COMPARATIVE ANALYSIS OF REPRESENTATIONS IN NATURAL SCIENCES TEXTBOOKS AND SENIOR PHASE CURRICULUM AND ASSESSMENT POLICY STATEMENT

by

Serapelo Boipelo Oreeditse Mofolo

(BSc; BSc.Hon; PGCE)

Dissertation submitted to fulfil the requirements for the degree

MASTER IN EDUCATION

in

Curriculum Studies

Faculty of Education

at the

University of the Free State

Bloemfontein

Supervisor: Dr Msebenzi Rabaza

Co-supervisor: Dr Moeketsi Tlali

2021

ACKNOWLEDGEMENTS

I give all glory to my Creator, my God and Abba, whose grace made the successful completion of this journey possible.

I also acknowledge the following important people for walking the journey with me:

Dr M. Rabaza, your invaluable commitment, guidance and patience ensured that this study reached fruition. Your inputs and wisdom are much appreciated. May you increase in wisdom and strength. I wish you a great future in your work and with your family.

Dr M. Tlali, your science knowledge and inputs for refinement of the written work are greatly appreciated.

ABSTRACT

Textbooks are known to be primary resources for teaching and learning in most classrooms. Many inexperienced teachers rely on textbooks for content, lesson planning and guidance when teaching natural sciences. Several studies have been conducted globally over the years regarding representations in natural sciences textbooks and national curriculum documents. In studies on natural sciences textbooks, multiple representations of matter and materials in natural sciences textbooks have been found to be particularly challenging, more so for Grade 9 learners in South Africa. This study sought to explore verbal and visual representations of matter and materials on multiple levels of chemistry representation in Grade 9 natural sciences textbooks when compared to the Curriculum and Assessment Policy Statement (CAPS).

By employing an exploratory research design through a deductive qualitative approach, a comparison was made between each of three preferred Grade 9 natural sciences textbooks and the senior phase CAPS document. Nonprobability sampling was employed through purposive sampling of data sources (textbooks and CAPS). Primary data collected from the three textbooks and the CAPS document were analysed using Yin's analysis framework stages. The findings revealed that all three natural sciences textbooks had limitations in representing the CAPS document. Most limitations were found in visual representations on the sub-microscopic level than in verbal and verbal-and-visual representations on the macroscopic and symbolic levels, respectively. The conclusion was that preferred textbooks have limitations, which may negatively impact the performance of natural sciences leaners taught by novice teachers that are dependent on the textbook.

Keywords: *natural sciences, limitations in textbooks, multiple representations, poor performance and verbal and visual representations.*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CAPS	-	Curriculum and Assessment Policy Statement
DoE	-	Department of Education
NCS	-	National Curriculum Statement
OBE	-	Outcomes Based education
RNCS	-	Revised National Curriculum Statement
TIMSS	-	Trends in International Mathematics and Science Study
FET	-	Further Education and Training

CHAPTER 1: ORIENTATION

1.1 INTRODUCTION AND BACKGROUND

Natural sciences in South Africa is a crucial subject, the curriculum content of which serves as a source of prior knowledge for several science subjects in Further Education and Training (FET) phase, such as Physical Sciences, Life Sciences, Earth Science and Agricultural Sciences (DoE, 2011). The content of natural sciences comprises four strands of science knowledge, namely, life and living, matter and materials, energy and change, and planet Earth and beyond (DoE, 2011). Life and living (biology) is foundational for life sciences, matter and materials (chemistry) is part of physical sciences, energy and change (physics) is also part of physical sciences and planet Earth and beyond (Earth science) is foundational for agricultural sciences. Among these four strands, many learners consider matter and materials difficult to understand (Musa and Ceyhan, 2019). Learners struggle with grasping the abstract concepts of matter and materials (Musa and Ceyhan, 2019) such as writing down chemical formulae and balancing chemical equations (Prinsloo et al., 2016).

Coupled with the difficulties that learners experience with the abstract nature of matter and materials, is the context of learners who are taught by teachers who rely on textbooks for subject matter instead of consulting the Curriculum and Assessment Policy Statement (CAPS) for prescriptions and guidelines (McDonald and Abd-El-Khalick, 2017; Attakumahi, 2020). While there are experienced teachers who rely heavily on the textbook, novice teachers rely heavily on the textbook due to a lack of pedagogical knowledge and/or limited content knowledge Orgoványi-Gajdos (2015). Because of this disadvantage of novice teachers, they were the ones the study was interested in.

Textbooks are ubiquitous teaching and learning resources. Reliance on textbooks by novice teachers could be because textbooks give guidance to teachers by providing them with readily available activities and planning of lessons (Ramnarain and Chanetsa, 2016), while presenting subject matter in a simplified, yet accurate manner to assist learners to learn (Karásková et al., 2019).

Several modes of representation are offered by textbooks. These modes can be verbal or visual representations (Sadoski & Paivio, 2001) in natural sciences and non-science textbooks. Verbal representation of subject matter in textbooks comprises definitions, descriptions, explanations and step-by-step methods (Devetak and Vogrinc, 2013), while visual representations may include drawings, graphs and models (Kapıcı and Savas-cı-Açıkalın, 2015). Verbal aspects are presented in more detail in textbooks than is the case in CAPS. Moreover, visual representations (images) are only discussed in CAPS and no images are provided. These differences between textbooks and the CAPS document may be additional reasons leading to novice teachers' inclination to seek guidance from the textbook rather than CAPS.

Other modes of representations are found specifically in science textbooks. For the knowledge strand of matter and materials, additional modes of representation are known as macroscopic, sub-microscopic and symbolic levels of chemical representation (Sujak and Daniel, 2017). The three levels of chemical representation in natural sciences textbooks speak to one another (Gilbert and Treagust, 2009) and emphasise the uniqueness of and relationship between verbal and visual representations (Sadoski and Paivio, 2001). The macroscopic level in a textbook offers verbal guidance for what can and should be observed in a science lesson to foster understanding of concepts through experience (Sujak and Daniel, 2017). This is more explicit in textbooks than in the curriculum document. The sub-microscopic level, on the other hand, makes use of visual representations to enhance understanding of abstract concepts of science (Gilbert and Treagust, 2009). Concurrently, the symbolic level seeks to consolidate the experiential (macroscopic) and abstract (sub-microscopic) levels of representation qualitatively and quantitatively using symbols (Gilbert and Treagust, 2009). Multi-faceted representation in natural sciences textbooks assists learners with making sense of complex science concepts (Khine, 2013). This may further explain why novice teachers tend to rely on the textbook when they should use the policy document (Attakumahi, 2020).

In addition, a combination of verbal and visual representations of chemistry (matter and materials) in textbooks impacts the pedagogical process and learner achievement (Bergqvista & Rundgren, 2017). Prinsloo et al. (2016) established that Grade 9 learners in South Africa perform poorly in the knowledge strand of matter and materials, due to an insufficient understanding of chemical concepts represented in textbooks. Textbooks are often used as a mirror image of the National Curriculum (McDonald and Abd-El-Khalick, 2017), even though they ought to serve as a link between curriculum policy and the implementation of the curriculum (Van den Ham and Heinze, 2018).

Despite the significance of representations in science textbooks and the inadequate performance of learners in matter and materials, reviewed literature acquired through the assistance of the university's librarian, an online library and several scholarly repositories uncovered a gap in South African natural sciences textbook research on comparison between representations in textbooks and the curriculum policy. Literature by several authors on representations in science textbooks was obtained and studied. The literature studied dated back to 2008. It included studies conducted for representations in science textbooks during the eras when the OBE syllabus transitioned into NCS, and when NCS transitioned into RNCS (Lemmer, Edwards and Rapule, 2008).

The literature also incorporated study findings on comparisons between the NCS and CAPS (Dempster et al., 2015). This range of literature was chosen to gain a perspective on developments in studies related to science textbooks and the respective national curricula. Additional literature offering a wide range of representations that were studied in natural sciences textbooks research was also acquired and studied. The representation topics obtained in the additional literature was relevant to Grade 9 natural sciences in South Africa. It included readability of science textbooks (Sibanda 2014), diversity in science textbooks (Ceglie and Olivares, 2012), nature of science (Ramnarain and Padayachee, 2015; Ramnarain and Chanetsa, 2016), representation of botanical content in the South African curriculum (Abrie, 2016), and racism, sexism and other forms of discrimination in South African textbooks (DBE, 2016).

No comparison of verbal and visual representations of matter and materials between Grade 9 natural sciences textbooks and CAPS could be identified in the literature discussed above. Neither was there a comparison between Grade 9 natural sciences textbooks and CAPS for the multiple levels of chemical representation. This dual gap in literature is discussed in the literature review chapter of this study.

To address the gap in South African literature, the study employed a review of literature from the Middle East. Middle Eastern learners showed similar performance to that of South African learners in grade 9 natural sciences (Reddy et al., 2016; Reddy et al., 2020). The study explored representations in natural sciences textbooks in the knowledge strand of matter and materials in the light of the poor performance of learners in matter and materials. The exploration was to reveal whether poor performance was due to limitations in the textbooks when representing the curriculum document. The limitations explored were areas of misalignment between verbal and visual representations of matter and materials in the textbooks and CAPS, as well as between multiple levels of chemical representation in textbooks and CAPS. If the preferred textbooks that were analysed were found to have limitations in representing CAPS in the knowledge strand of matter and materials, the findings could explain the contribution that the quality of preferred textbooks may have had on learner performance in matter and materials until now. The findings would also necessitate further research in an effort to close the gap and improve teaching and learning of matter and materials. Bhatti, Khurshid and Ahmad (2017) note that textbooks that meet the standards of a curriculum policy fully, facilitate better learner performance. Like the findings of Bhatti et al. (2017), the findings of this study could also be instrumental for guidance given by curriculum developers and policy makers to textbook authors to improve the quality of natural sciences textbooks in South Africa.

Due to the gap in South African literature for comparisons between matter and materials' representation in textbooks and curriculum documents over the years, a similar comparison had to be conducted in the other three knowledge strands of natural sciences, namely life and living, energy and change, and planet Earth and beyond, for reference. However, while studying literature, the researcher realised that multiple representations in other knowledge strands in natural sciences were partially applicable to matter and materials due to the unique particulate nature of matter and materials. This realisation was supported by study findings by Wu and Puntambekar (2012), Treagust and Tsui (2013); Opfermann, Schmeck, and Fischer (2017). Moreover, no comparison between verbal and visual representations of science concepts in textbooks and CAPS was identified in those strands. Thus, no conclusion in those strands could be used as a reference for matter and materials. Multiple representations of chemistry apply to matter and materials (Johnstone, 1993) and pose unique challenges in learner understanding and performance (Prinsloo et al., 2016).

1.2 RESEARCH INTEREST

In the researcher's eight years' combined experience as a Natural Sciences teacher and subject head, the researcher observed the reliance of inexperienced Grade 9 Natural Sciences teachers on the textbook. The researcher also observed that some textbooks did not support CAPS as they should. Some textbooks may have written explanations with limited visual representations, whereas the CAPS document requires teachers to complement verbal and visual representations when teaching. The researcher's observation and assumption are supported by the findings of the study by Bergqvista and Rundgren (2017) in which they discovered that visual representations of the sub-microscopic level of chemistry in senior phase textbooks made it challenging for learners to comprehend chemical concepts and constructs. In their study, Bergqvista and Rundgren (2017) discussed that science teachers depended on textbooks for planning, curriculum content and pedagogical guidance.

The purpose of this qualitative study was to explore verbal and visual representations of concepts, constructs and principles of matter and materials in Grade 9 natural sciences textbooks as identified in the Senior Phase CAPS document, through employing a comparative, thematic analysis of these representations on macroscopic, sub-microscopic and symbolic levels of representation. Primary data was collected from CAPS and textbooks for analysis. The researcher considered whether the quality of the textbooks influenced learner performance in Grade 9 natural sciences.

1.3 RESEARCH QUESTIONS

The primary question that informed this research was:

> How does the representation of concepts, constructs and principles of matter and materials in preferred Grade 9 natural sciences textbooks compare with CAPS?

In pursuit of answering the primary research question, the following sub-questions directed the study:

- How do the verbal representations of the identified matter and materials concepts, constructs and principles from CAPS compare with the ones in the preferred textbooks?
- How do the visual representations of the identified matter and materials concepts, constructs and principles from CAPS compare with the ones in the preferred textbooks?
- How do the verbal and visual representations of the identified matter and materials concepts, constructs and principles from CAPS compare with the ones in the preferred textbooks?

1.4 RESEARCH AIM AND OBJECTIVES

In line with the research question, the aim of the study was to compare the representation of matter and materials in preferred Grade 9 natural sciences textbooks with the CAPS document.

To address this aim, the following research objectives were formulated:

- To analyse the verbal representations of the identified matter and materials concepts, constructs and principles from CAPS with the ones in the preferred textbooks.
- To examine the visual representations of the identified matter and materials concepts, constructs and principles from CAPS with the ones in the preferred textbooks.
- To compare the verbal and visual representations of the identified matter and materials concepts, constructs and principles from CAPS with the ones in the preferred textbooks.

1.5 RESEARCH METHODOLOGY

The following approach and design were applied to the study.

1.5.1 Research approach

Methods

Through the interpretivist paradigm, assuming a relativist ontology (Kivunja and Kuyini, 2017), this qualitative study employed a deductive approach to explore and learn about the reality (Leavy, 2014) in South African preferred Grade 9 natural sciences textbooks when compared with CAPS for the representation of matter and materials. Identified textbooks and CAPS served as sources of primary data, as opposed to secondary data, which would have involved the authors' interpretations.

Compatible with the deductive, qualitative approach and anchored by thematic data analysis, primary document analysis was the method of choice, as opposed to enumerative content analysis that focuses on "elements that can be counted" (Ngulube, 2015). Primary document analysis was employed to analyse patterns in policy-prescribed textual content and images based on scientific concepts, constructs and principles in Grade 9 natural sciences textbooks in comparison with CAPS. The comparison was of themes identified in CAPS and the textbooks for the strand of matter and materials.

1.5.2 Design

Based on a lack of existing research on the limitations of natural sciences textbooks in comparison with CAPS, an exploratory research design was employed in the study (Takegami, 2016) to determine whether limitations existed in Grade 9 natural sciences textbooks for matter and materials' representations that are stipulated in CAPS prescriptions and guidelines. Three preferred Grade 9 natural sciences textbooks were analysed by comparison with CAPS, to determine their extent of verbal and visual representation of matter and materials on multiple levels of chemical representation.

1.6 DATA COLLECTION

Document analysis

Three Grade 9 natural sciences textbooks and the senior phase natural sciences CAPS document were selected as sources of primary data for the study. The textbooks were selected based on a list of textbooks acquired from an educational bookstore. From the information obtained, three most preferred textbooks were selected. The three most preferred textbooks were analysed because they were the most requested, thus the most commonly used. CAPS was used in the study because it served as the source of content that should be in the textbooks that are currently used in South African public schools.

- Textbooks

Each textbook consisted of the four strands of knowledge in natural sciences. Matter and materials is the knowledge strand that was analysed in each textbook because it is the most challenging knowledge for learners (Prinsloo et al., 2016; Musa and Ceyhan, 2019). Within matter and materials, description of compounds, naming and chemical formulae of compounds, and chemical reactions were analysed. Data from textbooks and CAPS were collected concurrently.

- CAPS

CAPS provides content prescriptions and guidelines for the four knowledge strands in natural sciences. The components of matter and materials that were analysed were identified in CAPS.

In line with the deductive approach and primary document analysis, the CAPS document was analysed and *a priori* codes (Kuckartz & Rädiker, 2019) of science concepts, constructs, and principles relating to matter and materials were identified. Through the *a priori* codes, verbal and visual representations from CAPS were classified into macroscopic and sub-microscopic levels of matter and materials, respectively, and then combined on the symbolic level. The textbooks identified were analysed for the same representations of concepts, constructs and principles identified in CAPS. The main question and sub-questions of the study were then directed to the textbooks.

Concepts, constructs and principles from CAPS were as follows. Concepts were compounds and chemical reactions. Constructs were the use of images to foster understanding of compounds and balanced equations for comprehending conservation of atoms. Principles were rules for naming compounds, writing down chemical formulae and the principle of conservation of atoms in a chemical reaction (DoE, 2011).

1.7 DATA ANALYSIS

A priori codes (Kuckartz & Rädiker, 2019) were determined and arranged in line with the methodology of the study. Data was analysed following the data analysis framework of Yin (2016) which consists of five stages. A minimum of two documents are required for document analysis (Bowen, 2009). For this study, three preferred textbooks identified from a list acquired from a renowned educational bookstore, and published as CAPS aligned, were anonymised as Textbook A, Textbook B and Textbook C (Ramnarain & Chanetsa, 2016). This selection provided a sufficient, yet manageable amount of data on elements highlighted in the research questions.

1.8 CONCEPTUAL FRAMEWORK

The framework through which the study was structured was a combination of the dual coding theory by Sadoski & Paivio (2001) and the chemistry triplet by Johnstone (1993). The dual-coding theory provided a relationship between verbal and visual representations (Sadoski and Paivio, 2001), while the chemistry triplet brought in three levels of depth into chemical representation namely, macroscopic, sub-microscopic and symbolic representations (Johnstone, 1993). Verbal and visual representations were dissected in the context of chemistry into the three levels of chemical representation. The dual-coding theory and chemistry triplet were weaved together through the taxonomy of representations proposed by Lemke (1998).

1.9 VALUE OF THE RESEARCH

The beneficiaries of the findings of this study will be the Department of Basic Education that may encourage authors to consider closing the gap between representation in textbooks and the prescribed curriculum. Importantly, the far-reaching benefit will be enhanced teaching, more fruitful learning and improved results in natural sciences (and hopefully other science subjects as well).

1.10 ETHICAL CONSIDERATIONS

The Research Ethics Committee of the University of the Free State granted Ethical clearance for the study.. A list of textbooks was requested from an educational bookstore that supplies textbooks to schools and individuals. To protect the identity of the authors and publishers, the three selected textbooks were anonymised as Textbook A, Textbook B and Textbook C (Tripathy, 2013). Paraphrasing and applicable citation and referencing rules were applied to avoid plagiarism.

1.11 LAYOUT OF CHAPTERS

The research study is presented in the following six chapters:

Chapter 1 Orientation

This chapter introduces and provides background to the study. It provides an outline of the study and its presentation.

Chapter 2 Literature Review: Representations in textbooks

Global, African and South African literature that was reviewed is discussed in this chapter.

Chapter 3 Dual Coding and Chemistry Triplet: A Conceptual Framework

A framework of concepts that was structured for the study is discussed in chapter 3.

Chapter 4 Research Methodology

This chapter explains the approach followed for the study.

Chapter 5 Data Analysis

In this chapter, the analysis of data is discussed in depth.

Chapter 6 Reflection, Implications and Recommendations

This chapter concludes the study by providing a reflection, implications and recommendations emanating from the findings of the study.

CHAPTER 2: LITERATURE REVIEW – REPRESENTATIONS IN TEXTBOOKS

2.1 INTRODUCTION

This chapter looks at learning, the purpose of textbooks and the review of literature regarding representations in natural sciences textbooks and CAPS. Literature reviewed was selected to ascertain possible limitations in South African natural sciences textbooks when representing content according to prescriptions and guidelines provided by CAPS. Literature selection was done against the backdrop of the poor status of academic performance of South African Grade 9 learners in natural sciences (Prinsloo et al., 2016) and novice teachers' reliance on the textbook (Orgoványi-Gajdos, 2015) in the place of the curriculum document (McDonald and Abd-El-Khalick, 2017).

2.2 LEARNING AND LEARNING IN SCIENCE

Learning is defined by Ambrose et al. (2010) as "a process that leads to change, which occurs as a result of experience and increases the potential for improved performance and future learning". In other words, learning is an active and dynamic process that takes place through constructing new knowledge upon existing or previous knowledge (Bada, 2015).

Regarding learning in science, Wellington and Ireson (2012) compare it to the process of acquiring knowledge of a new language; a new language whose vocabulary comprises words used in a familiar language, yet with peculiar meanings. This means that learners may encounter similar words in science as those found in a spoken language, yet with a completely different meaning. Examples of such words are *reaction, dense* and *neutral*.

Ayano (2018) argues that the main factor that impacts achievement in learning science is the quality of the pedagogical process. In the same breath, some learners are taught by novice teachers who rely strongly on textbooks for lesson planning and subject matter due to a lack of pedagogical knowledge and/or limited content knowledge (Orgoványi-

Gajdos, 2015). Some teachers even take this dependence on textbooks to a level of substituting the national curriculum document with the textbook (McDonald and Abd-El-Khalick, 2017; Koopman, 2017).

Learners' poor knowledge of subject matter in Grade 9 poses a challenge in teaching the abstract concepts (Musa and Ceyhan, 2019) of science in Grade 10 to 12 science subjects, because learners are expected to have already grasped the foundational concepts of the topics in Grade 9. A sound foundation in science in lower grades predisposes learners to better performance in higher grades and tertiary level (Ayano, 2018).

Effective science learning cannot take place without verbal and visual aids, which include textbooks (Devetak and Vogrinc, 2013). Khine (2013) notes that statistically, 89% of teachers offering science in high school preferred a textbook as an information resource for teaching and learning. In textbooks, both verbal and visual representations are used to complement each other's function to improve the quality of learning and the learning process (Treagust and Tsui, 2013). Science learning in the four knowledge strands of natural sciences (biology, chemistry, physics and Earth science) requires deeper levels of understanding through employing multiple levels of representations of science in textbooks, for acquiring adequate knowledge in each unique strand.

