with and integrating existing knowledge and concepts with newer, more abstract knowledge.

The semantic profile depicted below in Figure 25 is a heuristic representation of the ideal General Chemistry curriculum for South African students. In this scenario, Chemistry knowledge begins from the macroscopic using everyday examples that are concrete and context dependent and that have stronger semantic gravity and weaker semantic density. More abstract concepts and theory at the sub-micro and the symbolic levels of Chemistry knowledge that have a weaker semantic gravity and stronger semantic density are then introduced.

As the semester progresses the size of the wave shifts to indicate narrowing of semantic waves in an upward direction. As such, the semantic entry becomes progressively higher as the semester progresses, and consequently, the semantic exit point is also much higher, with the level of complexity becoming more advanced and the concepts becoming more abstract.

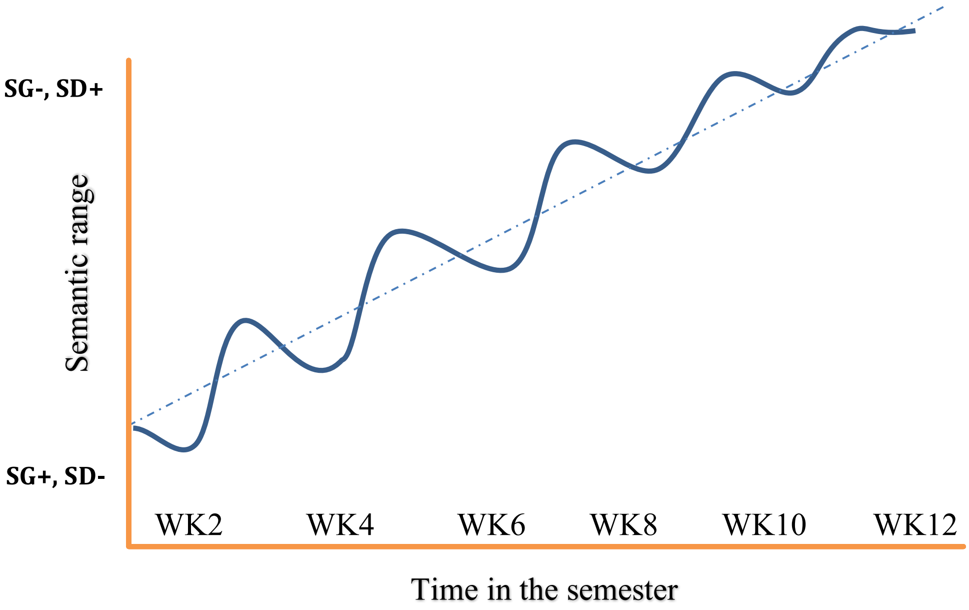

Figure 25. Model of semantic wave for General Chemistry

In the above representation, the semantic profile signifies changes in knowledge practices in terms of relations to context, abstraction and cognitive difficulty over time. A semantic profile with the downward slopes signifies processes of strengthening semantic gravity and weakening semantic density (SG↑, SD↓),) while the upward slope signifies a process of weakening semantic gravity and strengthening semantic density (SG↓, SD↑) as indicated in the Figure 25 above.

From the above example, the heuristic semantic profile of knowledge practices in the curriculum that would ideally be created in a situation aimed at maximising student involvement in their learning shows the characteristic of hierarchical knowledge structure in General Chemistry knowledge. Ideally the curriculum structure would demonstrate the progressive accumulative nature of Chemistry knowing through the weakening and strengthening of both semantic gravity and semantic density in successive waves over time.

Researchers such as Talanquer and Pollard (2010) and Carmichael (2010) suggest a transformational approach to designing the curriculum that views student learning needs holistically. The selection of curriculum content should also take into account the pre-requisite foundational knowledge necessary for students who will not continue with

Chemistry as a major, but who need the foundational knowledge to facilitate their further learning in other degree programmes. Therefore, the multiple purposes of General Chemistry as a service module are potentially problematic for curriculum design. The design of the curriculum might not be adequate in terms of the breadth and scope of content knowledge necessary for the learning needs of all types of students, i.e. those for whom Chemistry is a major subject, and those for whom it is not. A more nuanced approach that takes account of student learning needs should be taken to ensure the attainment of outcomes and improving fitness of purpose of introductory-level General Chemistry.

