Exploring the influences of an intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding

A thesis submitted in fulfilment of the requirements for the degree

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By

Aikanga Frans P S

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DECLARATION

I declare that the work contained in this thesis is my original work. It has not been previously submitted in any form for assessment or degree in any other higher education institution. All ideas, quotations, and other materials used in this study derived from the work of other people have been indicated in the list of references.

Signature *FPSaikanga* Date: 18/09/2020

DEDICATION

I dedicated this work to my father Aron Bonifatius, my late mother Victoria Newaka, my wife, my firstborn son, entire family and friends. Your support and advice have given me courage to complete this work and they will never be forgotten throughout my entire life.

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ABSTRACT

Anecdotal evidence from my 10 years' experience teaching Grade 9 Physical Science in Namibian schools revealed learners' difficulty with making sense of chemical bonding. The Junior Secondary examiners' reports in recent consecutive years (2014, 2015, 2016 & 2017) also revealed this challenge among Grade 10 learners (Namibia. Ministry of Education, Arts and Culture [MoEAC], 2017). The language of learning and teaching (LoLT) for most school subjects (including Physical Science) in Namibia is English, which is taken as a second language by most learners (Kisting, 2011). The results of the English Language Proficiency test written by all principals and teachers in Namibia show that most are not proficient in this language (Kisting, 2011). This has raised concern as to how teaching of content subjects may be undertaken effectively with English as the LoLT. In Namibia, chemical bonding is part of the chemistry section of Physical Science, taught as a sub-topic under the Matter section, where the nature, characteristics, and behaviour of three states of matter are explained. The difficulty students have with chemical bonding is identified as being due to complex chemical concepts (Chittleborough & Mamiala, 2006), and the specialised language of the topic these concepts involve (Gilbert & Treagust, 2009). Additionally, this difficulty may be ascribed to lack of suitable pedagogic approaches, which is linked to science teachers not being fluent in the LoLT. Despite this link, Johnstone (1982) posits that addressing the challenge of teaching and learning chemical knowledge requires teachers' understanding of three levels of representation: macroscopic, sub-microscopic, and symbolic.

Addressing this challenge may be accomplished by using multimodality in teaching, which is achievable via intersemiosis of different semiotic modes, drawing from Systemic Functional Linguistics. This is due to non-linguistic modes also having the potential to make meaning as language does, and the fact that language alone cannot fully enable effective meaning-making in discourses that are inherently multimodal, such as science. Some studies have suggested that the intersemiosis of visual and verbal semiotic modes has the potential to enable more meaning-making of scientific discourse than either of these two alone. The study reported on in this thesis has built on such previous studies in order to explore the influences of a visual-verbal intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding. No studies from Namibia exploring these influences on Grade 9 learners could be found. This revealed the knowledge gap that this study aimed to contribute to filling.

I accomplished this goal by embarking on a two-cycle action research study. The first cycle followed a traditional teaching approach and assessment, whereas the second cycle, the intervention, included a visual-verbal intersemiotic complementarity teaching approach and assessment. I achieved visual-verbal intersemiotic complementarity teaching and assessment by coordinating spoken and written language with visuals in the form of diagrams and physical models. The critical paradigm was adopted to explore the influences of this pedagogic approach, with the underlying aim of exploring the intervention approach for bringing about a change in learners' sense-making of chemical bonding, compared to traditional approaches that do not consider intersemiosis. This study is informed by Vygotsky's (1978) social constructivism to account for learning as a product of social construction, and Halliday's (1978) Systemic Functional Linguistics to account for the role played by semiotic modes in making meanings. This study involved collecting qualitative data that were accessed via document analysis, structured lesson observation, the teacher's and learners' reflective journals, and the pre- and post-test. Collecting these data was facilitated by a critical friend.

The results reveal a positive influence of the visual-verbal intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding. This influence was realised in the noticeable shift from the learners' discourse (use of talk and visuals) being perceptual (which is less scientific) to being idea-based (which is more scientific). Learners were also found to be self-motivated and keen to learn complex chemical bonding concepts after the intervention – another sign of their making sense of the topic. The implications of this study include that visual-verbal intersemiotic complementarity should be considered a pedagogic approach to chemical bonding by curriculum developers and reviewers, teacher training institutions, and science textbook authors.