2.3 TEXTBOOKS

Textbooks are all-pervading teaching and learning resources (Peterson, 2016) whose role is to represent subject matter in a simplified, yet accurate manner (Karásková et al., 2019). The relationship between curriculum policy and implementation of curriculum is, in most instances, strengthened by the use of textbooks for teaching and learning (Van den Ham and Heinze, 2018).

With the freedom afforded to authors to present the national curriculum through textbooks (Devetak and Vogrinc, 2013), the vastness of approaches in writing textbooks is unsurprising and teachers ought to be conscious of any textbook shortcomings that may compromise curriculum objectives and learning.

2.4 TEXTBOOKS AND REPRESENTATIONS

"Representations are the entities with which all thinking is considered to take place," (Gilbert and Treagust, 2009). Several modes of representation are offered by textbooks to assist learners in making sense of complex science concepts (Khine, 2013). Misrepresentation of scientific knowledge and inaccuracies in some science textbooks influence ideas that learners have about science and scientific concepts (Devetak and Vogrinc, 2013).

Because learners learn both verbally and visually (Devetak and Vogrinc, 2013), a combination of verbal and visual representations in textbooks makes understanding abstract science concepts easier (Khine, 2013). According to Upahi and Ramnarain (2019), representations are pivotal catalysts for learning and representations of chemistry in textbooks should be suitable to assist learners to grasp chemical concepts that are intangible, more so when teachers treat the textbook as a surrogate curriculum document (McDonald and Abd-El-Khalick, 2017).

Not only do representations in textbooks come in verbal (textual) and visual (images) forms (Sadoski and Paivio, 2001), they can be linked with three representation levels in chemistry textbooks. Introduced by Johnstone (1993) as the chemistry triplet, the three representation levels in chemistry are macroscopic, sub-microscopic and symbolic levels. These multiple levels of chemical representation in science textbooks are important because they speak to different aspects of the teaching and learning process (Kapıcı and Savas-cı-Açıkalın, 2015). A discussion of multiples levels of chemical representation follows later in this chapter.

2.4.1 Verbal representation

According to Muspratt and Freebody (2013), verbal representation in matter and materials is in the form of "rules, statements, procedures and arrangements".

For verbal representation, in the form of text, to be easily understood and represent concepts of interest clearly, it should possess four qualities that enhance learning. These are simplicity, clear arrangement of text, conciseness and interest arousal (Opfermann et al., 2017).

2.4.2 Visual representation

Representations of science in the form of iconic or realistic pictures makes visualisation and understanding of scientific entities and phenomena easier (Yang and Treagust, 2013; Opfermann et al., 2017). On the other hand, diagrammatic sketches may not be as assistive because they require an individual's ability to interpret such diagrams (Yang and Treagust, 2013). Images have an inherent communication ability, and each learner gets to understand what the image represents based on how they engage with the image through prior knowledge and experiences (Eilam and Gilbert, 2014). It is the teacher's responsibility to facilitate learning and minimize misconceptions.

2.4.3 Verbal and Visual Representations

Although there are differences between verbal and visual representations, there remains a close link between them (Sadoski & Paivio, 2001). Verbal representation in textbooks is substantially expressed in writing (Anwar and Rahmawati, 2017) and complemented by diagrams that are a simple visual representation of intricate concepts and rationalise how these concepts are interlinked (Kembhavi et al., 2016). Opfermann et al. (2017) seem to agree with this idea when they state that the learning process is enhanced by a combination of words and pictures than by words exclusively. However, that combination does not affirm productive learning, it should be carefully assembled (Opfermann et al., 2017).

2.4.4 Multiple representations in chemistry

Multiple representations in chemistry and other science domains are unique for each discipline (Wu and Puntambekar, 2012) and conclusions at the core level of multiple representations in matter and materials do not correlate with those in the other disciplines, although they all make use of verbal and visual representations (Johnstone, 1993; Prinsloo et al., 2016).

Adoption of multiple representations by science textbooks, particularly in matter and materials, should be carefully thought through in line with the content and context of the topic or lesson to accommodate a variety of learners (Nieminen, Savinainen and Viiri, 2017; Eilam and Gilbert, 2014). These representations should be both descriptive and depictive (Opfermann et al., 2017).

Macroscopic representation, also referred to as a phenomenological type of representation, implies representation of perceptible properties of matter observed through the senses and measured, as during an experiment (Sujak and Daniel, 2017). These properties include mass, density and temperature. On the other hand, sub-microscopic representation seeks to explicate components of matter and materials which are too minute to observe, even with the use of an optical microscope (Gilbert and Treagust, 2009). Kapıcı and Savas-cı-Açıkalın (2015) also referred to sub-microscopic representation as a model type of representation in the form of graphs (2-dimensional) and models (3-dimensional). Whereas symbolic representation uses symbols to represent chemical phenomena and may be used in conjunction with both the macroscopic and the sub-microscopic levels of representation (Gilbert and Treagust, 2009). Symbolic representation assists the macroscopic level with quantitative representation, while giving qualitative support to sub-microscopic representation of physical and chemical changes in chemical reactions (Gilbert and Treagust, 2009).

A variety of terms (some listed below) is used to describe or name each type of representation described above (Gilbert and Treagust, 2009):

- First level: macro level, macroscopic level, macroscopic world and microchemistry.
- Second level: sub-micro level, microscopic level, sub-microlevel, sub-microscopic level, molecular world, atomic world and sub-microchemistry.
- Third level: symbolic level, symbolic world, representational chemistry and algebraic system and representational chemistry.

For consistency, the terms that were used in the study to refer to the three levels of chemical representation were those uniformly used by a considerable number of authors such as Tan et al. (2009), Davidowitz and Chittleborough (2009); Bucat and Mocerino (2009); Van Berkel, Pilot and Bulte (2009); Cheng and Gilbert (2009); Taber (2009); Becker et al. (2015); Koopman (2017); Eliyawati, Rohman and Kadarohman (2018).

These terms are macroscopic level, sub-microscopic level and symbolic level.

2.5 TEXTBOOK LIMITATIONS

Textbook limitations in this study are viewed from the perspective of alignment of textbook content with curriculum standards. The findings from textbook alignment research conducted by Stern and Roseman (2001) were coupled with those of Bhatti et al. (2017) and together they were used as a benchmark while exploring limitations in preferred Grade 9 natural sciences textbooks.

2.6 REVIEWED LITERATURE: THE WORLD, MIDDLE EAST AND SOUTH AFRICA

In the review of literature, studies used included those conducted on the six continents of the world. While searching for literature, the researcher experienced difficulties to find literature pertaining to African and South African studies for natural sciences textbooks' relationship with the national curricula. Studies conducted on Middle Eastern textbooks were used instead of those on African textbooks, firstly because the findings from the Middle Eastern studies discussed limitations in science textbooks resulting from the relationship between science textbooks and the national curricula. Secondly, the studies from the Middle East explained that poor learner performance was an outcome of a weak correlation between science textbooks and the national curricula. Such findings were not identified for Africa; hence the Middle East was chosen instead. The literature reviewed was from a global perspective. In the discussion, the findings from all continents will be conducted simultaneously, yet systematically. More focus will be given to Middle Eastern findings than to global findings because of the close correlation between Middle Eastern and South African learner performance. Due to limited South African literature, Middle Eastern findings were used to make inferences tor South Africa.

The discussion is divided into three parts. It begins with literature findings on the relationship between natural sciences textbooks and national curricula in the world, the Middle East and South Africa. This is followed by the relationship between science textbooks and learner performance in the world, in the Middle East and in South Africa. It then ends with representations in other knowledge strands of natural sciences.

2.6.1 Relationship between natural sciences textbooks and national curricula

In a study by Vojíř and Rusek (2019) on trends in research of science textbooks, most science textbook research (41%) was on science in general, while 21% was on biology, 18% on chemistry, 8% on physics and 2% on geography. An interesting discovery that Vojíř and Rusek (2019) made was that analysis of the relationship between natural sciences textbooks and the curriculum comprised only 4% of textbook research globally, while errors in textbooks and possible problems made up 2%. In their study, out of thirteen topics on textbook analysis, Africa contributed only 3% of the findings. Within the group of countries with the most textbook research, South Africa contributed 3% of the research. This information sheds light on the struggle to find African and South African literature on textbook research for this study.

In their study, Bhatti et al. (2017) mention the gap they found in literature on alignment between textbooks and curriculum. This gap encouraged them to pursue their study. The researcher of this study found a similar gap in South African literature, between natural sciences textbooks and CAPS, and thus also included in the study, the possibility of natural sciences textbook limitations in the South African context.

Stern and Roseman (2001) emphasise that it was not enough for a textbook to provide the same topics as the curriculum, but a textbook must represent the specified knowledge that is required by curriculum standards for the relevant grade. Ideas in science are intricate and can be expanded on over several grade levels to meet specific science knowledge needs which are considered for a grade when a curriculum is developed. A textbook that represents less or more than what the curriculum stipulates is said to be out of alignment with the curriculum grade (Stern and Roseman, 2001). In other words, a textbook is limited if it provides less knowledge than learners are to acquire in the grade, but limitations also exist in a textbook that provides too much content than is prescribed or beneficial for the grade. The limitation in providing less content is that not all the content needed has been included. Limitations in providing too much content implies providing content beyond the scope of the knowledge that learners in the particular grade need to master the essence of the specified aspects of knowledge that are critical in the grade and are significant foundational knowledge for higher grades (Stern and Roseman, 2001). Bhatti et al. (2017) affirm the writings of Stern and Roseman (2001) by expressing that textbooks are aligned with a curriculum if they contain content that corresponds with curriculum, thus they are not limited in representing the prescribed aspects for the specific grade. In other words, curriculum aligned textbooks are neither deficient nor excessive in representing curriculum.

Limitations in textbooks impact negatively on learner achievement (Prinsloo et al., 2016). Learner achievement is used as one of the indicators of learning. Saeed and Rashid (2014) found that limitations in textbooks lead to large numbers of learners dropping out of school.

2.6.1.1 The world

In their study, Saeed and Rashid (2014) found that only 50% of the science textbooks studied in Pakistan represented the national curriculum. They indicate that the literature they reviewed also found little correlation between textbooks and curriculum. In a study conducted by Stern and Roseman (2001) in the United States of America, they found that although textbooks may offer the same concepts as those in the curriculum, the manner in which representations in the textbooks address the topics is crucial. They found that in some textbooks, the presentation of the content is not beneficial to the teachers nor the learners. Nimmermark et al. (2016) found limited verbal and visual representations in Swedish science textbooks; therefore indicating poor correlation with the curriculum.

2.6.1.2 Middle East

Hadar (2017) highlights autonomy in textbook selection in Israel amidst a spectrum of textbook alignment with the intended curriculum. Interestingly, Hadar (2017) points out Israel's textbook alignment research across different subjects offered by schools to ensure that the national goal is met. On the other hand, in other Middle Eastern nations such as the Arabic nations studied by Khaddoor, Al-Amoush and Eilks (2017), textbooks were found to be limited in the manner that they represent the national curricula. Savasci-Acikalin (2019) came across similar findings in their study, stating that there is a fragile relationship between Middle Eastern textbooks and national curricula.

2.6.1.3 South Africa

Within the South African context, Koopman (2017) discovered misconceptions among teachers and learners. The misconceptions found were induced by representations in science textbooks. For instance, he observed one teacher's tendency to lean towards the macroscopic level while guided by the textbook, in a lesson that required focus on sub-microscopic and symbolic levels of representation. This exposed the teacher's misconceptions and caused the learners to learn science concepts through the transference of those misconceptions from the teacher and the textbook. He also noted the imbalance in the three levels of chemical representations. He noted that textbooks employed mostly sub-microscopic and symbolic levels of chemical representation, leaving the macroscopic level to receive insufficient attention.

Another incident took place during an interview in the same study by Koopman (2017). When one teacher was asked why they stated a definition the way they did, they said it was because that was how it was written in the textbook. The teacher did not state the definition in the curriculum document, but instead relied on the textbook as though it were the curriculum document (McDonald and Abd-El-Khalick, 2017; Koopman, 2017) and stated the definition incorrectly, as it appeared in the textbook.

The two incidences experienced by Koopman (2017) during his study, revealed shortcomings in textbooks. The shortcomings or limitations may have a negative impact on learner performance especially when the textbook is used by a novice teacher. From the limitations revealed by the incidences, it could be inferred that the textbooks were limited in representing content that was prescribed by CAPS.

Another South African study was conducted by Nyanhi and Ochonogor (2020) to explore how science learners engaged with the sub-microscopic level of chemistry. In this study, it was found that teachers in the South African basic education system drilled knowledge for examinations and did not teach for understanding. Also, the three levels of chemistry representation were present in science textbooks, but teachers were not well versed in integrating them in practice.

In their study, Nimmermark et al. (2016) found that science textbooks in South Africa were very limited in providing chemical representations verbally and visually. They concluded that poor performance of learners in assessments of basic chemistry concepts such as chemical bonding, was impacted by the quality of representations in the textbooks, because representations influenced interpretation.

It can be concluded from these findings by Nyanhi and Ochonogor (2020), and Nimmermark et al. (2016) that representations in science textbooks in South Africa fail to meet the prescriptions and requirements of CAPS, in turn leading to learning outcomes not being met and learner performance weakened.

2.6.2 Relationship between science textbooks and learner performance

2.6.2.1 The world

In their study on trends in textbook alignment research, Vojíř and Rusek (2019) found that Europe, North America and Asia contribute 41%, 28% and 16%, respectively, of the publications used in the study. In the study by Reddy et al. (2016), the same continents performed above the TIMSS scale centrepoint. However, little research has been done to determine whether there is any correlation between leaner performance in a specific region of the world and textbook alignment research in the same region.

After reviewing literature for their study conducted in Pakistan, Saeed and Rashid (2014) assert that only few studies have investigated the relationship between textbooks and the national curriculum. Congruent with the limited literature found by Saeed and Rashid (2014) are the findings by Bhatti et al. (2017). In their study, Bhatti et al. (2017) discovered that little research had been done on textbook correlation with national curricula and that textbook content may not correspond with curriculum prescriptions. They also found that there is a misalignment in science textbooks in Punjab and emphasise that learner performance is directly impacted by the relationship between a textbook and curriculum.

2.6.2.2 Middle East

In the Middle East, there exists a weak relationship between representations in natural sciences textbooks and the curriculum document, leading to a deterioration in learner performance (Savasci-Acikalin, 2019). This is a finding similar to that which Khaddoor et al. (2017) came across in seven Arabic countries (Algeria, Egypt, Jordan, Kuwait, Palestine, Saudi Arabia and Syria) in which there was a wide variety of textbooks and no alignment with the national curricula. A TIMSS and PIRLS study by Mullis et al. (2020) also confirms that science performance in Middle Eastern schools is below average. This could be explained by the relationship between textbooks and national curriculum as found by (Savasci-Acikalin, 2019).

However, there appears to be a discrepancy among Middle Eastern findings. In the study by Reddy et al. (2016), Israel ranked among the top performing countries in the world, thus being the only Middle Eastern country in a high rank. Concurrently, Hadar (2017) highlighted that Israel frequently conducts research on textbook alignment. It is noteworthy that the country with regular textbook alignment research also produces above-average learner performance in natural sciences. Also noticeable is that the countries in which textbook alignment with national curricula is scarce (Khaddoor et al., 2017) show striking deficiencies in natural sciences performance. More interestingly, these countries are in the same region as Israel.

2.6.2.3 South Africa

Reddy et al. (2016) conducted a TIMSS study in the Northern Hemisphere, Asia, Middle East and Africa. They found similarities in performance of Grades 8 and 9 science learners from the Middle East and Africa. They indicate that the two continents performed the lowest among the four. Sadly, South Africa held the last position in science performance among the poorest performing nations. Better performance was found in the Northern Hemisphere and Asia.

Through their 2015 TIMSS study, Prinsloo et al. (2016) reveal that poor comprehension of chemical concepts represented in textbooks is a direct cause of the unsatisfactory academic performance of South African Grade 9 learners in matter and materials. Although the same study shows that poor performance of South African Grade 9 learners is evident in other knowledge strands of natural sciences, performance in matter and materials proves to be the weakest. South African learners obtained an average score of

22% in matter and materials and 25% in each of the other three strands.

In South Africa, for the curriculum of CAPS, Prinsloo et al. (2016), found that Grade 9 learners perform poorly in the content of matter and materials. During formal assessment, learners seem to be more prone to providing concrete and visible responses than abstract and theoretical alternatives. Prinsloo et al. (2016) base this level of performance on poor understanding of chemical concepts presented in textbooks. Musa and Ceyhan (2019) discovered that many learners consider matter and materials to be difficult to understand because it comprises mainly abstract concepts.

Reddy et al. (2016) found that Grades 8 and 9 science learners from the Middle East and South Africa perform similarly poorly. Because of a weak relationship between representations (verbal and visual) in Middle Eastern natural sciences textbooks and their curriculum document, learner performance there is weakened (Savasci-Acikalin, 2019).

In the report of the 2019 TIMSS study, Reddy et al. (2020) conclude that among 39 countries in the world, South African Grade 9 learners ranked in last position again, despite having improved from ranking ‘very low’ in 1995, 1999 and 2003 to ranking ‘low’ in 2011, 2015 and 2019.

Regrettably, neither statistics nor literature were found reflecting any comparison between verbal and visual representations or chemical representations in South African natural sciences textbooks and CAPS. The impact of the relationship between representations in natural sciences textbooks and CAPS on the academic performance of South African learners, needed exploring. Due to the similarities in performance of the Middle Eastern and South African cohorts, an assumption or inference was made for the negative impact on learner performance by poor representation of the curriculum document in the textbooks.

Although the relationship between insufficient research in textbook alignment and learner performance in South Africa still needs to be explored, it is interesting to observe that insufficient textbook research and poor learner performance appeared simultaneously in the Middle East and South Africa.

2.6.3 Representations in other knowledge strands of natural sciences

Although the literature discussed above was informative towards this study, inferences had to be made to link representations in textbooks with those in CAPS for verbal and visual representations of the macroscopic, sub-microscopic and symbolic levels in matter and materials. The literature obtained up to this stage did not explicitly discuss the relationship between natural sciences textbooks and CAPS for the representation of the three levels. The researcher yet had to fulfil the task of finding more studies that could assist to adequately address the research problem of poor learner performance in matter and materials while keeping in mind the context of learners taught by novice teachers that are textbook dependent. The situation necessitated a change in the type of literature that was sought.

The new angle that the researcher took was to find literature on representations in other knowledge strands of the natural sciences curriculum, so that reference could be made to ascertain possible limitations in natural sciences textbooks based on representations of concepts in each knowledge strand. This would assist the researcher to determine whether these limitations, if any, played a role in poor performance in natural sciences. Findings in the other knowledge strands, if any, would be even more relevant if they reflected on the South African context. Literature on representations in each knowledge strand will be discussed individually in the following sub-sections.

2.6.3.1 Representations in biology (life and living)

Johnstone (1991), cited in Tsui and Treagust (2013), insists that multiple representations in science are applicable to chemical and biological education. Although Tsui and Treagust (2013) agree with him on the most part, they highlight shortcomings that accompany his conviction. They explain that in biology (life and living), there are entities within other entities. Therefore, levels of representation do not necessarily represent the same entity. For instance, a cell is found in a tissue, which in turn is found in an organ, but all three are different entities. They contrast this characteristic of biology with that of chemistry (matter and materials). In chemistry, representation of one entity can be found in different forms. For example, a compound such as water can be seen, touched and measured. The molecules that make water are still water. Both the seen and the 'unseen' aspects of water are still of the same entity, water.

In life and living there are four levels of representations in comparison with the three that are employed in matter and materials. These are macroscopic, microscopic, sub-microscopic and symbolic. Those in matter and materials exclude the microscopic level and are not embedded within one another.

Despite the similarities representations between life and living and matter and materials stipulated above, the weight of the differences is such that no reference of multiple representations could be made from life and living to supplement the limited literature applicable to this study for matter and materials. Even if there were findings that indicated a relationship between life and living representations in textbooks and CAPS, it would have been challenging to draw conclusions regarding matter and materials representations in textbooks and CAPS because multiple representations in each knowledge strand are unique. Multiple representations in matter and materials apply specifically to matter and materials (Johnstone, 1993) and pose unique challenges in learner understanding and performance in that strand (Prinsloo et al., 2016).

2.6.3.2 Representations in physics (energy and change)

For the third knowledge strand in natural sciences, namely energy and change (physics), there happens to also be a use of multiple representations. These representations are text and pictures, but mostly come in the form of mathematical expressions involving variables and equations (Opfermann et al., 2017). Fatmaryanti et al. (2018) refer to a combination of two or more of verbal, mathematical, image and graphic representations as multiple representations in physics (energy and change). In their book dedicated to multiple representations in physics, Hubber and Tytler (2017) state, "*multiple representations are needed, including text, to satisfactorily solve problems and communicate explanations*". The multiple representations in energy and change are unique to energy and change therefore could not be transferred to matter and materials.

Nonetheless, studies comparing science textbooks and CAPS for representations of physics concepts could not be identified.

2.6.3.3 Representations in Earth science (planet Earth and beyond)

For the fourth knowledge strand called Planet Earth and beyond, literature found the discussed representations to be superficial. LaDue, Libarkin and Thomas (2015) make mention of earth sciences representations in their study. What they discuss in their study is visual representations used in assessments in the four knowledge strands of natural sciences. They note that the relationship between the different uses of images such as graphs, drawings, photographs and models across the four strands is inconclusive, meaning that the use of visual images in one strand may not be applicable to or provide the same meaning as in another strand.