Mbajiorgu and Reid (2006) suggest that, when introducing new topics in introductory courses such as General Chemistry, these should be based on real-life knowledge and experiences. The curriculum should have more examples located at the macro level, while knowledge at the symbolic level should be introduced gradually. Beginning with the macro level enables students to make connections with their prior knowledge. In Maton's terms this means entering the semantic profile at a point where semantic gravity is stronger and semantic density weaker, while the opposite will be true at the point of exit. In time, the variations in the levels of semantic entry and semantic exit should be congruent with the level of difficulty required to work with knowledge at all three levels of Chemistry knowledge as the semester progresses.

It is important to identify the moments in the curriculum where the learning gradually becomes less context dependent and more context independent, so that appropriate strategies can be devised to facilitate epistemological access for the majority of students. The verticality of the knowledge structure also requires that knowledge signposts should be clear, both illustratively and in terms of recognition and realisation rules for assessment tasks. It is important that this upward shift in complexity happens gradually at first to enable students to build the requisite cognitive structures to accommodate new concepts, theories, and procedures. Furthermore, students should be able to relate to the examples used, especially at the beginning of a new theme, with knowledge becoming progressively more abstract and semantically dense. In this way, the intrinsic cognitive load that is associated with the effort and difficulty associated with learning can be managed.

9.5 Implications for student learning in General Chemistry and cumulative learning

As already mentioned, in a situation where there is a high semantic flatline, i.e. where knowledge is introduced at a consistently high level of abstraction and cognitive complexity, the likelihood is that learning will not be cumulative, but accumulative. This means that complex concepts are added onto more complex concepts without meaningful integrative learning, thus potentially leading to rote memorisation without understanding. Many students tend to memorise information without necessarily understanding it or knowing how to apply it in a different problem context.

In a study on the learning of first-year non-Chemistry major students, Chittleborough, Treagust and Mocerino (2005) discovered that rote learning approaches were mainly adopted by students as a response to the assessment demands of the module. Although some aspects of the learning initially require memorisation, for meaningful learning to occur, students would need to integrate knowledge that traverses the three levels of chemical knowledge: the micro, sub-micro and symbolic levels of Chemistry knowledge. Meaningful understanding, and the ability to make connections between concepts, promotes meaningful learning.

In this regard, Respondent 2 noted the following:

> Yes, it’s all about problems and calculations and formulas. There is not a lot of learning, call it memorisation. Quite a bit of this … not all, but a substantial amount of the initial topics, involve things like learning the names and symbols of the elements, which they should know from school but they don’t know, defining the terminology, absolutely. And then what we use quite a bit later in the course - the names and symbols of what we call the polyatomic ions, yes. You could say more complex chemical structures. And there are a lot of them that are very basic, which we use all over. And it has been our common experience for years now that students, although we say in the study guide and stress it in the classes – things like these learning aspects – they don’t take it seriously. (Respondent 2)

As noted by Respondent 2 above, the role of memorisation is acknowledged[96] as a learning strategy in General Chemistry, but it is meaningful learning that is the aimed for.

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[96] See Johnstone 2006.

Luckett and Hunma (2013) argue that being cognisant of knowledge practices is a prerequisite for making more explicit what knowledge is valued, the kind of insight needed to be an ideal knower, as well as the nature of the *gaze* required. Making the rules of the game explicit aids the student's ability to develop the specialised consciousness associated with the peculiar way of knowing in a discipline. I would argue that a first step to ensuring that more students are included in processes of meaningful learning is to cultivate consciousness of the structuring principles of the knowledge practices of a discipline through adequate curriculum design. As suggested, the rules of the game can be transmitted in a discipline by making known the history of their development, their foci (the *what*) and the demands of their practices (the *how*) and by modelling the practices as well as scaffolding students' acquisition of these (Luckett and Hunma 2013). Therefore, the implications for epistemological access require that curriculum practices which occur at the level of the actual are congruent with the generative mechanisms structuring the curriculum so that cumulative knowledge-building can occur.