Key words: Social constructivism, Systemic Functional Linguistics, visual-verbal intersemiotic complementarity, multimodality, sense-making, chemical bonding

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LIST OF ABBREVIATIONS AND ACRONYMS

CA:	Connecting and analysing sense-making
CBF:	Chemical bonding facts sense-making
CK:	Challenging knowledge
Cl:	Clarification sense-making
DL:	Difficult lexical items
GC:	Grammatically complex phrases
GK:	Gained knowledge
ICB:	Ideas about nature of chemical bonding
JS:	Junior Secondary
L:	Learner
MBEC:	Ministry of Basic Education and Culture
MKO:	More knowledgeable others
MoEAC:	Ministry of Education, Arts and Culture
P:	Perceptual sense-making
Q:	Question
SF-MDA:	Systemic Functional Multimodal Discourse Analysis
ZPD:	Zone of proximal development

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CHAPTER 1: INTRODUCTION

1.1 Introduction

This study aimed to explore the influences of an intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding. According to the Namibian Grade 9 Physical Science syllabus (Namibia. Ministry of Education, Arts and Culture [MoEAC], 2015), chemical bonding is a subtopic of Matter (Topic 2). Some expectations of this syllabus for the topic involve learners exiting the Junior Secondary (JS) phase with an ability to understand both covalent and ionic bonding, and with the knowledge of how to illustrate these two bonding types (Namibia. MoEAC, 2015). However, based on what I noticed from my 10 years' experience as a Grade 9 Physical Science teacher, these expectations are difficult to meet. One impediment to meeting these expectations is that learners at the JS phase have difficulty making sense of chemical bonding. This difficulty was also identified at the international level decades ago by Johnstone (1982), who warned that it is impeding effective learning of all chemistry topics. At the national level (in Namibia), this difficulty was reported in the JS examiners' reports for the four years preceding this study (Namibia. MoEAC, 2014, 2015, 2016 & 2017).

The possible causes of learners' difficulty making sense of chemical bonding involve the topic covering complex chemical concepts (Chittleborough, Treagust, Mamiala, & Mocerino, 2005), comprising both concrete and abstract knowledge (Johnson-Laird, 1983), and being accessible through three levels of representation (Johnstone, 1982). These levels of representation are macroscopic, sub-microscopic, and symbolic. The sub-microscopic and symbolic levels are more challenging than the macroscopic due to their non-experiential nature. Concrete knowledge of chemistry topics includes knowledge of perceptible objects and processes of matter. This knowledge is observable and easily accessible by learners. In contrast, abstract knowledge of chemistry concerns knowledge of non-observable particles and processes of matter, which is often challenging to learners. Abstraction also arises from using forms of representation that are conventional in science, such as symbols, formulae, and equations, for explaining phenomena that occur at the molecular level (Griffiths & Preston, 1992). In addition to these, difficulty in learners' understanding of abstract knowledge of chemical bonding may be exacerbated in Namibia by teachers not being fluent in the language of learning and teaching (LoLT) (Kisting, 2011). Chemistry learners may also not be proficient in the LoLT (Kisting, 2011), negatively impacting on their learning of chemical bonding.

Johnstone's (1982) levels of representation of chemical knowledge include macroscopic: the representation of observable knowledge; sub-microscopic: the representation of unobservable knowledge; and symbolic: the representation of chemical knowledge via conventional symbols. In general, students have difficulty with the sub-microscopic and symbolic levels, as knowledge at these levels is only availed to them via teaching (Johnstone, 1982). Moreover, students have difficulty making links between knowledge across the three levels of representation (Gilbert & Treagust, 2009). Hence, sub-microscopic and symbolic are the levels of representation of chemical bonding knowledge requiring greater attention by teachers and researchers such as myself when pondering strategies for improving learners' sense-making.

Addressing learning difficulty, such as difficulty making sense of chemical bonding in schools, may be accomplished by drawing from social constructivism. Social constructivism asserts that learning is constructed through social interaction (Vygotsky, 1978). This interaction happens between people who are more knowledgeable in an area of knowledge and those who are less knowledgeable. This theory postulates that people who are within the Zone of Proximal Development (ZPD) may be aided to advance from a lower level to a higher level of doing things (Vygotsky, 1978). Moreover, this theory contends that this learning process is mediated by tools and signs. Vygotsky (1978) further postulates that language is a common tool that mediates human activities and cognitive functions. In order to find a pedagogic approach that aids learners in making sense of abstract knowledge of chemistry topics, it is thus necessary to explore how language enables meaning-making.