In the light of the intricate characteristics of the four knowledge strands reflected in the similarities between the strands and the uniqueness of each strand, natural sciences textbook analysis in the South African context needed to be explored to determine whether any limitations existed in verbal and visual representations on the three chemical representation levels found in natural sciences textbooks. Such limitations could prove to be a factor impacting the pedagogical process and learner performance (Bhatti et al., 2017).

Regardless of these glaring findings, which span almost two and a half decades, South African literature still does not provide evidence for research showing representations in textbooks being paralleled with those in CAPS to ascertain the possibility of limitations in verbal and representations or chemical representations in natural sciences textbooks.

Natural Sciences textbook analysis in the South African context includes an extensive scope of studies on textbook representation, but no documents reflecting research on comparison of natural sciences textbooks with CAPS were found. Studies on Natural Sciences textbooks in South Africa included representation of the nature of science (Ramnarain and Chanetsa, 2016), botanical representation (Abrie, 2016), diversity in science textbooks (Ceglie and Olivares, 2012) and readability of science textbooks (Sibanda 2014). In addition, Natural Sciences textbook analysis conducted to evaluate the representation of aspects of the curriculum policy occurred during the transition from OBE to NCS and from NCS to RNCS (Lemmer, Edwards and Rapule, 2008). Dempster et al. (2015) conducted a comparative study between NCS and CAPS. In 2016, a Ministerial Task Team investigated racism, sexism and other forms of discrimination in South African textbooks (DBE, 2016). The latest studies identified were on chemistry representations in South African textbooks (Nyanhi and Ochonogor, 2020).

The myriad of representations is acknowledged but was not included in this study, primarily to focus on an analysis of and a comparison between verbal and visual representations of matter and materials in Grade 9 natural sciences textbooks and CAPS.

To assist teachers who rely on textbooks to teach natural sciences, curriculum designers and developers could offer more guidance to authors of natural sciences textbooks that are yet to be published. In their guidance, they could focus more on representations in textbooks in line with CAPS. More importantly, the focus needs to be on how to represent the unique entities that comprise each of the four knowledge strands such that an inexperienced teacher may be able to assist their learners better to comprehend relevant concepts, constructs and principles of science. In turn, learning objectives stipulated in CAPS will also be reached better. Because there are textbooks that are already in circulation, they might continue to be used by some schools. It is therefore imperative that inexperienced teachers are trained at their schools by departmental heads or senior teachers on the use of the CAPS document in conjunction with the textbook for lesson planning, teaching and assessment.

2.7 SUMMARY

In Chapter 2, the literature that was reviewed proved that research in textbook-curriculum relationship still has a long way to go, both locally and internationally. In the following chapter, the conceptual framework that was employed to explore limitations in natural sciences textbooks in their representation of verbal and visual aspects of matter and materials, particularly of compounds, will be discussed.

CHAPTER 3: DUAL CODING AND CHEMISTRY TRIPLET: A CONCEPTUAL FRAMEWORK

3.1 INTRODUCTION

Chapter 2 unpacked the concept of learning and learning in science, textbooks and representations in science textbooks to enhance learning of concepts of matter and materials. We also engaged with the status of representations in science textbooks in different parts of the world and South Africa while comparing alignment of textbook representation research and learner performance in Grade 9 natural sciences.

This chapter will focus on the construction of a conceptual framework derived from the concepts of the dual-coding theory (Sadoski & Paivio, 2001) and the principles of the chemistry triplet (Johnstone, 1993), woven together through the four double-edged types of representation collectively described by Wu and Puntambekar (2012) as the taxonomy of representations.

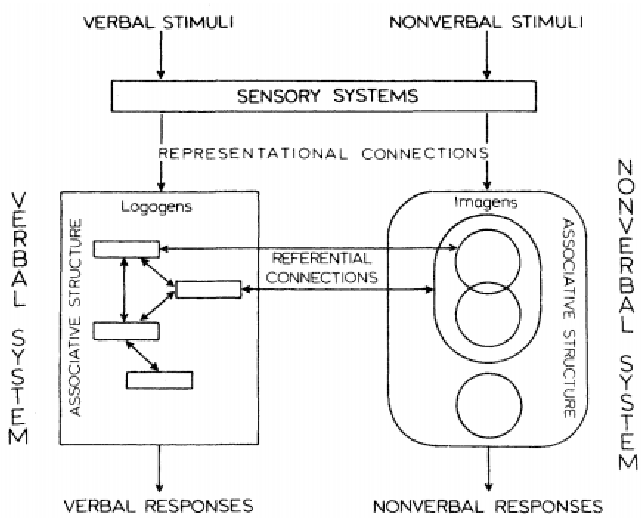
A conceptual framework maps out how the researcher intends to carry out their study and explore the concepts involved (Adom, Hussein and Adu-Agyem, 2018), while it knits together, graphically or narratively, the main ideas that comprise the research study (Miles, Huberman and Saldaña, 2014).

The purpose of the framework in this study was to explore the level of limitations in Grade 9 natural sciences textbooks in South Africa when compared with CAPS. It puts together three parts, namely the dual coding theory, the chemistry triplet and the taxonomy of representations. Verbal and visual representations (main components of the dual-coding theory) in the national policy document and textbooks are broken down into the three levels of the chemistry triplet, producing the representation taxonomy which forms an adhesion between the theory and the triplet.

A description of each component of the framework is detailed below, followed by a graphical representation of the framework.

3.2 DUAL-CODING THEORY

Dual Coding Theory is a connectionist theory which acknowledges the differences and the complementary link between representations of its verbal and visual sub-systems (Sadoski & Paivio, 2001). It embodies the crucial relationship between the two sub-systems which possess unique structures and functions, made evident through processing and retaining information acquired (Clark and Paivio, 1991). Dual coding involves *"referential connections [that] enable performing operations like imaging to words and naming to pictures or images to words"* (Paivio, 1990).



Paivio (1990)

Figure 3. 1: Referential connections between verbal and non-verbal systems

These connections can be seen in the science domain of matter and materials in which models can produce combinations of chemical symbols and symbol combinations can produce names of compounds. For instance, in the reaction equations below representing the formation of water from hydrogen gas and oxygen gas, the models allow for chemical symbol combinations, which in turn give rise to compound names.

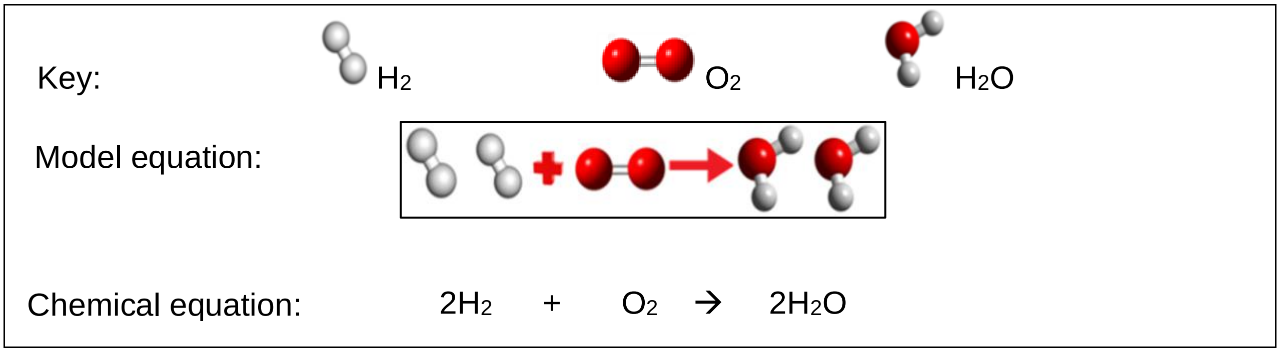
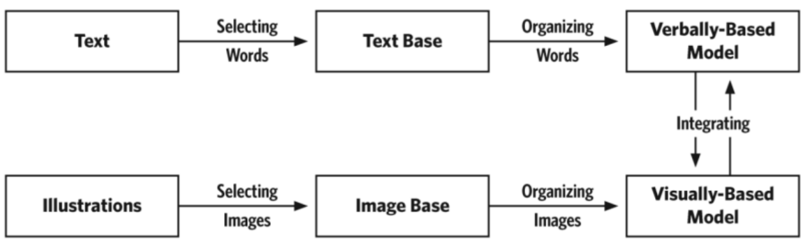


Figure 3.2: Naming compounds using models

Having been produced from hydrogen and oxygen, the chemical name for water is hydrogen oxide. This name can be derived from the chemical symbol combination as illustrated by the models above.

The theory by Paivio is supported by Peterson (2016) as illustrated in Figure 3.3 below.



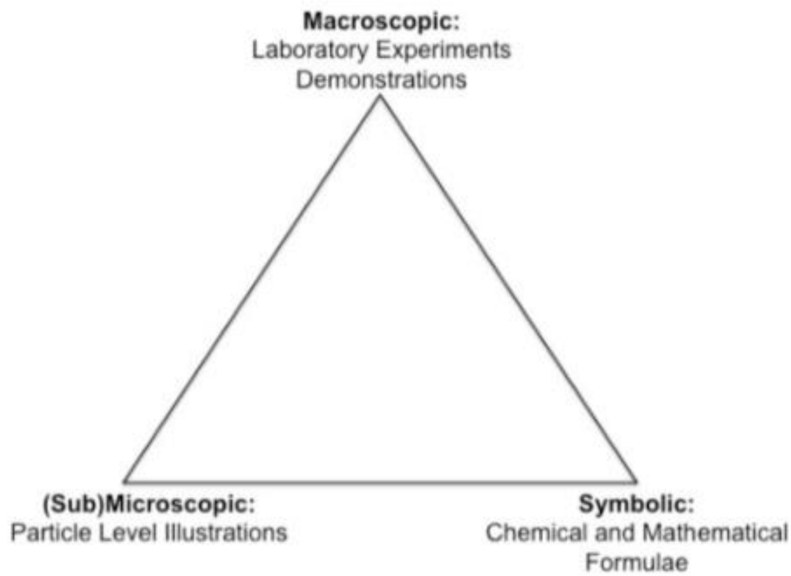
Source: Peterson (2016)

Figure 3.3: Mentally Integrating Text and Illustrations

Peterson (2016) advocates the interconnectedness of verbal and visual information in science textbooks. He insisted that text-visual integration ought to be employed effectively in every science textbook for the specific level of education.

3.3 CHEMISTRY TRIPLET

On the other hand, the chemistry triplet is a combination of multiple, external representations (macroscopic, sub-microscopic and symbolic) in natural sciences, particularly in chemistry (Johnstone, 1993), that seeks to collaboratively simplify scientific concepts and phenomena.



Source: Erica Posthuma (2016)

Figure 3.4: The chemistry triplet

The chemistry triplet integrates the three levels of chemical representation to allow for a comprehensive understanding of chemical concepts. The three levels can be understood individually and in combination with one another (Johnstone, 1993).

3.4 TAXONOMY OF REPRESENTATIONS

The representation taxonomy was employed to weave a link between the chemistry triplet and the dual-coding theory. As proposed by Lemke (1998) and Tsui (2003) and discussed by Wu and Puntambekar (2012), it comprises four types of representations in science, namely verbal-textual, symbolic-mathematical, visual-graphical and actional-operational.

Table 3.1: Representation types in the taxonomy of representations

Representation Type	Examples
verbal-textual	written text
symbolic-mathematical	equations and formulae
visual-graphical	diagrams
actional-operational	demonstrations

Adapted from Wu and Puntambekar (2012).

3.5 INTEGRATION OF DUAL-CODING AND THE CHEMISTRY TRIPLET

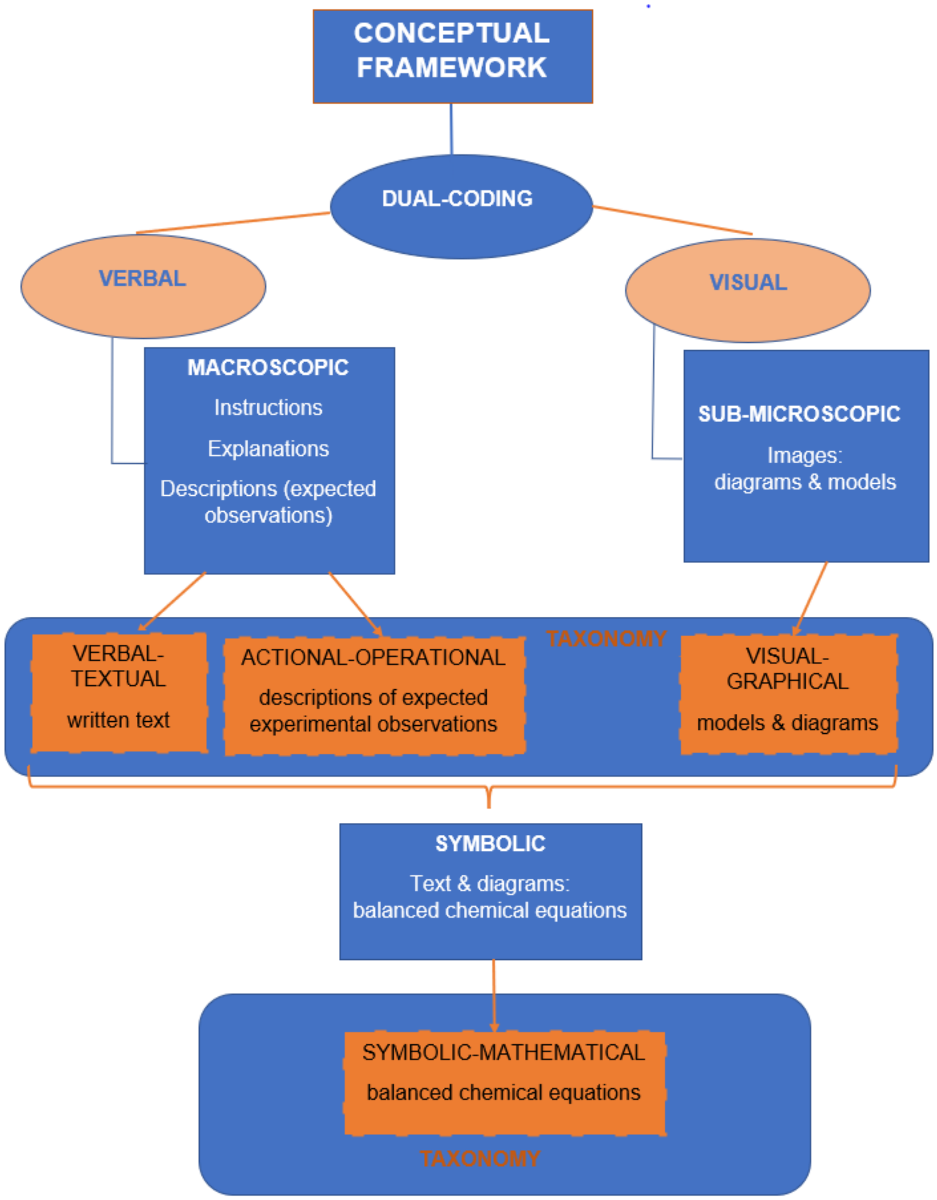
Dual-coding theory and the chemistry triplet are integrated through the taxonomy proposed by Lemke (1998) and Tsui (2003). The verbal and visual representations are broken down into three components of the chemistry triplet (Wu and Puntambekar, 2012).

Lemke (1998) and Tsui (2003) indicate that this combination of multiple external representations with verbal and visual representations gave rise to the four types of representations in the taxonomy detailed above.

The framework for the study is structured such that verbal and visual representations (dual coding) are dissected into the chemistry triplet in a similar relationship as exists in the taxonomy. In the study, Grade 9 natural sciences textbooks' representation of matter and materials were correlated with concepts, constructs and principles identified CAPS. An analysis of verbal representation was carried out on the macroscopic level in terms of instructions, explanations, and descriptions of expected observations. This relates to verbal-textual and actional-operational representations in the taxonomy (Lemke, 1998.; Tsui, 2003.; Wu and Puntambekar, 2012). Sub-microscopic representation, in the form of images (diagrams and models) of atoms and compounds, is the level at which visual representation was analysed congruent with visual-graphical representation (Lemke, 1998.; Tsui, 2003.; Wu and Puntambekar, 2012).

Symbolic representation depicted the relationship between the verbal and visual representations through the consolidation of text and diagrams in the form of balanced chemical equations. This correlated with symbolic-mathematical representation (Lemke, 1998.; Tsui, 2003.; Wu and Puntambekar, 2012).

The three levels of the chemistry triplet speak to one another (Gilbert and Treagust, 2009) and emphasise the uniqueness of and relationship between verbal and visual representations (Sadoski and Paivio, 2001).



Source: Constructed by author.

Figure 3.5: The conceptual framework

Figure 3.5 above illustrates how the researcher constructed the conceptual framework. The framework employed the taxonomy of representations to weave the dual-coding theory (verbal and visual) and the chemistry triplet (macroscopic, sub-microscopic and symbolic levels of chemical representation) together.

3.6 SUMMARY

In Chapter 3, the conceptual framework constructed by the researcher was discussed. It used the taxonomy of representations to consolidate the dual coding theory and the chemistry triplet. In Chapter 4, the research methodology applied to the study will be discussed.

CHAPTER 4:
RESEARCH METHODOLOGY

4.1 INTRODUCTION

The research questions of this study were addressed through the methodology that is explained in this chapter. The chapter is divided into sub-sections under which specific parts of the methodology are discussed.

4.2 RESEARCH DESIGN

A research design outlines the procedure that a research study follows to select and collect data for analysis so that research questions may be answered (Boru, 2018). The exploratory research design was the most suitable design for this study. Exploratory research design sheds light on a phenomenon that is of interest to the researcher if no similar research has been done previously (Bowen, 2009; Boru, 2018). The exploratory research design chosen for this study was the analysis of selected documents. The choice of the exploratory design was applicable to this study as explained below.

Through exploratory research design, the researcher was able to explore a two-fold problem of the study using thematic analysis. On the one end, the researcher explored the poor Grade 9 learner performance in natural sciences in South Africa. According to Reddy et al. (2020), poor performance of Grade 9 learners in South Africa, in the knowledge strand of matter and materials, spans more than two decades since the year 1995. Despite the assistance that the researcher received from the university's librarian, an online library and several academic repositories, documented studies for comparison between the South African senior phase curriculum policy document and Grade 9 natural sciences textbooks were not found by the researcher. This gap in literature was discussed in Chapter 2 of the study. Due to the lack of literature on this topic, the study employed an exploratory research design and therefore needed primary qualitative data collected directly from CAPS and textbooks to be collected to answer the research questions.

The other end of the problem was novice teachers' sole dependence on the textbook for subject matter due to a lack of pedagogical knowledge and/or limited content knowledge (Orgoványi-Gajdos, 2015). The dependence on textbooks is a problem when novice teachers replace the policy document with the textbook for subject matter. This side of the problem was observed by the researcher over a period of 8 years. The same problem was discovered by Orgoványi-Gajdos (2015), Ramnarain and Chanetsa (2016), and McDonald and Abd-El-Khalick (2017).

4.2.1 Sampling procedures

Non-probability sampling was the sampling technique chosen for the study because of the exploratory nature of the study. Within nonprobability sampling, purposive sampling was used to select documents namely, CAPS and three preferred Grade 9 natural sciences textbooks, because all four documents possessed similar characteristics (Kumar, 2011). The characteristics that CAPS and the three preferred textbooks had in common were the content of Grade 9 natural sciences and the representation of matter and materials verbally, visually and on the three levels of chemistry representation. Because the study sought to compare CAPS and preferred textbooks in Grade 9 natural sciences, the researcher visited an educational bookstore that supplies textbooks to schools. The researcher requested copies of the natural sciences textbooks for Grade 9 preferred the most. From those identified by the bookstore personnel, the three textbooks preferred the most were used for the study. The preferred textbooks were ones purchased the most. If these textbooks proved to have limitations when compared to CAPS, that would imply that many learners were exposed to learning through these limitations and that novice teachers with limited content knowledge using these textbooks were presenting limited content in practice.

4.2.2 Data collection instruments

Data were collected from primary sources which were purposively selected following a deductive approach. The primary sources were the Grade 9 senior phase CAPS policy document and three preferred textbooks. The researcher visited a bookstore that supplies textbooks to schools and individuals. The textbooks used in the study were identified by the bookstore as being the most preferred ones. CAPS was used in the study because it contains content that should be in the textbooks that are currently used in South African public schools.

- Textbooks

Each textbook consisted of the four strands of knowledge in natural sciences. Of the four strands (section 1.1) matter and materials is the knowledge strand that was analysed in each textbook because literature showed that it has the most challenging content for learners to understand (Prinsloo et al., 2016); Musa and Ceyhan, 2019). The components of matter and materials that were selected for analysis were description of compounds, naming and chemical formulae of compounds, and chemical reactions. Data from textbooks were collected together with data from CAPS.

- CAPS

CAPS outlines content prescriptions and guidelines for the four knowledge strands in natural sciences. The components of matter and materials that were analysed were identified in CAPS then listed. Based on that list, data were collected simultaneously from CAPS and the textbooks.

4.2.3 Data collection and analysis methods

The process of data collection using a data collection schedule for data to be analysed is discussed below.

4.2.3.1 Schedule for CAPS and Textbooks

The data collection schedule used for CAPS and the three preferred textbooks was made up of the prescriptions and guidelines from CAPS. The schedule was structured in table form to group similar aspects of curriculum content together (see Appendix C). The curriculum content used was concepts, constructs and principles of compounds. Data from CAPS and the three textbooks were collected concurrently, although the data were later analysed by comparing each individual textbook with CAPS. Each aspect of the content in textbooks was correlated with matching prescriptions and guidelines in CAPS.