9.6 Summary

In this chapter I presented and analysed data from the first semester General Chemistry curriculum for the purposes of understanding the curriculum's ability to facilitate cumulative knowledge-building. I used the conceptual and analytical tools of LCT: Semantics to analyse first semester learning activities.

Through the analysis of the learning activities or exercises provided to students in the first semester, I have made explicit the organising principles of the knowledge that students are required to engage with when doing the prescribed exercises. I have made an argument about the potential of these exercises to facilitate the kind of cumulative learning that is necessary for success in this module. As previously mentioned, Maton (2009, 2013, 2015) argues that cumulative learning is facilitated when the curriculum evinces regular episodes of strengthening and weakening semantic gravity, and strengthening and weakening semantic density.

From the analysis of the learning activities, I was able to create semantic profiles that illuminated changes in the sematic range of practices over a series of learning tasks given to students over a specific timeframe. I identified the semantic level of entry, the points at which the complexity of the knowledge changes – which, initially, is not too high on the semantic range. However, very early on in the first term (weeks 3 to 6) of the first semester, a high semantic flatline is evident within exercises and from exercise to exercise, with no weakening and strengthening of semantic gravity and semantic density, thus probably constraining student learning. Successful cumulative learning entails the creation of semantic waves depicting movements from the concrete to the abstract, weakening and strengthening semantic gravity and semantic density respectively in successive waves.

Knowing the semantic range of learning tasks offer insight into the potential of the curriculum to provide students with access to knowledge. As indicated by Johnstone's working space memory model (see Chapter 2; Section 2.3.2.1.1), the brain has finite capacity for processing information, especially in novel situations where the knowledge content is highly abstract. As the information increases in complexity, the memory struggles to process the information because not enough space is available for processing and storage, and "the system overloads and seizes up" (2006; p. 56). With an increase in complexity of the learning tasks, there is bound to be an overload and unsuccessful processing and storage of information which is likely to hinder learning. Therefore, when designing a curriculum aimed at facilitating cumulative learning, it is necessary to be aware of the General Chemistry content with high intrinsic load (see Chapter 2, Section 2.3.2.2.) The awareness should be reflected in the selection, sequencing, and timing of when and how the learning activities weaken and strengthen semantic gravity and semantic density. Failure to achieve the periodic shifts in semantic gravity and semantic density may lead to students struggling to understand abstract knowledge and being unable to transfer this knowledge to new learning contexts. As such epistemological access to knowledge would be compromised, resulting in students struggling to attain a meaningful learning experience.

CHAPTER 10 Conclusion

> All citizens should be provided with equality of access to the most powerful forms of knowledge through the means that most reliably enable that access (Maton and Moore 2010, p. 8)

10.1 Introduction

In this study, Social Realism was adopted as a conceptual framework for investigating how the knowledge practices evidenced in the design of the first-year General Chemistry curriculum allow or inhibit epistemic access to various forms of knowledge. The purpose of the study was to identify the organising principles embedded in the curriculum and knowledge practices that serve to hamper or facilitate student learning in General Chemistry. By so doing, the intention was to consider how epistemic access and cumulative learning was facilitated by the design of the introductory course in the General Chemistry curriculum.

10.2 The adoption of a realist approach to curriculum enquiry

In this concluding chapter, it is prudent that, before stating the case for how this study answered my research questions, I offer a brief reiteration of the critical realist philosophical orientation of the study to ground the explanation of the findings in this study.

Critical realism as an under-labourer provided the theoretical framework for inquiry into curriculum and knowledge practices in General Chemistry at LSAU. I adopted a social realist stance in the study. I have argued that Social Realism offers an alternative to reductionist and postmodernist theories for investigating and understanding knowledge and knowledge practices, and thus knowledge and knowing (see Chapter 3, Section 3.2). Reductionists critique knowledge in terms of interests and perspectives, whereas postmodernists describe, categorise and classify dominant knowledge and knowledge types. Both critical and Social Realism acknowledge the existence of a world that is independent of our knowledge or knowing of it. Realist theory acknowledges the emergent properties and powers of things, including knowledge, which is independent from the context of its emergence (Moore 2000, Luckett 2009, Young and Muller 2010, Maton 2014). The study enabled me to explain, to a large extent, how the structuring of the curriculum could arguably be linked to access to knowledge through the module design.