Interestingly, the difficulty in making sense of chemical bonding at the sub-microscopic and symbolic level may be eased through the use of visuals (diagrams and physical models) (Fiorea, Cuevasa & Oser, 2003). The impact of the visual mode has the potential to enhance the ability to develop the learners' mental models, which are indispensable for understanding knowledge of microscopic particles and conventional symbols (Fiorea, Cuevasa & Oser, 2003). The potential that visuals afford is realisable in the multiple functions they perform: explanation, description, instruction, and providing mental images of abstract concepts taught (Chittleborough &Treagust, 2008). The use of visuals is also recommended by the Namibian

National Curriculum for Basic Education for learning skills such as investigation, interpretation, analysis, and evaluation of knowledge (Namibia. MoEAC, 2015).

The curriculum has further recommended the use of mixed semiotic modes for various aspects of teaching and learning. Kress (2010) terms this mixing of modes as *multimodality*. Multimodality was hinted on earlier in Systemic Functional Linguistics (SFL). SFL is the theory proposed Halliday (1978) that recognises systems of making meaning, where language was viewed as a primary meaning-making mode, and hence previously considered as most functional in making meaning. Multimodality refers to the use of more than one semiotic mode in making meanings (Kress, 2010). The Systemic Functional approach to multimodal discourse analysis (SF-MDA) has been used in numerous studies to elucidate such meaning-making. SFL analyses alphabetic language in terms of its grammar and the role it plays in communication, while SF-MDA considers meaning-making through multiple semiotic resources, including spoken and written language, visual imagery, sculpture, architecture, and gesture (O'Halloran, 2008). SF-MDA posits that these semiotic resources simultaneously construct meanings within different fields of study (Lemke, 2000).

However, showing consideration of multimodality in pedagogy has two challenges: developing the model of functions and the grammar of the various semiotic resources; and developing theoretical explanations of intersemiosis between different semiotic modes (O'Halloran, 2008). Attempts at addressing these challenges are exemplified by Royce (1998) through the integrated construction of meaning between different semiotic modes, known as intersemiosis (Unsworth, 2006). Royce's (1998) study finds the intersemiosis of visual and verbal modes to be feasible for communication in advertising businesses, as well as in schools for the purpose of teaching and learning. However, no research was found on the combined use of visuals and verbal language towards Namibian science learners' sense-making, revealing a knowledge gap relevant to the current Namibian school science education context.

Considering that the discourse of science reveals it to be multimodal, all outcomes and processes of teaching science should recognise multimodality (Lemke, 2000). This makes sense when one considers that different semiotic modes have different affordances, thus addressing different specialised tasks (Kress, Jewitt, Ogborn, &Tsatsarelis, 2001). Hence, combining the visual and verbal modes yields combined affordances for making the meanings that the teachers intend (Gilbert & Treagust, 2009). This suggests that multimodal teaching has the potential to enhance students' meaning-making abilities during science lessons.

The meaning-making potential realised through the combined use of different semiotic modes has prompted this study to explore the influences of a coordinated visual-verbal teaching approach on Grade 9 Namibian science learners' sense-making of chemical bonding. Achieving complementarity between the two modes was enabled by incorporating particular visual-verbal sense relations of a particular meaning (ideational, as discussed in Section 2.2) into the lessons. The concept *sense-making* is defined as the ability of students to connect theories to evidence (Zangori, Forbes & Biggers, 2013). However, this term is often used interchangeably with the term *meaning-making* by different authors, such as Zimmerman, Reeve and Bell (2009), and Solomon (1997). Due to this interchangeable use, the term *meaning-making* in this study is used as being synonymous with *sense-making*.

Conducting this study first involved analysing the Physical Science syllabus and a Physical Science textbook to be aware of their stance on the combined use of visual and verbal modes for teaching and learning of chemical bonding by teachers and Grade 9 learners respectively. Moreover, the nature and the representational levels of chemical bonding knowledge were reviewed to elicit goals for guiding the intervention under investigation in this research. In this study, the influences of the intersemiotic complementarity intervention were explored in terms of sense-making (discussed in Section 2.2), with an analytical tool adapted from Zimmerman, Reeve, and Bell (2009). The term *learner(s)* is commonly used in Namibia for referring to students at primary and secondary school level, but due to its interchangeable use with the term *student(s)* by many authors, these terms are used interchangeably in this study. This introductory chapter presents the background of the study, problem statement, rationale, potential benefits of action research, thesis outline, and a conclusion to the chapter, before the literature review is presented in Chapter 2.