To ensure credibility of the schedule, the same aspects were considered when collecting data from CAPS, Textbook A, Textbook B and Textbook C. Furthermore, the schedule was piloted using a Grade 10 physical sciences textbook. A Grade 10 textbook was selected due to the relevance of matter and materials in physical sciences and the grade being higher than Grade 9. Gaps in physical sciences textbook would highlight a need for exploring textbooks of Grade 9 natural sciences. Grade 9 is a critical grade which concludes the senior phase and marks the introductory stage of physical sciences.

4.2.3.2 Collection of data

Primary data collected from the CAPS policy document and three preferred Grade 9 natural sciences textbooks were textual and visual data of the concepts, constructs and principles of compounds in the knowledge strand of matter and materials.

The study was conducted to compare textual and visual data in the four documents for possible limitations in the textbooks when representing compounds. Comparison of data from the documents required a document analysis method. Bowen (2009) refers to document analysis as a step-by-step procedure of examining data. It is therefore systematic. The systematic document analysis procedure applied to this study was the identification of themes from the documents. In other words, thematic analysis was applied to the primary data collected from CAPS and the textbooks. The choice of thematic analysis was informed by the exploratory nature of the study and the need for data comparison that was underpinned by the research questions. Bowen (2009) described thematic analysis as a procedure which produce themes and categories from identification of patterns within data.

To explore and compare data, common themes were identified systematically from similarities and differences between CAPS and each textbook. The study focused on comparing verbal and visual representations in the four documents for common themes produced by the primary data collected. Themes from verbal (textual) and visual data were used to answer research questions.

4.2.4 Data collection procedure

Prior to the collection of data from CAPS and three preferred Grade 9 natural sciences textbooks, curriculum prescriptions and guidelines for verbal and visual representations of matter and materials were identified in CAPS, on the three levels of chemical representation, and were used as the framework for data collection.

Thereafter data were collected from CAPS, Textbook A, Textbook B and Textbook C and tabulated according to the concepts, constructs and principles of compounds. These three aspects of compounds were allocated to groups identified from the research questions. The groups were verbal, visual and verbal-and-visual representations representing sub-questions 1, 2 and 3, respectively. This means that verbal representation consisted of some concepts, constructs and principles, as did visual representation and the combination of verbal and visual representations. Each group represented a specific level of chemical representation. Verbal represented macroscopic, visual represented sub-microscopic and verbal-and-visual represented symbolic.

The process of data collection was facilitated by the prescriptions and guidelines identified from CAPS and it was also informed by the research questions of the study to ensure that the research questions were answered. Curriculum prescriptions are the standards that policy makers expect for content, content delivery and assessment (Kauffman, 2005). In other words, the prescriptions specify aspects of the content that are to be taught and assessed within the subject and the Grade. For this study, the curriculum prescriptions were the verbal and visual representations of the content to be taught in Grade 9 natural sciences in the strand of matter and materials on the macroscopic, sub-microscopic and symbolic levels. That is, the verbal and visual representations that should be in 'CAPS-aligned' natural sciences textbooks. Verbal and visual representations of matter and materials broken down into macroscopic, sub-microscopic and symbolic representations resulted in:

- Concepts: the concept of compounds and how compounds are formed (chemical reactions),

- Constructs: balancing chemical equations to represent chemical reactions and foster understanding of compounds, and
- Principles: rules for naming compounds and principle for balancing chemical equations.

While curriculum prescriptions provide the ‘what’ of curriculum, curriculum guidelines provide the ‘how’. Curriculum guidelines outline the approach to be adopted to meet curriculum standards. These guidelines should be clearly provided by textbooks. In this study, the guidelines include revision of Grade 8 work, a list of compounds learners are required to know, and how practical work should unfold for naming compounds and for carrying out chemical reactions.

The curriculum prescriptions and guidelines used in the study are the prescribed content outlined in Appendix C.

4.2.4.1 CAPS

Data from CAPS were collected using the collection schedule constructed by the author and explained above. Data collected from CAPS were organised into verbal and visual aspects of concepts, constructs and principles in matter and materials. Under verbal representations were descriptions, explanations, instructions for practical work and observations to be made during practical work. All aspects pertaining to practical work were also clustered as macroscopic.

Under visual representations were images. Images included photographs, drawings and models. Although images were not found in CAPS, prescriptions and guidelines in CAPS regarding images, were the data captured under visual representations.

Data forming a link between verbal and visual representations were grouped together. The data were aspects presented in chemical symbolic, that is formulae and chemical equations together with principles (rules) governing naming, writing formulae and balancing equations.

All the data were organised in table form.

4.2.4.2 Textbooks

The textbooks that were used for data collection we renamed. The pseudonyms were Textbook A, Textbook B and Textbook C. The data collection from each textbook followed the same procedure as with CAPS for verbal representation and for the combination of verbal and visual representations. The difference with the textbook data collection was that real images were provided by textbooks for visual representation. The images were photographs, drawings and models.

4.2.5 Relationship between research methods and research questions

The method used to collect and analyse data was informed by the questions posed by the study. The study sought to explore how CAPS compared with the three preferred textbooks for verbal and visual representations as well as a combination of the two types of representation. Each sub-question pointed to verbal, visual or a combination of the two representations, respectively.

4.3 RESEARCH APPROACH

The study sought to explore data in documents by means of comparison. The documents under comparison were CAPS and three preferred Grade 9 natural sciences textbooks. The quest to explore data in CAPS and the three preferred textbooks was to discover whether there were limitations in natural sciences textbooks in representing curriculum. Limitations in the textbooks would imply that learning was compromised and thus poor learner performance in Grade 9 natural sciences was inevitable.

Because of the explorative nature of the study, a deductive qualitative approach was followed (Creswell and Creswell, 2018). A deductive approach is a procedure that begins with preconceptions, prior to collection of data Yin (2016). Qualitative research is explained by Kumar (2011) as one that makes use of "*descriptive or narrative statements as the units of measurement"* and its process of analysis seeks to determine variation without quantifying it. A deductive approach in qualitative research allows a researcher to develop codes prior to applying them to data for analysis rather than waiting for them to emerge (Yin, 2016). The *a priori* codes can be formulated from the researcher's propositions (Bingham and Witkowsky, 2021), as was the case in this study.

Advantages of employing the deductive approach (Bingham and Witkowsky, 2021) to this study were:

- Application of a conceptual framework.
- The formulation and application of the conceptual framework were discussed in Chapter 3.
- Sorting data into data types.
- This process was conducted in this study for data collection, as explained in Chapter 4.
- Organising data into categories to maintain alignment with research questions.
- Chapter 5 of the study discusses this process.

4.4 TRUSTWORTHINESS

The data collection instrument was tested through piloting it on a Grade 10 physical sciences textbook. The credibility of the data was strengthened by persistent observation during which the data were coded and recoded until meaningful findings were obtained. Also, the data that emerged from the four primary data sources were triangulated (section 5.3).

4.5 ETHICAL CONSIDERATIONS

Ethical clearance was sought from and granted by the Research Ethics Committee of the University of the Free State (see Appendix B). For data source selection, a list of preferred Grade 9 natural sciences textbooks was requested from a bookstore renowned for selling school textbooks to different schools and to individuals. To protect the identity of the authors and publishers the three selected textbooks, each textbook was given a pseudonym. The textbooks were renamed (Tripathy 2013); see Appendix C. Plagiarism was avoided by applying paraphrasing, citation and relevant referencing rules.

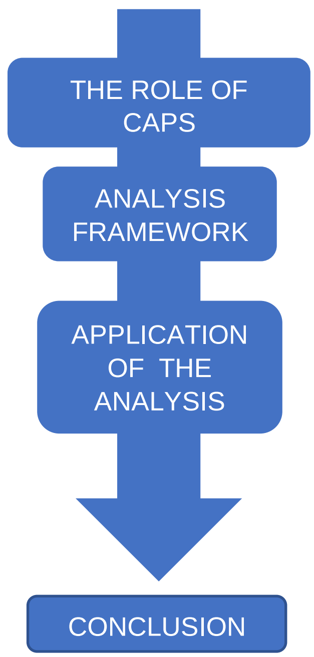
4.6 SUMMARY

Chapter 4 focused on the approach and design followed in the study. It also discussed ethical issues that were considered. Both the approach and design influenced the process of data collection. The analysis of the data is discussed in chapter 5.

CHAPTER 5:
DATA ANALYSIS

5.1 INTRODUCTION

Chapter 4 looked at the methodology and data collection procedure involving the methods and the design followed for the study. This chapter, pays attention to the analysis of primary data collected from the senior phase Curriculum and Assessment Policy Statement (CAPS) and three preferred Grade 9 natural sciences textbooks. The discussion of data analysis will follow the diagrammatic structure provided in Figure 5.1 below.



Source: Constructed by author

Figure 5.1: Structure of data analysis

5.2 THE ROLE OF CAPS

CAPS provide curriculum standards, which are prescriptions and guidelines for teaching and learning. It also provides learning outcomes that can be measured through formative and summative forms of assessment. CAPS prescriptions, guidelines and learning outcomes are key in determining aspects of curriculum that the researcher could analyse to explore the possibility of limitations in Grade 9 natural sciences textbooks, in the knowledge strand of matter and materials.

Primary data analysed to explore the possibility of limitations in the textbooks when compared to the CAPS policy document were obtained from three preferred Grade 9 natural sciences textbooks and CAPS. Possible limitations in textbooks pertained to verbal and visual representations of compounds on the three levels of chemical representation namely, macroscopic, sub-microscopic and symbolic.

5.2.1 Curriculum standards: Prescriptions and guidelines

Curriculum standards referred to in this study are prescriptions and guidelines for teaching and learning of matter and materials in Grade 9 natural sciences.

The prescriptions given by CAPS are non-negotiable verbal and visual content to be taught and assessed. Verbal and visual content in matter and materials must be taught and learnt on all levels of chemical representation. Each aspect of chemistry can be represented at the three levels.

The first level of chemical representation is the macroscopic level, which is an experiential level. It involves observations that can be made through the senses; that is, seeing, feeling, smelling and hearing. Chemical concepts, constructs and principles are described and explained through verbal representations in textbooks so that what is observed can be understood better.

The second level is the sub-microscopic level. It is the abstract level of the macroscopic observations. It employs visual representations through images to represent chemical concepts and constructs involved at the invisible level of chemistry. CAPS prescribes that the images used for teaching and learning should be in the form of drawings or models.

The third level merges the macroscopic and sub-microscopic levels into a verbal and visual combination. This combination represents chemical concepts, constructs and principles in a symbolic manner. It is known as the symbolic level of chemical representation which represents compounds by making use of symbols from the Periodic

Table of Elements. Element symbols are combined in specific ratios to form unique chemical formulae for different compounds. These formulae are instrumental in assigning chemical names to compounds. CAPS expects that the symbolic level be explained verbally in the text and shown visually through drawings or models to represent how compounds are formed during chemical reactions.

Although CAPS prescribes verbal and visual content, it affords teachers the opportunity to improvise on how to make models to represent the sub-microscopic level of compounds. It does this by providing guidelines which offer direction on how the teaching process could be approached. For instance, CAPS suggests using playdough or modelling clay among other materials that may assist with building compound models. Due to the complex and abstract nature of matter and materials, verbal and visual aspects of the content must be taught through macroscopic, sub-microscopic and symbolic representation levels of matter and materials for better understanding.

Hence, verbal representation in the study relates to the macroscopic level, visual representation refers to the sub-microscopic level and verbal-and-visual is a combination of the two on the symbolic level.

5.2.2 Learning outcomes

Learning outcomes referred to in this study pertain to that which must be achieved through teaching and learning of matter and materials in Grade 9 natural sciences. The achievement of these outcomes can be measured through classroom activities, homework activities, tests (formal and informal), projects and examinations.

CAPS specifies learning outcomes that must be reached and measured through formative and summative forms of assessment, for the content of matter and materials in Grade 9. The yardstick that CAPS provides for measuring learners' knowledge in matter and materials in Grade 9 is "*that they can:*

- distinguish between pure substances and mixtures
- distinguish between elements and compounds
- name and make models of simple molecules

- for any of the studied reactions: 1) describe it in general terms; 2) describe the changes that occur during the reaction; and 3) write a balanced equation
- describe the neutralisation of an acid with a base using pH. (DoE, 2011).

5.2.3 Formulation of *a priori* codes

CAPS played a significant role of providing curriculum standards and learning outcomes that the researcher used to formulate *a priori* codes. Another reason for employing CAPS for the formulation of *a priori* codes was the assumption that poor performance in Grade 9 natural sciences in South Africa, in the strand of matter and materials, cannot only be attributed to aspects related to the abstract nature of chemical concepts. The lack of research on possible limitations in textbooks' representation of the curriculum policy document in South Africa was a potential factor for poor performance and needed to be explored.

The reason for this assumption is supported by the following example. In the Middle East, Israel conducted studies on textbook alignment with curriculum policy and produced better learner performance in Grade 9 natural sciences (Hadar, 2017) than other Middle Eastern countries such as Kuwait, Jordan and Saudi Arabia, which provide poor evidence of similar studies (Khaddoor et al., 2017). The weaker-performing Middle Eastern nations produced similar results in Grade 9 chemistry as South African Grade 9 natural sciences learners did. This similarity in science performance between those poorly performing countries and South Africa as well as the insufficient evidence, from both, in studies for curriculum alignment of science textbooks, made it necessary to explore the limitations in science textbooks. Textbooks that meet national curriculum standards in full increase the quality of teaching and learning and improve learner performance (Bhatti et al., 2017).

Coupled with the possible effects of textbook limitations on learner performance was the observation made by the researcher that novice teachers tend to rely solely on textbooks for lesson planning and teaching, thus neglecting reference to the CAPS policy document. This aspect could influence learner performance negatively even further if textbook limitations are present.

Therefore, the choice to employ CAPS for formulating *a priori* codes for the study was made with reference to the CAPS provision of curriculum standards and learning outcomes, poor learner performance, the assumption that poor learner performance could be influenced by limitations in textbooks, and the observed trend of inexperienced teachers when using textbooks.

5.3 ANALYSIS OF DATA

In the discussion of the analysis of data, we will first look at specific aspects of verbal, visual and verbal-and-visual representations, then the use of *a priori* codes, followed by the analysis framework and lastly, the application of the framework.

Through the analysis of primary data, the researcher intended to explore limitations in preferred Grade 9 natural sciences textbooks when compared to the CAPS policy document. Three main aspects that were compared were listed according to the research questions in this study. These main aspects were verbal, visual and verbal-and-visual representations of concepts, constructs and principles identified in matter and materials in Grade 9. They were based on the prescriptions, guidelines and learning outcomes identified in CAPS.

Firstly, for verbal representation, each textbook was compared with CAPS for the representation of the macroscopic level of representing compounds. The purpose for comparison was to explore possible limitations within the text of the content and informal assessment activities in each textbook. Verbal aspects used for comparison were classified as verbal explanations. Verbal explanations were:

- Concepts
    - Descriptions of compounds (including definitions and macroscopic appearance)
- Constructs
    - Naming compounds

    - Instructions for practical work involving compounds (including observations to be made)
- Principles
    - Rules for naming compounds

Secondly, visual representation of the sub-microscopic level of compounds was compared between the textbooks and CAPS to discover whether there were limitations in the use of drawings or models of compounds that were used by each textbook in the content and assessment activities. According to CAPS, either drawings or models may be used to address the sub-microscopic level of compounds. Comparison was made through:

- Concepts
    - Sub-microscopic compound structures
- Constructs (to facilitate understanding of concepts)
    - Drawings
    - Models

Thirdly, verbal-and-visual representation of identified aspects presented symbolically in the textbooks were compared with CAPS for possible limitations in content and assessment activities of each textbook. Aspects compared were:

Verbal

- Concepts and Principles
    - Explanations, in the content, for balancing chemical equations.
    - Textual information in informal assessment tasks, for balancing chemical equations

Visual

- Constructs
    - Drawings or models in the content, for balancing chemical equations

    - Drawings or models in informal assessment tasks, for balancing chemical equations
- Verbal-and-visual
- Principles (Conservation of atoms)
    - Balancing chemical equations in the content.
    - Balancing chemical equations in informal assessment tasks

Although the aspects of comparison listed above were used to answer the research questions, they were not the ones initially identified. The following sections of this chapter discuss the process that took place from the beginning of data analysis until research questions had received satisfactory answers. The discussion begins with the formulation of *a priori* codes, then goes on to explain in theory, the framework employed for data analysis and finally, how the framework was applied to the study.

5.3.1 *A priori* codes

To allow room for the data that would be analysed to produce their own categories and themes, three broad codes were predetermined. The broadness of the *a priori* codes ensured that the data were not restricted to what the researcher expected to find. The codes were concepts, constructs and principles (in the knowledge strand of matter and materials in Grade 9). These three codes encompassed the essence of CAPS prescriptions, guidelines and learning outcomes for verbal and visual representations of matter and materials. The CAPS policy document was instrumental in formulating *a priori* codes for analysis of data because the study sought to explore possible limitations in natural sciences textbooks when compared to CAPS.

The first code was concepts. That is, compound names and chemical formulae. The second code was constructs for balancing chemical equations. Lastly, the third code was principles or rules that direct the formulation of compound names and formulae, as well as the balancing of chemical equations.

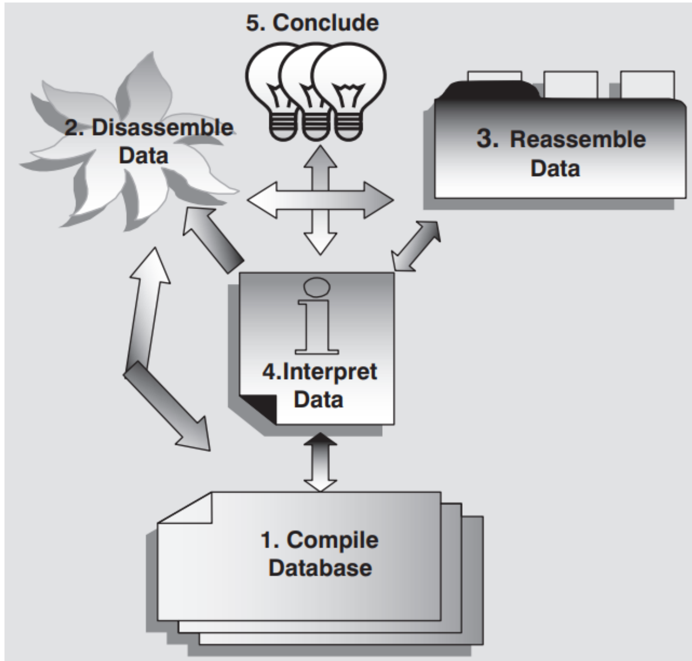
In the sections that follow, the analysis framework by Yin (2016) is discussed. The application of Yin's (2016) framework for analysis of primary data from CAPS and the three preferred Grade 9 natural sciences textbooks is also explained thereafter. The framework and its application were discussed separately to explain what the framework is, then elaborate on how it was applied in the study.

5.3.2 Analysis framework

Several analysis frameworks were explored. The framework used by Yin (2016) was best suited for the study, therefore it was selected and adapted. Many of the frameworks explored catered mainly for data collection instruments such as questionnaires, interviews and surveys. In their article, Castleberry and Nolen (2018) explain how Yin's framework sums up thematic analysis in general. This means that it is applicable to qualitative studies that seek to utilise thematic analysis of data from any type of data collection instrument, including textbooks used as sources of primary data.

This framework of thematic analysis comprises five stages, namely compiling, disassembling, reassembling, interpreting and concluding.

The stages are not necessarily clean-cut. The three middle stages need to be repeated throughout the analysis. For example, the process of interpreting data is needed to disassemble and reassemble the data repeatedly. Figure 5.2 below illustrates the framework and is followed by a description of each stage based on work by Yin (2016) and Castleberry and Nolen (2018). A flowchart is used to illustrate the interaction of the stages with one another (Verdinelli & Scagnoli, 2013).



Source: Yin (2016)

Figure 5.2: Yin's (2016) analysis framework stages

- Stage 1: Compiling

The initial stage of analysis involves arranging collected data in a manner that will make it 'user-friendly'. During the process, data is extracted from sources. In the quest to find meaning and answer research questions, the process requires that the data be read through repetitively. This is an important stage that affords the researcher an opportunity to acquaint themselves with the data before it is analysed (Yin, 2016). The study is of a deductive approach, *a priori* codes may be formulated (Creswell and Creswell, 2018; Castleberry and Nolen, 2018).

- Stage 2: Disassembling

After data is compiled, the second stage ensues. In this stage, data is pulled apart and clustered into groupings (Castleberry and Nolen, 2018). This process may recur multiple times throughout the analysis process (Creswell and Creswell, 2018). It may even occur in conjunction with other stages. For instance, through interpretation, data may be disassembled and reassembled several times (Yin, 2016).

- Stage 3: Reassembling

Once the data has been grouped, it is put together into codes and categories in alignment with research questions (Castleberry and Nolen, 2018). Themes will emerge from categories of the codes. The reassembled data may be tabulated, listed or graphically arranged (Yin, 2016).

- Stage 4: Interpreting

This crucial stage involves description of patterns and informs the conclusions that will be made about theme patterns for answering research questions. Interpretation must be comprehensive and scientifically sound (Castleberry and Nolen, 2018), because it weaves all the stages of analysis together as it also informs repetitive coding during analysis (Yin, 2016).