10.2.1 The realist research methodology

A qualitative case study research methodology with an intensive approach to curriculum enquiry was implemented in the research (see Chapter 6). Easton (2010), among others, argues that case studies have limited potential for representivity across contexts. However, Maxwell (2012a) states that causal explanations could be made if a rigorous and valid methodology was used, given the context of the study. The findings derived from this study can allow inferences to be made about entry-level university science courses offered in similar contexts to LSAU.

The data for the study comprised curriculum documents and data generated from interviews with academics involved in the design of the curriculum for and the teaching of General Chemistry. I developed a translation device for interpreting the different data sources through the lens of the theory (see Section 6.5). The analytical tools of retroduction and abduction (see Chapter 6, Section 6.5.2) were used to make inferences about what the General Chemistry curriculum must be like to enable successful learning for the majority of students. As such, it was important to ask questions about the nature of the messages transmitted by way the curriculum was structured.

In the following section, I consider the extent to which the findings addressed the research questions.

10.3 How the findings of the study addressed the research question

The inquiry centred on the question of whether, and in what ways, the module design and subsequent curriculum structure enabled or constrained epistemological access to knowledge of General Chemistry for the majority of students. In the following section, I present the findings of the study, taking into account the three levels of analysis that were undertaken. I begin with mentioning the findings pertaining to the discourses generated in the curriculum, followed by exploring the dominant organising principles and their effects. Lastly, I point out how the structuring of the curriculum contributed to cumulative learning.

10.3.1 The discourse in the curriculum

Since curriculum practices are knowledge practices (see Chapter 1, Section 1.4), I considered the various discourses that undergirded the practices in General Chemistry at LSAU as the first line of inquiry in the study. I attempted to determine how the pedagogic discourse was produced and how it served to enable or constrain student access to General Chemistry knowledge. In analysing curriculum discourses, I considered the knowledge base of the discipline and the stance adopted to curriculum design in the field, and how these related to ideas about student learning. I considered the classification and framing of the curriculum to demonstrate how the curriculum practices tended to include or exclude students from learning General Chemistry at LSAU.

10.3.1.1 The instructional and regulative discourses in the curriculum

The differentiation between the instructional and regulative discourse was discussed in Chapter 5 (see Section 5.2.2.1).

Chemistry as a field is considered as a central science that has a knowledge base with relatively strong classification, with explicit rules and conventions. As a sub-field of Chemistry, General Chemistry has weaker boundaries, thus making the knowledge of the other sciences like Physics and Mathematics essential additions for Chemistry knowledge. The connection between Chemistry and other disciplines is not necessarily made explicit to students and, because many of them do not make these connections, they are unable to access large parts of the knowledge base of the discipline.

The data provided evidence of strong framing of the instructional and regulative discourses, that is, of the processes of selection, sequencing, pacing and timing of the topics. The hierarchy or verticality of knowledge in General Chemistry points to a recontextualising principle that prescribes the selection and arrangement of knowledge, and the special relationship of actors and discourses. Strong framing of the instructional discourse implies a focus on the knowledge content to be learnt within a specified time frame and thus does not provide opportunities for the development of other graduate attributes, characteristics, and dispositions of students that are linked to the development of the student as a science knower. It could therefore be argued that the strong framing of the instructional discourse is likely to constrain epistemological access for large numbers of students.

In order to improve epistemological access to the field it seems as if there is a need for weaker framing of the instructional discourse in introductory science (see also Ellery 2016). Ellery's study shows that weaker framing is congruent with the development of the broader goals of higher education, such as the development of critical, independent scholars. Weaker framing of the General Chemistry curriculum would require, in particular, that changes be made to pacing, and that the evaluative criteria are made explicit. This is especially necessary when certain abstract and complex curricular content is taught, especially in the first semester.