1.2 Background of study

1.2.1 The international context

Chemistry is a scientific discipline that comprises many topics, including chemical bonding. It involves knowledge of how microscopic particles such as atoms, molecules, and ions make up different elements and compounds; how they behave chemically; and how understanding them contributes to understanding the physical properties and behaviours of substances we use (Chandrasegaran, Treagust & Mocerino, 2006). Teaching and learning of chemistry in schools and universities is a worldwide challenge, and so improving learners' understanding of chemistry topics is a global chemistry education objective. Some of the commonly cited studies related to this include the study undertaken by Gabel (1998) in the Netherlands on the complexity of chemistry and the teaching implications; Tan and Treagust's (1999) study in Singapore on the atomic structure and reaction; and Chandrasegaran, Treagust and Mocerino's (2008) study in Australia on the multiple levels of representation of chemical reactions. These studies have resulted in compelling findings regarding the teaching and learning of chemistry, and have identified problems aligned to its pedagogy and content. Identification of these problems is essential to conducting studies aimed at addressing the pedagogic and content difficulty of chemistry topics in schools.

Understanding of chemistry topics by students is attainable if they are chemically literate (Roberts, 2007). According to Swartz, Ben-Zvi and Hofstein (2006), chemical literacy involves being conversant with chemical ideas, context, and learning skills. This means being acquainted with knowledge of atoms, compounds, chemical reactions, chemical bonding, and chemical formulae. Shwartz, Ben-Zvi, and Hofstein (2006) posit that chemical literacy has three fundamental aspects: methods and norms of chemistry; key theories, concepts, and models of chemistry; and the impact of chemistry and chemistry-based technology on the physical world. They suggest that mastering these fundamental aspects by students is currently a challenge, but guarantees their chemical literacy. Gilbert and Treagust (2009) propose that the students' challenges in mastering these aspects warrants exploring pedagogic approaches effective for improving chemical literacy.

There is no doubt among chemistry teachers and education researchers that the topic of chemical bonding is difficult for students to understand (Ozmen, 2004). This difficulty stems from chemical concepts and processes being abstract, and also from abstract chemistry language (Ayas & Demirbas, 1997). This abstractness is due to much chemical knowledge being non-observable, difficult to comprehend, and difficult to represent in simple diagrams (Gilbert &Treagust, 2009). According to Kozma and Russel (1997), understanding of chemistry topics by students depends on how well they make sense of the invisible and untouchable particles of substances. The abstract nature of chemical bonding knowledge is also due to chemistry language containing words that are incompatible with those in everyday language (Gilbert &Treagust, 2009). For instance, there is no word in everyday English that is synonymous with the word *electron*. Chemistry words of this type make understanding chemistry topics a challenge to students, as highlighted by Ozmen (2004). In addition, chemistry language is precise and expressed in short and reduced forms, hindering students' successful gain of chemical knowledge (Gilbert & Treagust, 2009). Hence, addressing the students' difficulty of understanding chemical bonding also requires focusing attention on the abstract nature of chemistry concepts and processes evident in the language of chemistry.

Understanding chemical bonding is central to chemistry, as it is related to understanding other chemistry topics such as carbon compounds, polymers, and chemical reactions (Fensham, 1995; Gillespie, 1997; Hurst, 2002). This is because explaining or understanding any of these topics involves knowledge of chemical bonding, which concerns atoms, molecules, ions, and the forces between these particles (Gilbert & Treagust, 2009). Nimmermark (2014) argues that knowledge of chemical bonding is applicable in chemical industries. He asserts that lack of knowledge and correct mental models of chemical bonding by learners hampers their achievement of good results in chemistry education. Basic types of chemical bonding that most schools' curricula include are covalent, ionic, and metallic bonding (Hurst, 2002). The paucity of understanding of these basic types of chemical bonding by students is a barrier to gaining knowledge of other chemistry topics, and so is clearly very problematic.

Gilbert and Treagust (2009) assert that difficulties understanding chemistry topics may be addressed by accessing different ways of representing these topics. They realised this after conducting a study on multiple levels of representation in chemical education, prompted by their own introspection on why they use models in representing chemical knowledge to learners. They drew explanations for this notion from the way inscriptions (texts explaining a picture) and pictures on monuments work together to convey messages to the readers. Inscriptions are examples of written language, and pictures are examples of a visual mode. These work complementarily to make a full set of meanings for the reader (Gilbert &Treagust, 2009). Gilbert and Treagust (2009) relate their arguments on this idea to explain that the visual mode together with the verbal mode may be used to represent knowledge of unobservable entities taught in chemistry topics. This form of representation has the potential to develop both students' self-motivation, and active involvement in learning chemical concepts (Skamp, 1996).