- Stage 5: Concluding

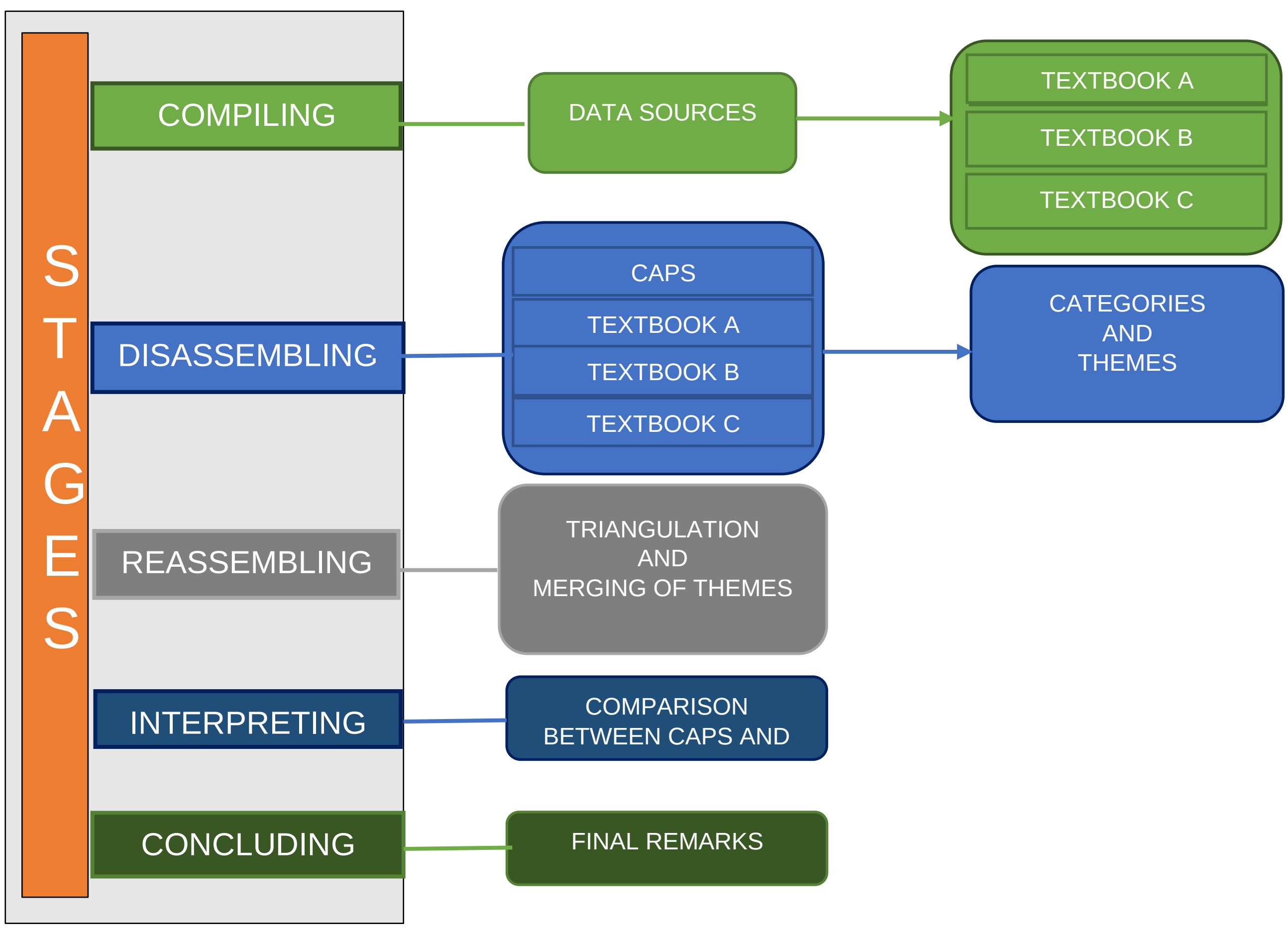
Research questions are addressed during the concluding stage of analysis by meaningfully relating themes to the research questions in the light of the interpretation that took place during the earlier stages (Yin, 2016; Castleberry and Nolen, 2018).

5.3.3 Application of the analysis framework

Primary data was compiled from the senior phase CAPS document and three preferred Grade 9 natural sciences textbooks for deductive analysis through the thematic analysis framework. The data were extracted from the text and transcribed from images in the three textbooks. The data were also drawn from CAPS so that a comparison between verbal and visual representations of chemical compounds in CAPS and the textbooks could be conducted.

A priori codes were formulated using CAPS. The textbooks were given pseudonyms Textbook A, Textbook B and Textbook C. Data were disassembled into codes and lists of categories. Initial themes were identified from those categories.

Reassembling took on the form of recoding and drawing up new categories, which produced new themes. The codes, categories and themes evolved over time as analysis advanced through the five stages, allowing data to progressively gain clearer meaning to answer the research questions. Throughout the stages, interpretation shaped the process of finding meaning in data and in relation to research questions about verbal, visual and verbal-and-visual representations in Grade 9 natural sciences textbooks and CAPS. At the end, conclusions were made regarding the data findings and the analysis process, and correlation was made with the research questions. The 5-stage framework was adapted for the study and applied as illustrated in Figure 5.2.



Source: Constructed by author

Figure 5.3: Analysis framework adapted from Yin (2016)

5.3.3.1 Stage 1: Compiling

During the first stage of analysis, data sources were acquired. The main data source was the natural sciences senior phase CAPS policy document. It provided different aspects of content that should be taught and therefore should be in textbooks. Other data sources were three preferred Grade 9 natural sciences textbooks used in South Africa. Two were borrowed from schools and the third was purchased by the researcher.

The researcher employed CAPS for formulating *a priori* codes for the study. The initial codes that were identified from CAPS were concepts, constructs and principles involving compounds. Identification of the *a priori* codes was anchored on CAPS standards (prescriptions and guidelines) and learning outcomes because the study sought to compare CAPS and three preferred textbooks for possible limitations in the textbooks when presenting verbal and visual representations of compounds on the macroscopic, sub-microscopic and symbolic levels of chemical representation.

Extracted textual data and transcribed visual data were tabulated (Castleberry and Nolen, 2018). Yin (2016) views it as creating a database. The codes under which the data were tabulated were concepts, constructs and principles identified in CAPS.

The table allowed for identification of initial similarities and differences in concepts, constructs and principles between data from the textbooks and from CAPS (Yin, 2016; Castleberry and Nolen, 2018). See Appendix C. The extracted and transcribed data were then ready for comparative analysis.

5.3.3.2 Stage 2: Disassembling

In the process of disassembling, tabulated data from the textbooks and CAPS were dismantled so that they could be grouped during stage 3 of analysis (Yin, 2016; Castleberry and Nolen, 2018) for relevant themes to emerge. Through continuous engagement with the data, codes were repetitively revised, and new ones assembled.

Initial codes, which were predetermined were:

- Concepts

- Constructs
- Principles of compounds

They were identified from CAPS prescriptions, guidelines and learning outcomes. The themes that emerged from them were:

- Grade 8 content revision on elements and compounds.
- Compound naming is limited.
- Rules for naming are not enough.
- Models to assist learners to visualise compounds at a sub-microscopic level.
- Learners should see the products formed during chemical reactions.

The codes were unable to bring forth themes that could answer the main research question: “How does the representation of concepts, constructs and principles of matter and materials in preferred Grade 9 natural sciences textbooks compare with CAPS?”

The codes were restrictive and the themes that they produced could not be linked to the main question, particularly with reference to the macroscopic, sub-microscopic and symbolic representations, collectively. Therefore, new codes, which were a more extensive list of aspects unique to matter and materials, were considered. The new codes were obtained from the CAPS policy document because textbooks were being compared to CAPS for limitations in representing compounds.

The new codes were:

- Description of compounds,
- Explanation of naming of compounds,
- Instructions for practical work on compounds
- Expected observations of compounds (practical work)
- Images
- Models
- Balanced equations

- Chemical reactions

The data, through the eight codes above, gave birth to new themes. The common emerging themes were:

- Incomplete description of compounds
- Incomplete naming of compounds
- Rules, drawings and models are necessary
- Where is the representation for observations in practical work?
- No drawings
- No models
- Where are the atoms?
- Reactions are almost complete

In the light of the main question, the themes did not yet provide adequate meaning to answer the research question. A repetition of data comparison between CAPS and the textbooks was done, but this time the existing codes were dismantled into verbal, visual and verbal-and-visual groups. New codes were informed by the sub-questions of the study. Final themes emerged as categories were identified from each textbook's data and listed under the relevant codes.

The data were structured according to the tables below. Each table lists codes, categories and themes from CAPS, Textbook A, Textbook B and Textbook C, respectively.

Table 5.1: Themes emerging from CAPS

CODES	CATEGORIES	THEMES
Verbal representations of concepts, constructs or principles.	Verbal explanations - descriptions - naming - instructions for practical work	The concept of compounds must be explained through descriptions, naming, formulae and origin of compounds.
Visual representations of concepts, constructs or principles.	Pictures or models; see where chemical symbols come from.	Images are necessary for understanding compounds.
Verbal-and-visual representations of concepts, constructs or principles.	**Verbal** - Why balance chemical equations **Visual** - Draw pictures or make models **Verbal-and-visual** - Use of symbols	Chemical reactions must be understood through explanations, images and symbols.

Emerging themes from CAPS are discussed in depth below.

Theme 1: The concept of compounds must be explained through descriptions, naming, formulae and origin of compounds.

- Verbal explanations

In the CAPS policy document, verbal explanations identified were a combination of descriptions of compounds, rules for naming compounds and instructions for practical work involving compounds. The essence thereof was prescriptions and guidelines given by CAPS for teaching and learning of matter and materials in Grade 9 natural sciences, on a macroscopic level of compound representation.

- Descriptions

CAPS began the topic of compounds in Grade 9 by firstly referring to the introduction of compounds in Grade 8. In Grade 8, compounds were described as pure substances made from two or more elements. The purpose was for Grade 9 knowledge to be built on that foundation.

- Rules for naming

Rules speak to steps involved in assigning chemical names to compounds and making chemical formulae meaningful. Chemical names are names of compounds formulated scientifically by chemists. CAPS described the chemical name of a compound as a name specific for that compound and derived from the elements the compound is made of. In CAPS used sodium chloride as an example of a chemical name explained that sodium chloride was a name acquired from the two elements that made the compound. The two elements were sodium and chlorine.

Some compounds also have common names which must be taught in Grade 9 according to CAPS prescriptions. Common names of compounds are informal names that chemists have assigned to compounds. A common name represents a specific compound. Common names are used daily by people who are not necessarily involved in chemistry. CAPS gave three examples of common names namely, table salt, water and ammonia.

- Instructions for practical work

Verbal prescriptions and guidelines for carrying out practical work are provided in the form of instructions. Instructions for the creation of compound models, either single compounds or compounds in a chemical reaction, are given by CAPS as a prescribed list of compounds to be included in teaching and learning. CAPS describes compounds as having formulae that support compound names. On the other hand, guidelines were provided by CAPS as recommendations for conducting experiments. Guidelines were also lists of macroscopic observations learners should make during practical activities.

Theme 2: Images are necessary for understanding compounds.

- Pictures or models; see where chemical formulae come from.

Visual representation of prescribed content from CAPS affords authors the option of representing the sub-microscopic level of compounds through a choice between drawings and models to guide the learning process of naming compounds and writing down their chemical formulae. CAPS also specifies the compounds that must be included in the process. Namely water, carbon monoxide, carbon dioxide, copper oxide, sodium chloride and sulphur trioxide.

Theme 3: Chemical reactions must be understood through explanations, images and symbols

- Verbal
    - Why balance chemical equations?

The answer that CAPS gave for balancing chemical equations was that chemical equations represent the principle of conservation of atoms. Stated in CAPS, the principle read: “the atoms of the reactants cannot be lost during a chemical reaction. They are merely rearranged when products are formed” (DoE, 2011).

- Visual
    - Draw pictures or make models

CAPS offered the option of either using drawings or making models of the sub-microscopic level of compounds. CAPS also mentioned that drawings and models could be used for naming compounds and for writing their chemical formulae. The importance of drawing pictures or making models to show how products are formed from the rearrangement of atoms when a reaction takes place was emphasized by CAPS.

- Verbal-and-visual
    - Use of symbols

A link between the symbolic, verbal and visual representations is referred to by CAPS. CAPS firstly gives a verbal explanation about chemical equations having to be balanced. It gives the explanation through stating the principle of conservation of atoms. Secondly, it explains visual representation of chemical equations using drawings or models of reactants and products. Of the compounds involved in chemical reactions, the only polyatomic ions CAPS mentions are the hydroxide (-OH) and carbonate ($-CO_3$) ions. Thirdly, it uses symbols and numbers to support explanations and drawings or models. The three facets of the chemistry triplet namely macroscopic, sub-microscopic and symbolic, are catered for by CAPS.

CAPS prescribes one reaction for which learner must know the word *equation*. This equation represents the oxidation or combustion reaction between copper and oxygen to produce copper oxide. The reaction between copper and oxygen is the only one whose word equation is prescribed for learners to know.

Table 5.2: Themes emerging from TEXTBOOK A

CODES	CATEGORIES	THEMES
Verbal representations of concepts, constructs or principles.	▪ What is in a name? ▪ Explanation for writing compound formulae.	Relationship between compound names and formulae must be explained.
Visual representations of concepts, constructs or principles.	▪ Pictures of models	Creating models of the invisible particles of compounds helps with visualisation.
Verbal-and-visual representations of concepts, constructs or principles.	▪ Symbolism - Symbols of individual compounds - explanation and use of symbols of compounds in chemical reactions.	Symbols of chemical reactions are understood through explanations and images.

Emerging themes from TEXTBOOK A are discussed in the points that follow.

Theme 1: Relationship between compound names and formulae must be explained.

- What is in a name?

Textbook A explains how names give identity to compounds and that the name of a compound is specific for that compound. It continues by saying that a chemical name comes from the elements that the compound is made of. Also, the number of atoms of each element in a compound influences the chemical name of the compound. It differentiates between chemical and common names of compounds.

Two of the examples that Textbook A uses for giving chemical names are carbon monoxide (CO) and carbon dioxide (CO_2). Although both compounds are made from the same elements (carbon and oxygen), the number of atoms of each element is unique for each compound. In the two examples given by Textbook A, one carbon atom and one oxygen atom represent carbon monoxide (CO) while one carbon atom and two oxygen atoms represent the compound, carbon dioxide (CO_2). Textbook A further explains that this is the reason for the prefixes mono- (one) and di- (two) for the oxygen part of the compound name.

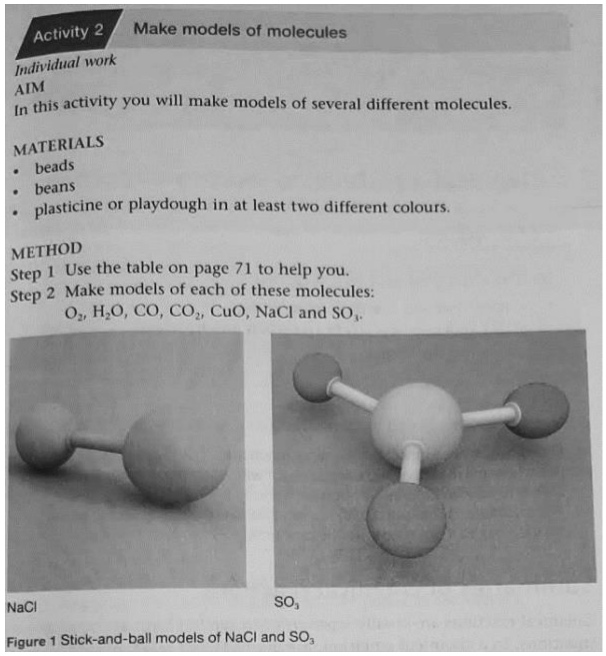
Some compounds have common names, according to Textbook A. An example of a common name found in Textbook A is water. People generally know which substance the name water represents. They might not associate it with chemistry, but they know that it represents a specific substance. Another common name that Textbook A gives is the compound, ammonia.

- Explanation for writing chemical formulae

The formula gives an indication of elements in a compound. Those elements are found in specific ratios for specific compounds. This is how the concept of chemical formulae was introduced in textbook A. The textbook used examples of compounds to explain formulae. The two examples that it used were sodium chloride (NaCl) and carbon dioxide (CO_2). It mentioned that in NaCl, for each atom of sodium (Na) there will be one atom of chlorine (Cl). Therefore, the ratio of atoms in sodium chloride is 1:1. Carbon dioxide (CO_2) consists of one carbon atom and two oxygen atoms. The subscript indicates that there are two oxygen atoms and the ratio of carbon to oxygen is 1:2, the book explained.

Theme 2: Creating models of the invisible particles of compounds helps with visualisation

- Pictures of models



Activity 2 Make models of molecules

Individual work

AIM

In this activity you will make models of several different molecules.

MATERIALS

- beads
- beans
- plasticine or playdough in at least two different colours.

METHOD

Step 1 Use the table on page 71 to help you.

Step 2 Make models of each of these molecules: O_2, H_2O, CO, CO_2, CuO, $NaCl$ and SO_3.

NaCl

SO_3

Figure 1 Stick-and-ball models of NaCl and SO_3

Figure 5.4: Textbook A activity on models of molecules

The practical activity in the excerpt above was obtained from Textbook A. Through this activity the textbook gives verbal instructions and explanations of how practical work is to be carried out and what learners are to experience through observation. This is a verbal representation of compounds (and one element) through a macroscopic experience. Although the explanations and steps for the macroscopic observations are verbal, the models also represent the sub-microscopic level of representation.

Theme 3: Symbols of chemical reactions must be understood through explanations and images

- Symbolism
    - Symbols of individual compounds

Textbook A gives verbal explanations and models for the principle of conservation of atoms. This principle is also represented in Textbook A in symbol form. Examples used by the textbook to illustrate this principle are $C + O_2 \rightarrow CO_2$ and $2H_2 + O_2 \rightarrow 2H_2O$. An activity is also given by Textbook A to make models of the reactants then rearrange them to show the formation of products.

- Explanation and use of symbols of compounds in chemical reactions

Textbook A explains that no atoms are lost or gained in a chemical reaction. Hence chemical equations are balanced. Chemical equations are made up of symbols of elements and compounds involved. The symbols and the numbers that accompany them are there to illustrate that "no atoms are lost or gained in a chemical reaction; they are simply rearranged". This is a direct quote from Textbook A.

Table 5.3: Themes emerging from TEXTBOOK B

CODES	CATEGORIES	THEMES
Verbal representations of concepts, constructs or principles	▪ What is a compound? ▪ Is that all there is to chemical reactions?	Compounds are explained by connecting elements compounds are made of, to reactions that form those compounds.
Visual representations of concepts, constructs or principles	▪ Draw your creation	The concept of compounds must be practised.
Verbal-and-visual representations of concepts, constructs or principles	▪ Verbal - Balancing chemical equations ▪ Visual - Drawings and models ▪ Verbal-and-visual collaboration - Symbolising explanations and models	Chemical equations can be balanced if symbols of compounds are known.

Themes emerging from TEXTBOOK B are explained as follows.

Theme 1: Compounds are explained by connecting elements compounds are made of, to reactions that form those compounds.

- What is a compound?

In Textbook B, compounds were defined as "*pure substances formed by a chemical reaction between two or more different elements*". The book goes on to explain that compounds receive their names from the names of the elements they are made of. It discusses four steps for naming compounds:

> *Step 1: identify elements in the compound.*
> *Step 2: write down the name of the metal first.*
> *Step 3: if the compound contains only two elements, name the second element and change the ending with '-ide'.*
> *Step 4: if the compound contains three elements, one of which is oxygen, name the element that is not oxygen and change the ending to '-ate'.*

It further explains that there are exceptions to the rules. The one exception it discusses is ending a name with '-ide' even though a compound is made of three elements. The example given by the textbook is that of the polyatomic ion, hydroxide (-OH) found in sodium hydroxide (NaOH).

Prefixes are also discussed for naming of compounds with the explanation that they indicate the number of atoms a certain compound contains. The examples given are carbon *mon*oxide (CO), carbon *di*oxide (CO_2), sulfur *tri*oxide (SO_3) and carbon *tetra*chloride (CCl_4).

Textbook B also provides common names of some compounds, such as water, ammonia and vinegar.

- Is that all there is to chemical reactions?

Textbook B refers to Grade 8 work by mentioning that in Grade 8, learners learn that "*chemical substances can break apart and join together in a chemical reaction*". Also, reacting substances are called reactants and those formed are called products.

Theme 2: The concept of compounds must be practised

- Draw your creation

An activity in Textbook B requires of learners to make models of several compounds, then name them and draw picture diagrams of the models they have created. See the excerpt below.

Formula	Name	Picture diagram
H_2O	Water	
H_2		
O_2		
CO		
CO_2		
CuO		
NaCl		
SO_3		

Figure 5.5: Textbook B activity on compound naming and drawing models

Theme 3: Chemical equations can be balanced if symbols of compounds are known.

- Verbal
  - Balancing chemical equations

The purpose for balancing chemical equations is explained by Textbook B by referring to the atoms involved. The textbook explains that initial atoms react by becoming rearranged into new combinations to form products.

- Visual
  - Drawings and models

Drawings are used by Textbook B to explain steps for balancing chemical equations. The textbook explains the process of balancing through seven steps. Activities for balancing follow the discussion of the steps. In the content, the textbook also states that models can be used to represent chemical reactions, although it does not show any models at that stage.

- Verbal-and-visual collaboration
  - Symbolising explanations and models

In the text and activities in Textbook B, the explanations of chemical reactions and balancing their equations are symbolised by chemical formulae. The models used to illustrate rearrangement of atoms to form compounds are also represented in symbol form.