The General Chemistry curriculum is explicit about what knowledge is valued and how it is to be acquired. However, I have found that how students are to put meanings together to produce legitimate texts is not specified in the self-assessment activities. In addition, the absence of formal opportunities for formative feedback limits opportunities to make these messages clear to students (see Chapter 7, Section 7.3.2.4).

10.3.2 The organising principles of the curriculum of General Chemistry

The second line of inquiry sought to uncover how the organising principles of the General Chemistry curriculum generated legitimate knowledge and knowers. Given my social realist orientation, I aimed to explain the effects of the structuring of the curriculum on student learning. To this end, I examined the organising principles of the knowledge selected and of the organisation of the curriculum. LCT: Specialisation and LCT: Semantics were used to analyse the same data. These two sets of concepts and tools complement each other as "they explore not different practices, but rather different organising principles that underlie the same practices" (Maton 2016, p. 17).

10.3.2.1 The specialisation code in General Chemistry at the LSAU

The General Chemistry curriculum generated a *knowledge code* and downplayed differences among social categories of actors, thus positioning all equally in relation to the knowledge and practices of the field (see Chapter 8). In other words, the curriculum subscribes to the view that, "anyone can ostensibly claim legitimate knowledge so long as they follow scientific principles and procedures" (Maton 2014, p. 91). The significance of the above assertion implies that anyone studying in a knowledge code discipline has the same likelihood of accessing ‘the goods’ of the discipline as the next person since the code signifies relations to the object of study and not relations to the knower. This study examined this assertion and whether it applied to General Chemistry at the LSAU. The findings confirmed that the organising principles underlying curriculum practices in the first-year General Chemistry module evinces a *knowledge code* (see Chapter 8, Section 8.3). Therefore, structuring of the curriculum emphasises and legitimates students having attained specialist knowledge, which is likely to constrain student learning, especially considering the nature of the new student coming into the educational setting.

10.3.2.2 The ideal General Chemistry knower

From the data it is apparent that the ideal General Chemistry knower should possess specialised knowledge, principles and procedures. Thus s/he should possess what Maton (2014) terms a *trained gaze* (see Chapter 8, Section 8.6) able to traverse the different levels of chemical knowledge *viz.,* the macro, sub-micro and the symbolic level.

The study established that the focus of the learning activities in the curriculum developed a *purist insight* for the knower; this type of insight requires the student to engage with *what* is known, as well as with *how* to know in the subject. Simply, what is privileged is both the object of study (theoretical knowledge) and how it is studied (procedural knowledge). This finding is in line with the general outcomes of Chemistry education.

I would argue that the absence of social relations in the data provides evidence that the attitudes and dispositions that students should possess to be successful in the field are not consciously developed. The lack of social relations therefore posed a challenge for the development of appropriate student identities for students studying General Chemistry. The focus on cognition should be supplemented with the recognition that it is necessary to develop other attributes of knowers and knowing that can contribute to the holistic development of the student.

10.3.3 Designing for cumulative knowledge-building

The third line of inquiry was concerned with understanding how the structuring of the curriculum contributed to epistemological access and cumulative knowledge-building in General Chemistry. Since General Chemistry has a hierarchical knowledge structure and a hierarchical curriculum structure, it is important to facilitate cumulative knowledge-building.

In Chapter 5 (Section 5.11), I showed the varying strengths in semantic gravity and semantic density of the learning activities to make sense of their capacity to contribute to cumulative learning. The strengthening and the weakening of the semantic gravity and semantic density in General Chemistry knowledge is indicative of the cumulative knowledge-building properties of learning activities as found in the curriculum.

The findings of my analysis of learning activities in Chapter 9 showed code shifts in the curriculum. Code shifts indicate different cognitive demands and modes of thinking. I would argue that making the implicit knowledge requirements more explicit for students by signalling or signposting the changes in complexity of knowledge and in the mode of thinking required could make learning, and thus epistemological access, more possible.

My analysis of the introductory module of the General Chemistry curriculum has led me to conclude that in designing a curriculum to enable the kind of cumulative learning necessary in a discipline with a hierarchical knowledge structure, it is necessary to take a holistic approach to curriculum development. This means taking into account the organising principles in the curriculum, as well as how curriculum coherence is achieved. Furthermore, it is necessary to explicitly integrate simple, everyday knowledge with abstract and complex knowledge.

10.4 Implications for curriculum design practices and recommendations

10.4.1 The current curriculum design perspective

As mentioned in Chapter 4 (see Section 4.6), in the view of Moore and Young (2001), different curriculum models are closely linked to assumptions about knowledge and the curriculum. From the findings, it is evident that the approach to curriculum design currently adopted for General Chemistry at the LSAU does not adequately facilitate cumulative learning. Moreover, the constructivist approaches to learning in the field (see Section 2.3.1) and the subsequent approaches to curriculum design in the subject are not aligned with the learning needs of the students at LSAU, nor with the espoused student-centred model for curriculum design. There is tension between the need to introduce students to disciplinary knowledge, and to taking into account how students learn.

It has been shown in numerous studies that level of preparedness to study science disciplines of the majority of South African students (see Chapter 1, Section 1.7) poses challenges for epistemological access to General Chemistry.

Based on research on the role of prior knowledge and the articulation between high school and university Chemistry in the South African context[97] (see Chapter 7, Section 7.5), it can be argued that the curriculum practices in higher education should be modified and should acknowledge, make explicit, and systematically mediate engagement with both the epistemic relations and social relations of General Chemistry. Therefore, it is recommended that curriculum content should address the gaps in knowledge. Determining students' prior Chemistry knowledge can reveal the misconceptions they hold and that may pose barriers to learning. I contend that implementing practices that lead to determining students' prior knowledge early on in the semester can assist academics when designing the curriculum to enable and support student learning.

10.4.2 Social realist considerations for curriculum design

Even students who do not continue studying Chemistry beyond the first year should learn how to transfer the learning gained from engaging in General Chemistry to novel learning contexts. It is this characteristic of transferability of knowledge across contexts which is a condition for social inclusion in education and for epistemic access.

The study established that the General Chemistry curriculum at the LSAU is designed in a manner that does not signpost the critical places where an increase in the levels of difficulty or complexity of the knowledge occurs. Clear signposting[98] seems to be a

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[97] See Potgieter *et al* 2008, Potgieter 2010, and Sedumedi 2008.

[98] See Chapter 9 Section 9.3.1 on the role played by flagging the places where code shifts occur in the curriculum.

significant curriculum design principle for enabling cumulative knowledge-building and epistemological access at university. Simply, the module design should demonstrate varying strengths of semantic gravity and semantic density from the beginning of the semester and maintain a consistent progression of upward movement, signifying the gradual weakening of semantic gravity and the strengthening of semantic density as the knowledge becomes more abstract and condensed. The formation of the upward escalators should evince progression from the more contextual and simpler meaning to the more abstract and condensed meaning.

When students have to learn highly abstract, decontextualised knowledge, they generally find it very difficult, unless they are able to see how the knowledge relates to more concrete contexts. Mbajiorgu and Reid (2006) suggest that when introducing new topics in introductory courses such as General Chemistry these should be based on real-life knowledge and experiences. The curriculum should have more examples located at the macro level, while knowledge at the symbolic level should be introduced gradually.

Johnstone (2006) recommends multilevel learning and problem solving in chemical education as important considerations for chemical education. Therefore, I suggest that, as part of the curriculum design process, the knowledge content should be divided into manageable tasks where appropriate metaphors, analogies and representations are used in a language that students can relate to and understand. By structuring the curriculum into manageable tasks of interconnected information the intrinsic load can be taken into account, thus creating spaces for innovative pedagogies.