Table 5.4: Themes emerging from TEXTBOOK C

CODES	CATEGORIES	THEMES
Verbal representations of concepts, constructs or principles.	▪ Grade 9 learners already know what compounds are. ▪ Advanced naming of compounds.	Explaining the concept of compounds using the Grade 10 physical sciences curriculum.
Visual representations of concepts, constructs or principles.	▪ Drawings – so unrelated.	Images can 'miss the mark'.
Verbal-and-visual representations of concepts, constructs or principles.	▪ Chemical symbols need context.	Drawings of chemical equations gone wrong.

An explanation of themes emerging from TEXTBOOK C is provided below.

Theme 1: Explaining the concept of compounds by referring to Grade 8 and using Grade 10 physical sciences curriculum

- Grade 9 learners already know what compounds are

The chapter on matter and materials In Textbook C began with a three-page revision of elements on the periodic table, taught in Grade 8. It then continued directly to the naming of compounds related to Grade 10 physical sciences.

- Advanced naming of compounds

Textbook C explained naming of compounds briefly as follows. "The name of an element changes at the end of a name where it forms part of a compound." It then listed examples of name changes. Three of the examples given are: oxygen becomes oxide; sulphur becomes sulphide; and chlorine becomes chloride. In one sentence, it mentions four examples of compounds in which such name changes exist. The examples of compounds were sodium chloride, iron sulphide, lithium bromide, magnesium oxide. Textbook C then goes on to explain naming of various oxides. That is: one oxygen is monoxide and two oxygens are dioxide. The list is given up to five oxygens, which make a pentoxide.

Another explanation for naming compounds is that of binding ratios and valance numbers allocated according to the periodic table of elements. The textbook mentions that more detail will be given in Grade 10, but for Grade 9, eight valence numbers are explained.

The second-last part of naming in Textbook C involves polyatomic ions; that is, their names, formulae and binding possibilities. It is accompanied by an activity involving 40 compounds, 22 of which contain polyatomic ions. The last part of naming compounds is that of common names. A table of chemical formulae, chemical names and common names is provided. Examples of the compounds in the table are sodium chloride, sodium hydroxide and potassium hydroxide. An activity of 50 marks followed common names of compounds. In the activity 14 marks are allocated to binding possibilities, 20 marks to polyatomic compounds and 16 marks to common names.

Theme 2: Images

- Drawings – so unrelated

Data from Textbook C contain three drawings. The drawings are of two elements and one compound, namely sodium (Na), chlorine (Cl) and water (H_2O), respectively. The drawings are used by Textbook C to explain binding ratios and binding possibilities for creating chemical formulae.

Theme 3: Drawings of chemical equations gone wrong

- Chemical symbols need context

A myriad of chemical symbols representing compound formulae are given in Textbook C. Some are mentioned and others are referred to in the discussion of Theme 1 above. Images such as drawings and models are necessary for understanding symbols used in balancing of chemical equations. Images of two reactants and their product are provided by Textbook C to illustrate why chemical equations should be balanced. The excerpt below shows the balancing of a chemical equation for the reaction between hydrogen (H_2) and oxygen (O_2) to form water (H_2O) using drawings.

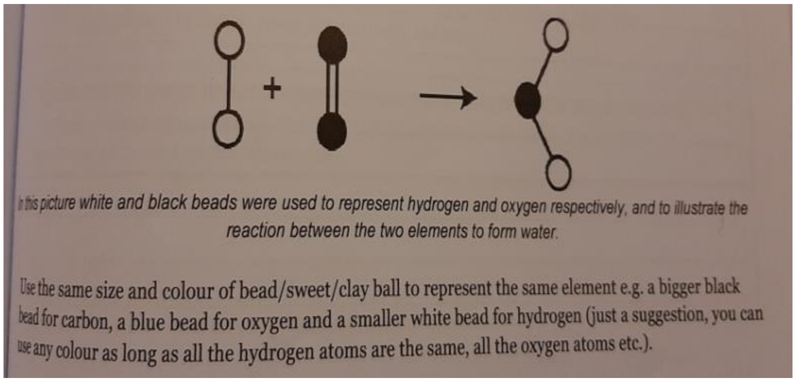


Figure 5.6: Textbook C activity on balancing of a chemical equation

The drawings and the explanations that accompany them do not support the principle of conservation of atoms. This is the principle that gives meaning to balancing of equations.

5.3.3.3 Stage 3: Reassembling – Triangulation of data

Reassembling of data is conducted through the process of triangulation. To curb bias that might have risen from codes and themes formulated by one researcher, it is necessary to triangulate the data to establish credibility of the findings of the study.

Triangulation was conducted through merging themes

Themes from CAPS, Textbook A, Textbook B and Textbook C were merged for triangulation. The combined themes that resulted from merging are shown in the last column of Table 5.5 below. Only the themes that were common among the four data sources and that spoke to the research sub-questions were considered and merged.

Table 5.5: Merging of themes identified in CAPS, Textbook A, Textbook B and Textbook C

Emerging themes				***Combined themes***
CAPS Themes	**TEXTBOOK A Themes**	**TEXTBOOK B Themes**	**TEXTBOOK C Themes**	
The concept of compounds must be explained through descriptions, naming, formulae and origin of compounds	Relationship between compound names and formulae must be explained	Compounds are explained by connecting elements compounds are made of, to reactions that form those compounds	Explaining the concept of compounds using the Grade 10 physical sciences curriculum	***Incomplete explanations of compounds fail to build sufficient foundational knowledge in matter and materials***
Images are necessary for understanding compounds	Creating models of the invisible particles of compounds helps with visualisation	The concept of compounds must be practised	Images can 'miss the mark'	***Images are important for understanding compounds - but be careful how you use them.***
Chemical reactions must be understood through explanations, images and symbols	Symbols of chemical reactions are understood through explanations and images	Chemical equations can be balanced if symbols of compounds are known	Drawings of chemical equations gone wrong	***Explanations, images and symbols must complement one another***

The merged themes from the four documents are listed as follows:

- Incomplete explanations of compounds fail to build sufficient foundational knowledge in matter and materials.
- Images are important for understanding compounds - but be careful how you use them!
- Explanations, images and symbols must complement one another.

Each theme spoke to a specific sub-question. The connection between the sub-questions and the themes is highlighted in the concluding stage and a detailed discussion thereof will be conducted in Chapter 6. The combined themes are discussed as findings of the study in chapter 6.

5.3.3.4 Stage 4: Interpreting

During the stage of interpreting data, each textbook's similarities, differences and limitations were compared with CAPS, and are discussed below.

Textbook A is similar to CAPS in a few aspects; firstly, in explaining the naming of compounds. This is true for both chemical names and common names. Secondly, it explains how chemical formulae are written. Thirdly, visual representations in Textbook A are similar to what CAPS requires are presented. An activity in the book affords learners the opportunity to learn through practice by providing steps for making own models. The activity should help learners to visualize the sub-microscopic level of compounds. The teacher's task to foster learning of these abstract particles will also be made easier. Fourthly, similarities are found in the choice of chemical reactions used for balancing of reactions and for the different kinds of chemical reactions.

Nonetheless, Textbook A's description of compounds differs when compared to CAPS. CAPS describes compounds as pure substances. Textbook A describes them as a combination of elements. Although the description that the textbook gives for elements is that they are pure substances, it does not directly associate compounds with being pure like elements are. This limitation in Textbook A means that teachers without adequate knowledge of elements and compounds may fail to represent elements and compounds correctly when they teach.

Textbook B has similarities to CAPS for the description and naming of compounds. It agrees with CAPS that a compound is a pure substance. It continues to add that compounds are formed by a chemical reaction between two or more different elements. The description/definition that it gives represents and elaborates correctly on the one given by the CAPS policy document. A teacher with insufficient knowledge of compounds will be in a better position to give a well-rounded description of compounds to learners during teaching.

However, several limitations could be identified in Textbook B. Firstly, in the unit of elements and formulae for compounds, one model of a water molecule is used. It was accompanied by the chemical formula for water. Because CAPS does not mention the chemical name of water, it would have been better for the textbook to use a different example that links a chemical name to a drawing or model. Secondly, in the unit for names of compounds, no drawing or model of a compound is used to explain how images relate to names and formulae of compounds. Neither the content nor an activity provides such images. Thirdly, in the unit that explains chemical reactions and equations, Textbook B uses an activity that relates compound formulae, names and models to one another, using water again as an example. There are no images on the content of chemical reactions and equations to explain how compounds acquire their chemical names from the elements they are made of. These limitations in making use of models for different concepts and constructs of compounds in several units in Textbook B will make it challenging for inexperienced teachers in practice. This will be in particular where the teachers need to explain chemical naming of compounds and writing formulae for compounds without the use of images; thus, making it difficult for learners to grasp the concepts of chemical names and formulae.

In Textbook C, there are more limitations than similarities. In essence, similarities between CAPS and Textbook C are in very short supply.

Similarities identified are the inclusion of the content that explains chemical and common names, and activities for writing down names and formulae.

Textbook C differs from CAPS in the following aspects. Firstly, CAPS provides a description for compounds, but Textbook C does not mention nor describe what compounds are. Textbook C has a lengthy revision about elements on the Periodic table, then proceeded to naming compounds. This approach may cause confusion for learners attempting to understand the connection between elements and compounds. Also, a novice teacher who lacks pedagogical knowledge may omit explaining what compounds are or misrepresent compounds at the beginning of the chapter. Secondly, the three drawings provided by Textbook C for naming of compounds are unrelated and deviate from the purpose of images in naming compounds. The combination of drawings may cause confusion for learners who are introduced to naming of compounds for the first time. Thirdly, data from Textbook C pay special attention to valence numbers, binding ratios, binding possibilities and polyatomic ions. As important as these concepts might be, CAPS does not prescribe them for Grade 9. Furthermore, their explanation may produce misconceptions because it accompanies incomplete basic content whose gaps the explanation cannot fill. The concept of compounds is not described, and the images provided for naming are unrelated and insufficient for comprehending how to name compounds.

Fourthly, the illustration used for modelling an example of a chemical reaction is misrepresentative of the principle of atom conservation. It shows one molecule of hydrogen (two atoms) reacting with one molecule of oxygen (two atoms) to form one molecule of water (one oxygen and two hydrogen atoms); that is, 2 atoms + 2 atoms = 3 atoms. There is no explanation for or further representation of the 'missing' oxygen atom. Moreover, no other examples of chemical reactions are provided for balancing chemical equations. The gap created by the unexplained, missing information may lead to confusion and misconceptions. A teacher with poor content knowledge and who fails to refer to the CAPS policy document for lesson preparation, will experience difficulty presenting lessons on balancing chemical equations. Fifthly, no symbols accompanied the incomplete illustration of a chemical reaction. Sixthly, Textbook C does not provide teachers or learners with an explanation of the purpose of balancing chemical equations. Lastly, the reaction for the formation of copper oxide is not represented. According to CAPS, this reaction must be represented in words and in symbols. The word *equation* for the copper oxide reaction is the only one CAPS specifically refers to as the one that learners must know.

The misrepresentation of such crucial concepts, constructs and principle in matter and materials, as found in Textbook C, could lead to shortcomings in learning about compounds, which may be difficult to undo and in turn cause learner performance in natural sciences to remain poor or deteriorate further.

5.3.3.5 Stage 5: Concluding

The aim of the study was to compare the representation of matter and materials in preferred Grade 9 Natural Sciences textbooks with the CAPS document. The combined themes identified in the reassembling stage of analysis were collectively related to the main question and aim while they individually addressed the sub-questions and objectives. The concluding stage of analysis will be discussed in detail in Chapter 6, during which the combined themes will be discussed as the findings of the study.

5.4 SUMMARY

During the stages of analysis, data were repeatedly disassembled and reassembled while being interpreted for meaning. In Chapter 6, the relationship between the findings from CAPS and the three preferred textbooks, main question, sub-questions, aim and objectives will be discussed. The discussion will be followed by implications and recommendations in the same chapter.

CHAPTER 6:

FINDINGS, IMPLICATIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

In Chapter 5, data were delved into through analysis and combined themes between CAPS and the three preferred textbooks were identified. Chapter 6 is dedicated to a discussion of findings that collectively spoke to the main question and aim of the study and individually addressed the sub-questions and objectives. The discussion in the chapter is carried out by firstly reflecting on the findings from the analysis, then discussing the implications of the findings and lastly, making recommendations based on those findings.

6.2 FINDINGS

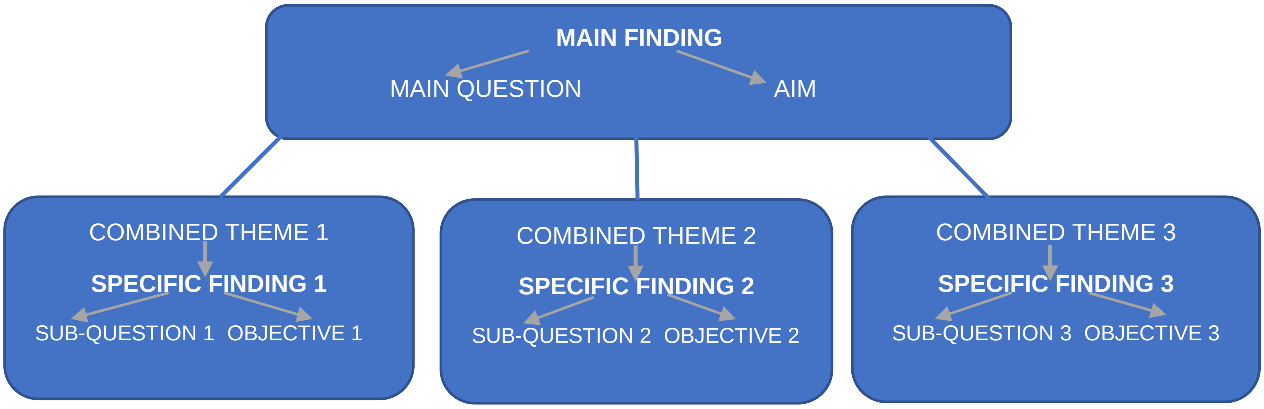
Two types of findings are discussed in this chapter. The first is the main finding and the second is specific findings. The main finding was:

- Although some textbooks may be preferred, they are not deficient of limitations in representing content matter.

Specific findings were made based on the three combined themes listed in chapter 5. The three specific findings were:

- Incomplete explanations of compounds fail to build sufficient foundational knowledge in matter and materials.
- Images are important for understanding compounds - but be careful how you use them.
- Explanations, images and symbols must complement one another.

The main finding was related to the main question and aim of the study, while the three specific findings were directly related to the three sub-questions and objectives of the study. Each finding is discussed below. The relationship between findings, main question, sub-questions, aim and objectives is also discussed according to the structure below.



Source: Constructed by author

Figure 6.1: Findings, questions, aim and objectives of the study

6.2.1 Main Finding: Although some textbooks may be preferred, they are not deficient of limitations in representing content matter

The main finding sums up the specific findings of the study. It also addressed the main research question and aim of the study. Its relationship with the main question and aim are discussed below.

In the content of the three textbooks, concepts, constructs and principles of matter and materials were discussed. More specifically, the focus of the discussion of concepts, constructs and principles in the textbooks was on compounds.

The study found that the representation of concepts, constructs and principles of matter and materials was limited in preferred Grade 9 natural sciences textbooks. Although some textbooks may be preferred over others, that does not imply that they are completely without limitations. The themes that gave rise to the main finding are elaborated upon in the specific findings of the study.

6.2.2 Specific finding 1: Incomplete explanations of compounds fail to build sufficient foundational knowledge in matter and materials

The first specific finding was related to the first sub-question and first objective of the study.

Pertaining to the description of the concept of compounds, each textbook had a unique approach to presenting the meaning of compounds to Grade 9 learners. Textbook A gives a partial description when compared to CAPS. Textbook B duplicates the description provided by CAPS and added more detail to that description, yet still within the scope of the curriculum. Textbook C offers no description of compounds. Textbook A and Textbook C lack proper description of compounds that are prescribed by CAPS. Textbook B manages to incorporate CAPS prescriptions but added to them.

The study found that the explanation of compounds in Grade 9 is complete if it incorporates four aspects. The four aspects are elements that compounds are made of, naming of compounds, chemical formulae of compounds and chemical reactions from which compounds are formed. In its explanation of compounds, CAPS includes the four aspects that are identified from the combined themes emerging from CAPS and the three textbooks.

In its explanation of compounds, all three textbooks address the principles of naming compound and assigning formulae. Textbooks A and B place the focus on principles mentioned by CAPS for naming and assigning formulae to compounds, while textbook C's explanations are haphazard.

In an activity, Textbook A includes verbal instructions and explanations for practical work to represent the macroscopic level of chemistry representation. Textbook B emphasises elements that compounds are made of and mentioned that compounds are produced during chemical reactions. It also gives verbal guidance for macroscopic observations in a practical activity. Textbook C battles to keep up with the CAPS. It explains compounds by partially addressing the prescribed content and affords much attention to chemical bonds, which form part of physical sciences content in Grade 10. Stern and Roseman (2001) call this type of misrepresentation of curriculum, misalignment. That means that

Textbook C neglects some concepts and constructs and although it manages to provide additional information about compounds, it fails to adhere to CAPS prescriptions and guidelines and is therefore limited in representing the intent of the curriculum.

In relation to the first sub-question and objective, two of the three textbooks are deficient in describing and explaining compounds in the manner that CAPS prescribed. The macroscopic level of chemistry representation is not fully in line with the curriculum. For each aspect analysed in verbal representations, limitations are found in the majority (2 out of 3) of the textbooks studied each time, therefore, verbal representations of matter and materials in preferred Grade 9 natural sciences textbooks have limitations in comparison to CAPS for identified concepts, constructs and principles. This finding is the type that Stern and Roseman (2001) report about in their article. Stern and Roseman (2001) write that a textbook is not aligned or is 'limited' when the content it provides is less than that which the curriculum prescribes. That means, if a textbook fails to represent content in alignment with curriculum (Bhatti et al., 2017), it is limited.

6.2.3 Specific finding 2: Images are important for understanding compounds - but be careful how you use them!

The second specific finding was related to the first sub-question and first objective of the study.

The study found that all three textbooks contain visual representation of compounds to assist learners to visualise the sub-microscopic level of compounds. All three textbooks use visual representations prescribed by CAPS: either drawings or models.

Textbook A uses a table in the content that contained compound names, formulae and models. It also has a practical activity for creating compound models for the constructs of naming and writing formulae. Textbook B omits visual representations in the content but includes them in a practical activity that related naming and writing formulae to models of the sub-microscopic particles. Drawings are used in Textbook C. However, the manner in which the drawings are employed is misleading. Some drawings are unrelated to the concept and principle under discussion; others are unrelated to one another. The scientific principle of atom conservation is also misrepresented by the drawings.

In relation to the second sub-question and objective, while examining how visual representations of identified concepts, constructs and principles in textbooks compare to CAPS, it was therefore determined that two out of the three textbooks represent CAPS better that the third one. One textbook has visual representations in the content and assessment activity; the second has them in an assessment activity only; and the third has them in the content, but they are used incorrectly. Because CAPS does not specify whether visual representations have to be included in both content and activities, it can be assumed that correct representation in just an activity, as is the case in Textbook B, is sufficient. It can therefore be concluded that one out of the three textbooks has great limitations in visual representations of the sub-microscopic level. Therefore, one can conclude that there are still limitations in visual representations of preferred Grade 9 natural sciences textbooks (Stern and Roseman, 2001), although to a lesser extent than in verbal representation.

6.2.4 Specific finding 3: Explanations, images and symbols must complement one another

The third specific finding was related to the first sub-question and first objective of the study.

Chemical reactions and equations were the focus of the verbal and visual representation on the symbolic level of representing chemistry. The principle of atom conservation was central to both verbal and visual representations on the symbolic level.

Textbook A and Textbook B represent CAPS adequately for the combination of verbal and visual representations given symbolically as balanced chemical equations. Balancing of chemical equations is found in the content and assessment activities of both textbooks. The purpose for balancing chemical equations is explained in both textbooks. The principle of conservation of atoms during a chemical reaction is also addressed verbally, visually and symbolically by both textbooks. In Textbook C, an attempt is made to represent chemical reactions verbally and visually using explanations and drawings, respectively. It was found that the verbal explanations in Textbook C do not provide the purpose for balancing chemical equations. Moreover, the explanation and the drawings given are both scientifically incorrect and misrepresent the principle of atom conservation, which governs balancing of equations. The explanation and drawings do not reflect in any way on balancing equations. Where symbols are given, there is no correlation between them to signify balancing of equations. The symbols are unrelated and can therefore not be put together to form an equation that could potentially be balanced. There are also no assessment activities found in Textbook C for balancing of chemical equations.

The only chemical reaction that learners are required to learn in word form, according to CAPS, is included in Textbook A content. The same equation is found in Textbook B; however, it is not found in the content, but it is listed in passing among other equations in an assessment activity and no emphasis is placed on it. The reaction is not found in the content, nor assessment activities in Textbook C.

In the findings for verbal and visual representations on the symbolic level for the concepts, constructs and principles of matter and materials, Textbook A presents alignment with CAPS, Textbook B presents some limitations in content and assessment when compared to CAPS, and Textbook C has more limitations in both content and assessment when compared with CAPS.

In summary, content and assessment activities in the three preferred Grade 9 natural sciences that were analysed in this study have limitations for verbal, visual and verbal-and-visual representations of matter and materials. Neither verbal, visual nor verbal-and-visual representation is represented by all three textbooks without limitations.