Knight (2001) suggests that curriculum development for complex learning has to consider spaces, interactions, experiences, opportunities and the environment in which the learning will occur. The notion of the creation of spaces that support the nurturing of epistemic access in the curriculum is an important consideration that should be taken into account when designing curriculum for meaningful learning. One of the ways of creating space in the curriculum relies greatly on the structuring of the introductory curriculum for the development of the requisite disciplinary knowledge (epistemic relations) and the requisite attributes associated with being a scientific knower (social relations).

Finally, in support of the idea of creating spaces for learning in the curriculum, a proposal for a change in the structure of some degree programmes at a national level, including the Bachelor of Science degree, has been made by Scott (2014) as a measure to intentionally improve student learning. A key suggestion made by Scott involves engaging in an exercise of reducing the difficulties experienced by students, and addressing the learning challenges that result from the articulation gap between school and university learning. The extension of learning time in the Bachelor's degree from three to four years has implications for curriculum design. I believe that extending the duration of programmes, especially in the sciences, will allow the curriculum to be restructured to create learning spaces that will address complex and abstract theoretical concepts, but also introduce issues pertinent to the development of the student as a social being in a higher education setting.

Given the findings of this study, I would support the proposal for the modification of the structure of the first-year General Chemistry curriculum which would improve learning prospects for the majority of the students. A modified structure of the curriculum for General Chemistry should include time for students to acquire the appropriate scientific literacy practices as well as to develop their identity as knowers in the subject. In addition, more time can be allocated to the identification of the relevant threshold concepts in the discipline.

10.5 Limitations of the study

As a sociological study into the structuring of a General Chemistry curriculum with a focus on its capacity to provide epistemological access for more students, this study posed various challenges in relation to the research methodology and, in particular, in relation to the validity of the findings. The main sources of data for the study were curriculum documents such as the study guide, lecture notes and self-assessment activities. One of the challenges I experienced was deciphering the meaning of the different terminology in the study guide in the process of developing the translation device. For example, specific objectives were stipulated instead of learning outcomes. The specific objectives were written in the form of topics to be covered in the module. As such, the manner in which the students are informed about the module indicates that focus is on the knowledge content that will be covered and the skills needed for that knowing, rather than on developing the students' dispositions as knowers.

It could be argued that the study suffered from some methodological limitations and that it would have been strengthened by the development of more nuanced translation devices for both Specialisation and Semantics that would have enabled an analysis of the internal composition of the learning exercises. A translation device that made it possible to recognise ER- could enable the analysis of implicit knowledge of Chemistry embedded in the exercises – something that the translation devices used in the current study were not able to achieve.

The translation devices used in this study aligned with the focus of the research and served the purposes of uncovering the dominant organising principles in the curriculum. The study did not explore the variations of the strengths in either Specialisation or Semantics in the curriculum. The development of translation devices for these purposes is recommended for future investigations into the knowledge practices in the field. Such analyses would likely result in different findings and provide richer discriptions of how the General Chemistry module at LSAU enable or constrain learning and enhance or inhibit cumulative learning.

Lastly, an important limitation relates to the non-availability of formative assessment tasks for General Chemistry. The analysis of formative assessments would have shed more light on what was valued in the curriculum and where emphasis for learning was placed. However, I was not granted access to the formal test papers, and only managed to gain access to a mid-year examination paper.

In order to develop a more nuanced comprehension of cumulative learning in General Chemistry and of the student experience of the course, it would be useful to conduct research into the pedagogy and assessment of the course. Although there is an inextricable link between curriculum and pedagogy**,** the pedagogic practices for this module were not examined. An analysis of students' written responses to assessment tasks could offer insights into how the educational practices in General Chemistry enable knowledge-building over time.

10.6 Contributions of the study

In undertaking this study, I developed an approach to interrogating the inner logic of the structuring of the General Chemistry curriculum at a LSAU. I have shown that laying bare these principles enables one to understand the affordances and limitations of the curriculum to enable epistemological access to the discipline for the majority of students. In doing so, I was able to draw conclusions about ways in which the curriculum could be developed to enable more students to make sense and build cumulative knowledge in the discipline.

I have argued that a social realist approach to curriculum design acknowledges not only the knowledge and knowledge practices, i.e. the theory and procedural knowledge (epistemic relations) but also the kinds of knowers that students have to be in order to achieve success in the discipline; the approach therefore also takes into account the social relations of the discipline.

There have, to date, been few studies on science education employing a social realist perspective. As such this study contributes to answering some important educational questions about how to improve equity of outcomes for all students. The study was aimed at adding a different perspective to the body of knowledge on curriculum design practices in General Chemistry that may lead to enhanced student learning.

Some proponents of the constructivist paradigm are pushing the boundaries and expanding understanding of the effects of educational practices on student learning in Chemistry and, specifically, Introductory Chemistry. For example, Talanquer (2010) argues that the role played by the human element in Chemistry education should be considered. From a social realist perspective, this means cultivating the social relations in chemical education. This study adds to the body of knowledge that supports the foregrounding of social relations to improve student learning in the sciences. The acknowledgement of both the epistemic relations and social relations in curriculum practices can make curriculum developers more cognisant of the development of the kind of knower and the ways of knowing that are appropriate for the purposes of inclusion.

10.7 Concluding remarks

In the study, I examined how the General Chemistry curriculum reflects the nature of knowledge in the discipline of Chemistry (field of production). I then proceeded to analyse the curriculum as planned and assessed (field of recontextualisation). Through embarking on the research process, I have developed a *cultivated gaze*. According to Maton (2014) a *cultivated gaze* is developed through the “attainment of legitimate dispositions through interaction with a significant other or immersion in a canon of great works”. By undertaking this doctoral study, I have engaged in advanced scholarship and, in the process, I have become a specialised knower in the field of curriculum design. The doctoral process itself, which privileges specialised ways of knowing, has given rise to my emerging scholarliness. The notion of scholarliness has been attained through an ongoing process of immersion in intellectual engagement and inquiry into educational practices. I have developed a critical realist *gaze* on the design of curriculum which has enabled me to look beyond the surface features of the curriculum and to focus my *gaze* on the intangible engines driving curriculum inquiry.

Knowledge practices do not occur in a vacuum. All knowledge is underpinned by historical, economic, social, and political circumstances at any given time and space. This conception of knowledge is essential for exploring the possibilities for social inclusion in higher education. The curriculum is only useful if it can meet whatever society’s needs are at a particular time. For example, the current discourse on the knowledge society can influence the development of curricula to provide “persons that exhibit qualities of trainability and flexibility that is assumed is needed in the future knowledge society” (Moore and Young 2001, p. 448).

In the South African context, higher education holds the promise of contributing to societal good and a better life for those fortunate enough to engage in higher education. As such, the curriculum is a powerful tool for social inclusion and for the achievement of social justice. It is for this reason that it is important to understand what enables or constrains student access to the powerful knowledge of intellectual fields such as Chemistry.

A critical question linked to the decolonisation of the curriculum discourse currently occupying higher education in South Africa concerns whose knowledge is regarded as legitimate and whose experiences are valued and validated by the academy. Educators are asking questions about what knowledge and whose knowledge to draw on in the process of cultivating the kinds of knowers and ways of knowing necessary to develop scientific expertise. Asking questions about what constitutes the curriculum in order to make a subject like General Chemistry more accessible for students should not focus on the acquisition of a certain type of knowledge without also considering how that knowledge contributes to the development of certain values, dispositions and characteristics which will distinguish the student as a knower with a particular context.

Given such questions, it is evident that the thoughtful integration of specialised and everyday knowledge to facilitate successful scientific meaning-making may offer a key to the discourse on how learning in the sciences can enable epistemological access.

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Appendix 1

Open-ended interview schedule:

1. What are we trying to do when constructing the 1st year curriculum?
    - What is the aim of first year Chemistry
    - Why are we teaching what we teaching?
2. What do students need to know in order to be successful?
    - What can you say is essential for student success in this module?
    - What do students need to know in order to be successful (in terms of the content)
    - What does it take for successful learning in this module?
3. What is the basis for designing the current curriculum?
    - Why are we teaching what we are teaching in this module?
    - How are curriculum decisions made in this context?
4. What do we know about student learning in chemistry/ in first year chemistry?