6.3 IMPLICATIONS

Stern and Roseman (2001) indicate that it is not enough for a textbook to provide the same topics as prescribed by curriculum, it must represent the specified knowledge that is required by curriculum standards for the relevant grade. Curriculum designers and developers pay special attention to the different levels of complexity of science concepts and ideas. They therefore distribute science content with care to achieve specific learning outcomes in a specific grade. A textbook that represents less or more than what the curriculum stipulates is said to be out of alignment with the curriculum. It is said to have limitations if it provides less content matter than that required for the amount and type of knowledge learners are to gain in the grade. Bhatti et al. (2017) affirm the conclusions made by Stern and Roseman (2001) by expressing that textbooks are aligned with a curriculum if they contain content that corresponds with the curriculum; thus they are not limited in representing the prescribed aspects for the specific grade. Having stated that, it is implied that limitations also exist when a textbook provides too much content over what is prescribed for the grade. When less content is provided, the limitation is that the curriculum is not represented in full and not all the content needed is available. Limitation in providing too much content implies providing content beyond the scope of the knowledge that learners in the particular grade need to gain to grasp the essence of the specified aspects critical in the grade (Stern and Roseman, 2001). These aspects of knowledge needed by learners are also significant foundational knowledge for higher grades.

6.3.1 Although some textbooks may be preferred, they are not deficient of limitations in representing content matter

Against the backdrop of what textbook limitations are, the findings of this study imply that preferred Grade 9 natural sciences textbooks are limited in representing the intentions of CAPS. Poor pedagogical and/or lack of content knowledge of novice teachers (Orgoványi-Gajdos, 2015) may be of greater disadvantage to learners for knowledge of the abstract concepts of matter and materials (Musa and Ceyhan, 2019) and performance in natural sciences due to teachers' reliance on the textbooks in the place of CAPS (McDonald and Abd-El-Khalick, 2017; Bhatti et al., 2017; Attakumahi, 2020). Coupled with being taught by inexperienced teachers who are limited in pedagogical approaches and knowledge of science content, learners are also exposed to textbook content that fails to represent the full intent of the curriculum. Thus, learners' understanding of matter and materials' concepts, constructs and principles is impacted such that their performance is rendered among the weakest in the world (Reddy et al., 2016; Prinsloo et al., 2016). The implications of the findings of this study are discussed below per specific finding.

6.3.2 Incomplete explanations of compounds fail to build sufficient foundational knowledge in matter and materials

Some preferred textbooks fail to present compounds in a structured manner that is in line with CAPS prescriptions and guidelines. This failure may hinder some learners from acquiring adequate foundational knowledge of compounds. Foundational knowledge of compounds is essential for understanding the content of chemistry in Grade 9 and in successive grades. Without such understanding, poor learner performance in South Africa may persist and be perpetuated into the following grades.

6.3.3 Images are important for understanding compounds – but be careful how you use them

Schools using textbooks that contain a great number of limitations may experience lower learner performance in comparison with those that use textbooks with less limitations. Since images are used in science textbooks to enhance understanding of the sub-microscopic level of compounds, lack or incorrect use of images in textbooks may lead to difficulty in teaching and understanding such concepts. Furthermore, these difficulties may produce confusion and misconceptions which may be difficult to undo and thus reduce learners' ability to comprehend the more complex concepts of chemistry in grades to come. Learners taught by inexperienced teachers that depend on the textbook for content knowledge may be at a great disadvantage when taught using such textbooks. The performance of such learners may be at risk.

6.3.4 Explanations, images and symbols must complement one another

Limitations in verbal-and-visual representations in preferred science textbooks mean that the symbolic level on which compounds can be represented is not adequately used. Verbal explanations and visual images of compounds should be expressed in symbol form as in the case of chemical equations. In this study, insufficient symbolic representations in one textbook and incorrect ones in another imply that in practice, a novice teacher lacking content knowledge may fail their learners in providing adequate or correct chemical knowledge. More concerning is the incoherence in verbal and visual representations which may induce confusion for both novice teacher and learner. The result of which may impact learner performance in natural sciences.

6.4 RECOMMENDATIONS

The recommendations are presented according to the main finding and the specific findings of the study.

6.4.1 Although some textbooks may be preferred, they are not deficient of limitations in representing content matter

In matter and materials, curriculum prescriptions and guidelines enhance the teaching and learning process to meet curriculum standards of verbal and visual representations of science concepts on the three levels of chemical representation. For this reason, textbook authors should adhere to prescriptions and guidelines if their textbooks are to fulfil the standards of the natural sciences curriculum (Saeed and Rashid, 2014). This will ensure proper coverage of curriculum content and satisfy the standards set for curriculum in the strand of matter and materials. For a textbook not to have limitations, it must address all the content specified in the prescriptions and guidelines at the relevant grade levels and have no content beyond the scope provided by the curriculum document (Polikoff, 2015).

In other words, a textbook that has no limitations is an invaluable tool in the pedagogical process – most particularly for a novice teacher – during planning and teaching. If the novice teacher falls short in pedagogical and/or content knowledge, the textbook may provide sufficient assistance, and simultaneously, help learners to learn what is expected of them at their grade level.

6.4.2 Incomplete explanations of compounds fail to build sufficient foundational knowledge in matter and materials

Verbal representations are necessary for descriptions and explanations of concepts, constructs and principles in science methods (Devetak and Vogrinc, 2013). Observations that are to be made during practical work can only be understood if accompanied by an in-depth explanation (Sujak and Daniel, 2017). Natural sciences textbooks should be drafted such that the textual content correlates with CAPS to ensure that the outcomes CAPS set out to reach are achieved (Stern and Roseman, 2001; Bhatti et al., 2017). Although the topics in the curriculum document and the textbooks may be the same, extra attention should be given by authors to the manner that the content is presented. Curriculum designers or developers could assess the correlation between the curriculum document and each textbook before the textbooks are accepted for publication and distribution.

6.4.3 Images are important for understanding compounds – but be careful how you use them

Images in science textbooks bring abstract concepts ‘to life’ and foster the understanding of such concepts (Sujak and Daniel, 2017). The sub-microscopic aspects of matter and materials that can only be understood through imagination are simplified through drawings and models (Gilbert and Treagust, 2009). Natural sciences authors should ensure that the images they provide support the textual content in the book. Moreover, the images must be aligned with the prescriptions and guidelines of the curriculum document (Stern and Roseman, 2001; Bhatti et al., 2017). Curriculum designers or developers could assist authors by reviewing the use of images in relation to textual content and with reference to that which was intended by the curriculum.

6.4.4 Explanations, images and symbols must complement one another

Verbal representations in textbooks provide clarity on aspects that must be addressed in the content, without which visual representation will make no sense (Sadoski and Paivio, 2001). The two modes of representation complement each other. In matter and materials, they can be presented together in the form of chemical equations where symbols are involved (Gilbert and Treagust, 2009; Sujak and Daniel, 2017). Full understanding of chemical concepts, construct and principles in any grade level cannot be achieved without blending verbal, visual and verbal-and-visual representations on the macroscopic, sub-microscopic and symbolic levels (Khine, 2013). Curriculum designers or developers could advise natural sciences textbook authors about the significance of the combination of multiple representations in matter and materials. Again, textbooks should undergo greater scrutiny for representation of curriculum prescriptions and guidelines to prevent limitations (Stern and Roseman, 2001; Bhatti et al., 2017).

6.5 LIMITATIONS OF STUDY

The study was conducted on three preferred Grade 9 natural sciences textbooks based on information provided by an educational bookstore in the Free State. The information could have also been acquired for more than one province that might have used different preferred textbooks. More information could have also been sought from other textbook providers for selection of data sources.

The study was also conducted on one out of four knowledge strands of natural sciences. Matter and materials is the only knowledge strand that was considered for analysis. Had the study analysed data from the other knowledge strands, the findings could have provided different outcomes and conclusion.

6.6 OVERCOMING LIMITATIONS

The researcher requested a list of preferred textbooks from the District Office, but after being unable to receive assistance for a period of time, an alternative source was considered.

Due to limited literature of comparisons between science textbooks and national curricula in Africa, literature from the Middle East was used instead.

Conducting the study during a Covid-19 pandemic could have been challenging had the study followed a different approach. The execution of the study was convenient and practical because the study employed document analysis for which data sources were relatively easy to access.

6.7 CONCLUSION OF THE STUDY

The study set out to explore the representations in preferred Grade 9 natural sciences textbooks. The pursuit for the exploration was inspired by the observation made by the researcher that learners taught by novice teachers tend to perform poorer than those taught by seasoned ones. In addition, the researcher also observed that novice teachers tended to rely strongly on the textbook and neglected referring to the CAPS document for guidance. Moreover, literature showed that South African Grade 9 learners were among the weakest-performing learners in the world in matter and materials. With these three aspects in mind, the researcher wanted to discover whether the quality of textbooks might have had any contribution to learner performance in natural sciences. The findings showed that although certain textbooks are preferred for teaching and learning natural sciences, they are not entirely representative of CAPS intentions. Limitations exist in all textbooks, albeit to different extents. It is necessary that research be conducted for correlation between textbook content and CAPS for similar aspects, as addressed by the study and others not reflected by this study; yet may be contributing to quality of education in natural sciences in South Africa.

REFERENCE LIST

Abrie, A.L. 2016. The botanical content in the South African curriculum: A barren desert or a thriving forest? *South African Journal of Science*, 112(1/2), 45-51. Available from: http://dx.doi.org/10.17159/sajs.2016/20150127 (Accessed: 17 November 2020).

Adom, D., Hussein, E.K. and Adu-Agyem, J. 2018. Theoretical and conceptual framework: mandatory ingredients of a quality research. *International Journal of Scientific Research*, 7(1), 438-441.

Ambrose, S.A., Brides M.W., DiPietro. M., Lovett, M.C. and Norman M.K. 2010. *How research works: 7 research-based principles for smart teaching.* San Francisco: Jossey-Bass.

Anwar, R.B. and Rahmawati, D. 2017. Symbolic and Verbal Representation Process of Student in Solving Mathematics Problem Based Polya's Stages. *International Education Studies*, 10(10), 20-28. DOI:10.5539/ies.v10n10p20

Attakumahi, D. 2020. Textbooks use and academic achievement of senior high school students in core subjects. *Journal of Education Studies,* 6(12). DOI:10.5281/zenodo.3669362

Ayano, E.I. 2018. Western Cape Senior Phase Learners' Conceptions of Magnetism, Chemical Change of substances and the Environment. Unpublished master's dissertation, University of the Western Cape, Cape Town.

Bada, S.O. 2015. Constructivism Learning Theory: A Paradigm for Teaching and Learning. *IOSR Journal of Research & Method in Education,* 5(6), 66-70.

Becker. N., Stanford, C., Towns, M. and Cole. R. 2015. Translating across macroscopic, submicroscopic, and symbolic levels: the role of instructor facilitation in an inquiry-oriented physical chemistry class.

Bergqvista, A. and Rundgren, S.C. 2017. The influence of textbooks on teachers' knowledge of chemical bonding representations relative to students' difficulties understanding. *Research in Science & Technological Education* [online]. Available from: http://dx.doi.org/10.1080/02635143.2017.1295934 (Accessed: 28 July 2020).

Bhatti, A.J., Khurshid, K. and Ahmad, G. 2017. Curriculum Alignment: An Analysis of the Textbook Content. *Pakistan Journal of social Sciences*, 37(1), 30-43.

Bingham, A.J., & Witkowsky, P. 2021. Deductive and inductive approaches to qualitative data analysis. *In*: Vanover, C, Mihas, P. & Saldaña, J., eds., *Analyzing and interpreting qualitative data: After the interview.* SAGE, 133-146.

Boru, T. 2018. Chapter five: Research design and methodology. Unpublished PhD thesis, University of South Africa, Pretoria. Available from: https://www.researchgate.net/publication/329715052 (Accessed: 14 October 2021).

Bowen, G. 2009. Document Analysis as a Qualitative Research Method Article. *Qualitative Research Journal*, 9(2). DOI: 10.3316/QRJ0902027

Bucat, B. and Mocerino, M. 2009. Learning at the Sub-microlevel: Structural Representations. *In*: Gilbert, J.K and Treagust, D., eds., *Multiple Representations in Chemical Education*. Dordrecht, The Netherlands: Springer, 11-29.

Castleberry, A. and Nolen, A. 2018. Thematic analysis of qualitative research data: Is it as easy as it sounds? *Currents in Pharmacy Teaching and Learning*. Available from: https://doi.org/10.1016/j.cptl.2018.03.019 (Accessed: 19 July 2021).

Ceglie, R. and Olivares, V. 2012. Representation of diversity in science textbooks. *In*: Hickman, H. and Porfilio, B.J., eds., *The New Politics of the Textbook*. Rotterdam: Sense Publishers, 49-68.

Cheng and Gilbert, J.K. 2009. Towards a Better Utilization of Diagrams in Research into the Use of Representative Levels in Chemical Education. *In*: Gilbert, J.K and Treagust, D., eds., *Multiple Representations in Chemical Education*. Dordrecht, The Netherlands: Springer, 55-73.

Clark, J.M. and Paivio, A. 1991. Dual Coding Theory and Education. *Educational Psychology Review*, 3(3), 149-210. Available at: http://www.jstor.org/stable/23359208 (Accessed:13 August 2020).

Creswell, J.W. and Creswell, J.D. 2018. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 5th ed. California: SAGE.

Curriculum Assessment and Policy Statements [CAPS]. 2011. Available at: https://www.education.gov.za/Curriculum/CurriculumAssessmentPolicyStatements(CAPS).aspx (Accessed: 28 March 2020).

Davidowitz, B and Chittleborough, G. 2009. Linking the macroscopic and sub-microscopic levels: Diagrams. *In:* Gilbert, J.K and Treagust, D., eds., *Multiple Representations in Chemical Education*. Dordrecht, The Netherlands: Springer, 169-191.

Dempster. E.R., Ramnarain. U.D., Cadle Thomas, P.J., Mukwevho. N.P., Grussendorff, S. and Mchunu, S. 2015. Umalusi curriculum evaluation Senior Phase: A Comparative Analysis of the National Curriculum Statement (NCS) and the Curriculum and Assessment Policy Statement (CAPS). Umalusi, 2015. DOI: 10.13140/RG.2.2.17604.73602

Department of Basic Education. 2017. *Textbook evaluation report of the ministerial task team*. Pretoria: Department of Basic Education.

Department of Education [DoE]. 2011. Curriculum and assessment policy statement (CAPS): Natural Sciences Senior Phase Final. Available from: http://www.thutong.doe.gov.za (Accessed: 11 August 2020).

Devetak, I. and Vogrinc, J. 2013. The Criteria for Evaluating the Quality of the Science Textbooks. *In:* Khine, MS., ed., *Critical Analysis of Science Textbooks: evaluating instructional effectiveness*. Dordrecht: Springer, 3-16.

Eilam, B. and Gilbert, J.K. 2014. The Significance of Visual Representations in the Teaching of Science. *In:* Eilam, B. and Gilbert, J.K., eds., *Science Teachers' Use of Visual Representations*. Cham: Springer, 3-28.

Eliyawati, E., Rohman, I.N. and Kadarohman, A. 2018. The effect of learning multimedia on students' understanding of macroscopic, sub-microscopic, and symbolic levels in electrolyte and nonelectrolyte. *Journal of Physics: Conference Series 1013 012002* [online]. 4th International Seminar of Mathematics, Science and Computer Science Education 14 October 2017, Bandung. DOI: 10.1088/1742-6596/1013/1/012002

Fatmaryanti, S.D., Suparmi, S.A., and Kurniawan, H. 2018. Magnetic force learning with Guided Inquiry and Multiple Representations Model (GIMuR) to enhance students' mathematics modelling ability. *Asia-Pacific Forum on Science Learning and Teaching*, 12, 19(1), 1, 1-22.

Gilbert, J.K. and Treagust, D. 2009. Introduction: macro, submicro- and symbolic representations and the relationship between them: key models in chemical education. *In*: Gilbert, J.K and Treagust, D., eds., *Multiple Representations in Chemical Education*. Dordrecht, The Netherlands: Springer, 4-6.

Hadar, l.l. 2017. Opportunities to learn: Mathematics textbooks and students' achievements. *Studies in Educational Evaluation* [online], 55(2017), 153-166. Available from: https://doi.org/10.1016/j.stueduc.2017.10.002 (Accessed: 15 March 2021).

Hubber, P. and Tytler, R. 2017. Enacting a Representation Construction Approach to Teaching and Learning Astronomy. *In:* Treagust, D.F., Duit, R and Fischer, H.E., eds., *Multiple Representations in Physics Education*. Gewerbestrasse, Cham: Springer, 139-161.

Johnstone, A.H. 1993. The Development of Chemistry Teaching: A Changing Response to Changing Demand. *Journal of Chemical Education* [online], 70(9), 701-705. Available from: https://booksc.org/book/11375284/4d6065 (Accessed: 28 July 2020).

Kapıcı H.Ö., and Savas-cı-Açıkalın, F. 2015. Examination of visuals about the particulate nature of matter in Turkish middle school science textbooks. *Chemistry Education Research and Practice* [online]. DOI: 10.1039/c5rp00032g

Karásková, N., Doležal, R., Maltsevskaya N. and Kolář, K. 2019. Didactic capacity of selected Czech and Russian organic chemistry textbooks. *Chemistry-Didactics-*

Ecology-Metrology – Sciendo, 24(1-2), 61-76. [online]. DOI: 10.2478/cdem-2019-0005

Kauffman, D. 2005. Curriculum prescription and curriculum constraint: Second-year teachers' perceptions. NGT Working Paper. Cambridge, MA: Project on the Next Generation of Teachers. Available from: http://www.gse.harvard.edu/~ngt (Accessed: 24 July 2021).

Kembhavi A., Salvato M., Kolve E., Seo M., Hajishirzi H. and Farhadi A. 2016. A Diagram is Worth a Dozen Images. *In*: Leibe B., Matas J., Sebe N., Welling M., eds., *Computer Vision – ECCV 2016. ECCV 2016.* Lecture Notes in Computer Science, vol 9908. Springer, Cham. Available from: https://doi.org/10.1007/978-3-319-46493-0_15 (Accessed: 22 July 2020).

Khaddoor, R., Al-Amoush, S. and Eilks, I. 2017. A Comparative Analysis of the Intended Curriculum and Its Presentation in 10th Grade Chemistry Textbooks from Seven Arabic Countries. *Chemistry Education Research and Practice*,18(2), 375-385.

Khine, M.S. 2013. The Criteria for Evaluating the Quality of the Science Textbooks. *In*: Khine, M.S., ed., *Critical Analysis of Science Textbooks: evaluating instructional effectiveness*. Dordrecht: Springer, 303-310.

Kivunja, C and Kuyini, A.B. 2017. Understanding and Applying Research Paradigms in Educational Contexts. *International Journal of Higher Education*, 6(5), 26-41.

Koopman, O. 2017. Investigating How Science Teachers in South Africa Engage with all Three Levels of Representation in Selected Chemistry Topics. *African Journal of Research in Mathematics, Science and Technology* [online], 21(1), 15–25. Available from: http://dx.doi.org/10.1080/18117295.2016.1261546 (Accessed: 16 August 2020).

Kuckartz, U. and Rädiker, S. 2019. *Analyzing Qualitative Data with MAXQDA Text, Audio, and Video*. Cham: Springer.

Kumar, R. 2011. *Research methodology: a step-by-step guide for beginners*. Third edition. Cornwall, Great Britain: TJ International Ltd.

LaDue, N.D., Libarkin, J.C. & Thomas, S.R. 2015. Visual Representations on High School Biology, Chemistry, Earth Science, and Physics Assessments. *Journal of Science Education and Technology,* 24(6), 818-834. Available from: https://www.learntechlib.org/p/175252/ (Accessed: 16 October 2021).

Leavy, P. 2014. Independent Scholar. *In:* Leavy, P., ed. *The Oxford Handbook of Qualitative Research.* New York: Oxford University Press, 1-13.

Lemke J.L. 1998. Multiplying meaning: visual and verbal semiotics in scientific text. *In*: Martin JR, Vell R., eds., *Reading science: critical and functional perspectives on discourses of science*. New York: Routledge, 87–113.

Lemmer, M., Edwards, J. and Rapule, S. 2008. Educators' selection and evaluation of natural sciences textbooks. *South African Journal of Education,* 28(2). [online], Available from: https://hdl.handle.net/10520/EJC32163 (Accessed: 6 May 2020).

McDonald, C.V. and Abd-El-Khalick, F. 2017. Representations of Nature of Science in School Science Textbooks. *Taylor & Francis*, 20, 1. [online] Available from: https://www.researchgate.net/publication/317184412 (Accessed: 11 July 2020).

Mullis, I.V.S., Martin, M.O., Foy, P., Kelly, D.L. and Fishbein, B. 2020. *TIMSS 2019 international results in mathematics and science*. TIMSS & PIRLS International Study Center, Lynch School of Education and Human Development, Boston College and International Association for the Evaluation of Educational Achievement (IEA).

Musa, Ü. and Ceyhan, İ. 2019. Misconception in chemistry education and practices to eliminate them: literature analysis. *Journal of Education and Training Studies*, 7(3), 202.

Muspratt, S. and Freebody, P. 2013. Understanding the Disciplines of Science: Analysing the Language of Science Textbooks. *In:* Khine. M.S., ed., *Critical Analysis of Science Textbooks: Evaluating instructional effectiveness*. Dordrecht, Netherlands: Springer, 33-59.

Miles, M.B., Huberman, A.M. and Saldaña, J. 2014. *Qualitative data analysis*. Third edition. Thousand Oaks: SAGE.

Ngulube, P. 2015. Qualitative data analysis and interpretation: systematic search for meaning. *In:* Mathipa, E.R. and Gumbo, M.T., eds., *Addressing research challenges: making headway for developing researchers*. Noordwyk: Mosala-Masedi Publishers & Booksellers cc, 131-156.

Nieminen, A., Savinainen A., and Viiri, P. 2017. The Effect of Using a Visual Representation Tool in a Teaching-Learning Sequence for Teaching Newton's Third Law. *Research in Science Education*, 47(1), 119-135.

Nimmermark, A., Öhrström, L., Mårtensson, J. and Davidowitz, B. 2016. Teaching of chemical bonding: a study of Swedish and South African students' conceptions of bonding. *Chemical Education Research and Practice*, 17, 985-1005.

Nyanhi, G.M. and Ochonogor, C.E. 2020. Grade 10 physical science students' reasoning about basic chemical phenomena at sub-microscopic Level Institute for Science and Technology Education, University of South Africa. 2020. Available from: https://www.researchgate.net/publication/344179327 (Accessed: 2 November 2021).

Opfermann, M., Schmeck, A. and Fischer, H.E. 2017. Multiple Representations in Physics and Science Education – Why Should We Use Them? In Treagust, D.F., Duit, R. and Fischer, H.E., eds. *Multiple Representations in Physics Education*. Gewerbestrasse, Cham: Springer, 13.

Orgoványi-Gajdos, J. 2015. Expert and novice teachers' approaches to problematic pedagogical situations [online]. *INTCESS15-2nd International Conference on Education and Social Sciences* 2-4 February 2015- Istanbul, Turkey. Available from: https://www.researchgate.net/publication/320267965 (Accessed: 11 August 2020).

Paivio, A. 1990. *Mental Representations: A Dual Coding Approach*. Oxford University Press. New York. 53-95.

Peterson, M.O. 2016. Schemes for Integrating Text and Image in the Science Textbook: Effects on Comprehension and Situational Interest. *International Journal of Environmental & Science Education*, 11(6), 1365-1385.

Polikoff, M.S. 2015. How Well Aligned Are Textbooks to the Common Core Standards in Mathematics? *American Educational Research Journal*, 52(6), pp. 1-27. Available from: https://doi.org/10.3102/0002831215584435 (Accessed: 6 August 2021).

Posthuma, E. 2016. *Integrating Three Types of Chemical Representation* [Diagram]. Available at: Integrating Three Types of Chemical Representation | Chemical Education Xchange (chemedx.org) (Accessed: 29 May 2021).

Prinsloo, C.H., Harvey, J., Mosimege, M., Beku, U., Juan, A., Hannan, S. and Zulu, N. 2016. *TIMSS item diagnostic report: South Africa grade 9 science* [online]. Pretoria: Department of Basic Education.

Ramnarain, U. and Chanetsa, T. 2016. An analysis of South African Grade 9 natural sciences textbooks for their representation of nature of science. *International Journal of Science Education*, 38(6):1-12.

Ramnarain, U. and Padayachee K. 2015. A comparative analysis of South African Life Sciences and Biology textbooks for inclusion of the nature of science. *South African Journal of Education* [online] 35(1), 1-8. Available from: https://10.15700/201503062358 (Accessed: 27 December 2020).

Reddy, V., Visser, M., Winnaar, L., Arends, F., Juan, A and Prinsloo, C.H., and Isdale, K. 2016. *TIMSS 2015: Highlights of Mathematics and Science Achievement of Grade 9 South African Learners*. Human Sciences Research Council.

Reddy, V., Winnaar, L., Juan, A., Arends, F., Harvey, J., Hannan, S., Namome, C., Sekhejane, P., and Zulu, N. 2020. *TIMSS 2019: Highlights of South African grade 9 results in mathematics and science*. Pretoria: Department of Basic Education.

Sadoski, M., and Paivio, A. 2001. Imagery and text: a dual coding theory of reading and writing. London: Lawrence Erlbaum Associates, Inc.

Saeed, M., and Rashid, S. 2014. Alignment between chemistry curriculum and textbooks at secondary level. *The Sindh University Journal of Education,* 43, 29-46

Savasci-Acikalin, F. 2019. How Middle School Students Represent Phase Change and Interpret Textbook Representations: a Comparison of Student and Textbook Representations. *Research in Science Education* [online]. Available from: https://doi.org/10.1007/s11165-019-9834-z (Accessed; 13 August 2020).

Sibanda, L. 2014. The readability of two Grade 4 natural sciences textbooks for South African schools. *South African Journal of Childhood Education,* 4(2), 154-175.

Stern, L. and Roseman, J. 2001. Textbook alignment. *The Science Teacher*, 68(7), 52-56.

Sujak, B.K. and Daniel, E.G.S. 2017. Understanding of Macroscopic, Microscopic and Symbolic Representations Among Form Four Students in Solving Stoichiometric Problems. *Malaysian Online Journal of Educational Sciences*, 5(3), 83-96.

Taber K. S. 2009. Learning at the symbolic level. *In*: Gilbert, J.K and Treagust, D., eds., *Multiple Representations in Chemical Education*. Dordrecht, The Netherlands: Springer, 75-108.

Takegami, F. 2016. An Exploratory Study on the Impact of the New Teaching English Through English (TETE) Curriculum Policy in Japan: A Case Study of Three Teachers. *International Journal of Social and Cultural Studies*, 9, 18.

Tripathy, J.P. 2013. Secondary data analysis: ethical issues and challenges. *Iranian Journal Public Health*, 42(12), 1478-1479.

Tsui, C-Y. 2003. Teaching and learning genetics with multiple representations. *Journal of Science Education*, 25(11), 1353-1368.

Tsui, C. and Treagust, D.A. 2013. Introduction to Multiple Representations: Their Importance in Biology and Biological Education. *In:* Treagust D.A. and Tsui. C., eds., *Multiple Representations in Biological Education.* Perth: Springer, 3-18.

Upahi, J.E. and Ramnarain, U. 2019. Representations of chemical phenomena in secondary school chemistry textbooks. *Chemistry Education research and Practice* 20, 146-159. [online], DOI: 10.1039/C8RP00191J

Van Berkel, B., Pilot, A. and Bulte, A.M.W. 2009. Micro-Macro Thinking in Chemical Education: Why and How to Escape. *In*: Gilbert, J.K and Treagust, D., eds., *Multiple Representations in Chemical Education*. Dordrecht, The Netherlands: Springer, 31-54.

Van den Ham, A. and Heinze, A. 2018. Does the textbook matter? Longitudinal effects of textbook choice on primary school students' achievement in mathematics. *Studies in Educational Evaluation*, 59, 133-140. [online] Available from: https://doi.org/10.1016/j.stueduc.2018.07.005 (Accessed: 28 July 2020).

Verdinelli, S. and Scagnoli, N.I. 2013. Data Display in Qualitative Research. *International Journal of Qualitative Methods* [online]. Available from: https://doi.org/10.1177/160940691301200117 (Accessed: 16 August 2021).

Vojíř, K. and Rusek, M. 2019. Science education textbook research trends: a systematic literature review. *International Journal of Science Education*, 41(11), 1496-1516. [online] Available from: https://doi.org/10.1080/09500693.2019.1613584 (Accessed: 18 August 2020).

Wellington, J. and Ireson, G. 2012. *Science learning, science teaching*. 3rd ed. New York: Routledge.

Wu, H. and Puntambekar, S. 2012. Pedagogical Affordances of Multiple External Representations in Scientific Processes. *Journal of Science Education and Technology*, 21(6), 754-767.

Yang, L. and Treagust, D. 2013. Content Analysis of Diagrams in Secondary School Science Textbooks. *In:* Khine. M.S., ed., *Critical Analysis of Science Textbooks: Evaluating instructional effectiveness*. Dordrecht, Netherlands: Springer, 287-300.

Yin, R.K. 2016. *Qualitative Research from Start to Finish*. 2nd ed. New York: The Guilford Press.

APPENDICES

Appendix A: Letter of Registration of Research Title

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Postgraduate Office
Faculty of Education

Room 16
Winkie Direko Building
Faculty of Education
University of the Free State
P.O. Box 339
Bloemfontein 9300
South Africa

T: +27(0)51 401 3651

www.ufs.ac.za
Duvenhagecs@ufs.ac.za

10 November 2020

APPLICATION FOR TITLE REGISTRATION

Applicant: Mofolo, SBOM
Student Number: 1997270432
Discipline: Curriculum Studies
Study Code: Masters (EDCI8900)

Dear Ms Mofolo

Your registered title is as follows*:*

"A comparative analysis of representations in natural sciences textbooks and the Curriculum Assessment Policy statement"

All of the best with your studies.

Yours sincerely,

Prof Patrick Mafora
Chair: CTR committee

Ms CS Duvenhage
Secretary: CTR committee

Appendix B: Approval of Ethical Clearance

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

GENERAL/HUMAN RESEARCH ETHICS COMMITTEE (GHREC)

19-Feb-2021

Dear Mrs Serapelo Mofolo

Application Approved

Research Project Title:
COMPARATIVE ANALYSIS OF REPRESENTATIONS IN NATURAL SCIENCES TEXTBOOKS AND SENIOR PHASE CURRICULUM AND ASSESSMENT POLICY STATEMENT

Ethical Clearance number:
UFS-HSD2021/0055/172

We are pleased to inform you that your application for ethical clearance has been approved. Your ethical clearance is valid for twelve (12) months from the date of issue. We request that any changes that may take place during the course of your study/research project be submitted to the ethics office to ensure ethical transparency. furthermore, you are requested to submit the final report of your study/research project to the ethics office. Should you require more time to complete this research, please apply for an extension. Thank you for submitting your proposal for ethical clearance; we wish you the best of luck and success with your research.

Yours sincerely

Dr Adri Du Plessis
Chairperson: General/Human Research Ethics Committee

205 Nelson Mandela Drive
Park West
Bloemfontein 9301
South Africa

P.O. Box 339
Bloemfontein 9300
Tel: +27 (0)51 401 9337
duplessisA@ufs.ac.za
www.ufs.ac.za

Appendix C: Data Collection Schedule

	CAPS	TEXTBOOKS A, B AND C
Concepts	**VERBAL** Compounds	**VERBAL** Compounds
	VERBAL and VISUAL Chemical reactions	**VERBAL and VISUAL** Chemical reactions
Constructs	**VISUAL (sub-microscopic)** Use of **images** to foster conceptual understanding of compounds - writing symbols - drawing pictures or models	**VISUAL (sub-microscopic)** Use of **images** to foster conceptual understanding of compounds - writing symbols - drawing pictures or models
	VERBAL (macroscopic), VISUAL (sub-microscopic) VERBAL and VISUAL (symbolic) **Balanced equations** for comprehending conservation of atoms: - Combustion reactions • reactions between metals and oxygen • reactions between non-metals and oxygen - Neutralization reactions (between acids and bases) • reactions between acids and metal oxides • reactions between acids and metal hydroxides • reactions between acids and metal carbonates • reactions between acids and metal hydrogen carbonates	**VERBAL (macroscopic), VISUAL (sub-microscopic) VERBAL and VISUAL (symbolic)** **Balanced equations** for comprehending conservation of atoms: - Combustion reactions • reactions between metals and oxygen • reactions between non-metals and oxygen - Neutralization reactions (between acids and bases) • reactions between acids and metal oxides • reactions between acids and metal hydroxides • reactions between acids and metal carbonates • reactions between acids and metal hydrogen carbonates
Principles	**VERBAL (macroscopic) & VISUAL (sub-microscopic)** **Rules for naming compounds** - naming simple compounds **Writing down chemical formulae (symbols)**	**VERBAL (macroscopic) & VISUAL (sub-microscopic)** **Rules for naming compounds** - naming simple compounds **Writing down chemical formulae (symbols)**
	VERBAL (macroscopic), VISUAL (sub-microscopic) VERBAL and VISUAL (symbolic) **Conservation of atoms** (in a chemical reaction) - Principle statement	**VERBAL (macroscopic), VISUAL (sub-microscopic) VERBAL and VISUAL (symbolic)** **Conservation of atoms** (in a chemical reaction) - Principle statement

Appendix D: Confirmation of Language Editing

CORNELIA GELDENHUYS

✆ 083 2877088
corrieg@mweb.co.za
geldenhuysc@ufs.ac.za

9 November 2021

TO WHOM IT MAY CONCERN

Herewith I, **Cornelia Geldenhuys (ID 521114 0083 088)** declare that I am a qualified, accredited language practitioner and that I have edited the following master's dissertation:

COMPARATIVE ANALYSIS OF REPRESENTATIONS IN NATURAL SCIENCES TEXTBOOKS AND SENIOR PHASE CURRICULUM AND ASSESSMENT POLICY STATEMENT

by

Serapelo Boipelo Oreeditse Mofolo

All changes were indicated by track changes and comments **for the author/student to verify, clarify aspects that are unclear, make the necessary adjustments and finalise.** The editor takes no responsibility in the instance of this not being done. The document remains the final responsibility of the student.

....

C GELDENHUYS
MA (LIN – *cum laude*), MA (Mus), HED, Postgraduate Dipl, Library Science, UTLM

Accredited member/Geakkrediteerde lid, SATI, Membership/Lidmaatskap: 1001474 (A/E-E/A)
Full member/Volle lid, Professional Editors Guild (PEG, Membership GEL001)
Mediterranean Editors and Translators (MET: Membership 02393)
European Association of Scientific Editors (EASE: Membership 5523)

Appendix E: Turnitin Report

COMPARATIVE ANALYSIS OF REPRESENTATIONS IN NATURAL SCIENCES TEXTBOOKS AND SENIOR PHASE CURRICULUM AND ASSESSMENT POLICY STATEMENT

by Serapelo Boipelo Oreeditse Mofolo

Submission date: 30-Nov-2021 09:31AM (UTC+0200)
Submission ID: 1716168488
File name: SBO_MOFOLO_MEd_Dissertation_Submission_TII.docx (1.15M)
Word count: 25341
Character count: 146395

COMPARATIVE ANALYSIS OF REPRESENTATIONS IN NATURAL SCIENCES TEXTBOOKS AND SENIOR PHASE CURRICULUM AND ASSESSMENT POLICY STATEMENT

ORIGINALITY REPORT

7%	6%	3%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	uir.unisa.ac.za Internet Source	1%
2	hdl.handle.net Internet Source	1%
3	nect.org.za Internet Source	<1%
4	www.education.gov.za Internet Source	<1%
5	researchspace.ukzn.ac.za Internet Source	<1%
6	Emmanueula Ndumanya, Umesh Ramnarain, Hsin-Kai Wu. "An Analysis of Selected South African Grade 12 Physical Sciences Textbooks for the Inclusion of the NGSS Science Practices", Canadian Journal of Science, Mathematics and Technology Education, 2021 Publication	<1%

link.springer.com

7	Internet Source	<1%
8	scholarworks.waldenu.edu Internet Source	<1%
9	docplayer.net Internet Source	<1%
10	www.saarmste.org Internet Source	<1%
11	www.science.gov Internet Source	<1%
12	Scholar.ufs.ac.za Internet Source	<1%
13	dokumen.pub Internet Source	<1%
14	www.scribd.com Internet Source	<1%
15	www.ijopr.com Internet Source	<1%
16	repository.nwu.ac.za Internet Source	<1%
17	my.unisa.ac.za Internet Source	<1%
18	eprints.usq.edu.au Internet Source	<1%

19	repository.up.ac.za Internet Source	<1 %
20	Eliyawati, I Rohman, A Kadarohman. "The effect of learning multimedia on students' understanding of macroscopic, sub-microscopic, and symbolic levels in electrolyte and nonelectrolyte", Journal of Physics: Conference Series, 2018 Publication	<1 %
21	Umesh Ramnarain, Lydia Mavuru. "Chapter 32-1 Fostering a Multicultural Science Curriculum in South Africa", Springer Science and Business Media LLC, 2021 Publication	<1 %
22	espace.library.uq.edu.au Internet Source	<1 %
23	ir.cut.ac.za Internet Source	<1 %
24	mafiadoc.com Internet Source	<1 %
25	www.ncbi.nlm.nih.gov Internet Source	<1 %
26	www.slideshare.net Internet Source	<1 %
27	creativecommons.org Internet Source	<1 %

28	John K. Gilbert. "Introduction: Macro, Submicro and Symbolic Representations and the Relationship Between Them: Key Models in Chemical Education", Multiple Representations in Chemical Education, 2009 Publication	<1 %
29	Albaiti, Liliasari, Omay Sumarna, Muhamad Abdulkadir Martoprawiro. "A Study of Oil Viscosity Mental Model", Journal of Physics: Conference Series, 2017 Publication	<1 %
30	Umesh Dewnarain Ramnarain, Tarisai Chanetsa. "An analysis of South African Grade 9 natural sciences textbooks for their representation of nature of science", International Journal of Science Education, 2016 Publication	<1 %
31	www.scientificamerican.com Internet Source	<1 %
32	A Albaiti, S Liliasari, O Sumarna, M A Martoprawiro. "The Binary System Laboratory Activities Based on Students Mental Model", Journal of Physics: Conference Series, 2017 Publication	<1 %
33	eprints.bournemouth.ac.uk Internet Source	<1 %

34	open.uct.ac.za Internet Source	<1 %
35	pureadmin.qub.ac.uk Internet Source	<1 %
36	"Interactive Collaborative Learning", Springer Science and Business Media LLC, 2017 Publication	<1 %
37	Savin-Baden, Maggi, Wilkie, Kay. "EBOOK: Problem-based Learning Online", EBOOK: Problem-based Learning Online, 2006 Publication	<1 %
38	cris.brighton.ac.uk Internet Source	<1 %
39	digitalcommons.odu.edu Internet Source	<1 %
40	doras.dcu.ie Internet Source	<1 %
41	etd.cput.ac.za Internet Source	<1 %
42	id.scribd.com Internet Source	<1 %
43	sajip.co.za Internet Source	<1 %
44	www.int-e.net Internet Source	<1 %

45	İlhan Özgül, Lütfi İncikabı. "Prospective Teachers' Representations for Teaching Note Values: An Analysis in the Context of Mathematics and Music", Journal of Education and Training Studies, 2017 Publication	<1 %
46	"Mathematical Modelling Education in East and West", Springer Science and Business Media LLC, 2021 Publication	<1 %
47	Emma R. Douma, Martina Valente, Elena V. Syurina. "Developmental pathway of Orthorexia Nervosa: factors contributing to progression from healthy eating to excessive preoccupation with healthy eating. Experiences of Dutch Health Professionals", Appetite, 2020 Publication	<1 %
48	F Q Aini, Z Fitriza, F Gazali, Mawardi. "First-year university students' understanding of chemical equilibrium", Journal of Physics: Conference Series, 2019 Publication	<1 %
49	Lucy Sibanda, Mellony Graven. "Can mathematics assessments be considered valid if learners fail to access what is asked of them?", South African Journal of Childhood Education, 2018	<1 %

Publication

50	Patrick Ngulube. "chapter 2 Theory and Theorising in Information Science Scholarship", IGI Global, 2020 Publication	<1 %
51	a0272912-4303-4a2a-97f1-0fc5400ae5fd.filesusr.com Internet Source	<1 %
52	aa-rf.org Internet Source	<1 %
53	baixardoc.com Internet Source	<1 %
54	bura.brunel.ac.uk Internet Source	<1 %
55	coek.info Internet Source	<1 %
56	cuadernos.info Internet Source	<1 %
57	end-educationconference.org Internet Source	<1 %
58	etd.uwc.ac.za Internet Source	<1 %
59	files.eric.ed.gov Internet Source	<1 %

hrm.ru.ac.th

60	Internet Source	<1 %
61	journals.openedition.org Internet Source	<1 %
62	pdfs.semanticscholar.org Internet Source	<1 %
63	pythagoras.org.za Internet Source	<1 %
64	scholar.ufs.ac.za Internet Source	<1 %
65	www.ijrte.org Internet Source	<1 %
66	www.uj.ac.za Internet Source	<1 %
67	Critical Analysis of Science Textbooks, 2013. Publication	<1 %
68	M Makgato. "Factors associated with poor performance of learners in mathematics and physical science in secondary schools in Soshanguve, South Africa", Africa Education Review, 2007 Publication	<1 %
69	Mansoor Niaz. "Feyerabend's Epistemological Anarchism", Springer Science and Business Media LLC, 2020 Publication	<1 %

70	Yew-Jin Lee, Aik-Ling Tan. "Science Education at the Nexus of Theory and Practice", Brill, 2008 Publication	<1%
71	Zheng Jiang, Ida Ah Chee Mok, Jianhua Li. "Chinese Students' Hierarchical Understanding of Part-whole and Measure Subconstructs", International Journal of Science and Mathematics Education, 2020 Publication	<1%
72	etheses.lse.ac.uk Internet Source	<1%
73	westminsterresearch.westminster.ac.uk Internet Source	<1%
74	"Multiple Representations in Chemical Education", Springer Science and Business Media LLC, 2009 Publication	<1%
75	"Multiple Representations in Physics Education", Springer Science and Business Media LLC, 2017 Publication	<1%
76	"Nature of Science for Social Justice", Springer Science and Business Media LLC, 2020 Publication	<1%

77	"The Effect of Different Textual Narrations on Students' Explanations at the Submicroscopic Level in Chemistry", EURASIA Journal of Mathematics, Science and Technology Education, 2013 Publication	<1 %
78	Maurice M. W. Cheng, John K. Gilbert. "Students' Visualization of Metallic Bonding and the Malleability of Metals", International Journal of Science Education, 2013 Publication	<1 %
79	uwe-repository.worktribe.com Internet Source	<1 %

Exclude quotes	Off	Exclude matches	Off
Exclude bibliography	On		