Ascertaining the importance, the challenges, and the levels of representation of chemistry topics has provided a guideline for exploring pedagogic approaches that have the potential to enhance learners' sense-making of chemical bonding. The idea that visual and verbal modes may be used jointly to represent knowledge of microscopic entities to secondary school learners (Gilbert &Treagust, 2009) provides grounds for exploring the influences of a visual-verbal intersemiotic complementarity teaching approach on learners' sense-making of chemical bonding. The challenge of the pedagogy of chemistry topics to both teachers and learners was also identified in Namibia.

1.2.2 National context

In Namibia, as in most African countries, the education sector has a Ministry that undertakes a series of curriculum reviews with the intention of improving the country's education standard and outcomes. The authority to develop and implement the curriculum is awarded by Article 20 of the Constitution of the Republic of Namibia (Republic of Namibia, 1998). A curriculum is an official and a broad policy that guides teaching, learning, and assessment in schools (Namibia. MoEAC, 2015). It is also a framework that guides the documentation of syllabi from which textbooks, schemes of work, and lesson plans of both promotional and support subjects are developed. Promotional subjects are school subjects where both formative and summative assessments of learners are undertaken, and letter grades are awarded to determine a pass or a fail (Namibia. MoEAC, 2015). Examples of promotional subjects at the Junior Secondary phase in Namibian schools include English (a second language in most schools, and the language of learning and teaching in Namibia), Oshindonga (a first language taught in most northern schools), Mathematics, Physical Science, Life Science, Agriculture, History, Geography, and Entrepreneurship. Support subjects are formatively assessed to determine letter grades, but they are not considered for determining a pass or a fail (Namibia. MoEAC, 2015). Examples of support subjects at the Junior Secondary phase in Namibian schools include Arts, Life Skills, Physical Education and Information Technology. Namibia's first education curriculum was developed and implemented in 1990 – the year in which the country gained political independence (Namibia. MoEAC, 2015). The current curriculum model in Namibia operates on a five-year term. Towards the end of each term, a curricular review targeting areas of improvement and sustained successes is carried out.

Namibia's first post-independence curriculum aimed for equal access to education for the entire nation (Namibia. Ministry of Basic Education and Culture [MBEC], 1993). This curriculum and the subsequent curricula were reviewed and developed to aid the country in achieving Vision 2030. Vision 2030 aims to transform Namibia into a prosperous and industrialised country, developed by its own resources, where inhabitants enjoy peace, harmony, and political stability (Namibia. MoEAC, 2015). The MoEAC (2015) outlines that Vision 2030 is attainable mainly through the development of human resources. This task was entrusted to the Ministry of Basic Education, as it is viewed as the steering wheel of the schooling system. Curriculum development and review are viewed as significant processes in Namibia attaining its education goals (Namibia. MoEAC, 2015).

The curriculum in use during the time of this study is the National Curriculum for Basic Education, first implemented in 2015, and which replaced the previous curriculum that was implemented in 2010 (Namibia. MoEAC, 2015). However, the use of this older 2010 curriculum has not completely ended, since new curricula for different phases and grades are phased in year by year over the five year cycle, per phase (in primary phases – junior and senior primary) and per grade (in secondary phases – junior and senior secondary). This old curriculum had grades classified into four phases: Junior Primary (Grades 1-4), Senior Primary (Grades 5-7), Junior Secondary (Grades 8-10) and Senior Secondary (Grades 11-12) (Namibia. MoEAC, 2010). The phasing out of curriculum 2010 and the implementation of curriculum 2015 happen concurrently in different grades for both primary and secondary phases over different years. The timeline for this implementation is as follows: Junior Primary phase was in 2015, Senior Primary phase was in 2016, Grade 8 was in 2017, Grade 9 was in 2018, Grade 10 was in 2019, Grade 11 is in 2020, and Grade 12 will be in 2021 (Namibia. MoEAC, 2015).

In the current curriculum, the phases of schooling have changed as follows: Junior Primary (Grade 0 [pre-primary]-Grade 3), Senior Primary (Grades 4-7), Junior Secondary (Grades 8-9) and Senior Secondary (Grades 10-11: Namibian Senior Secondary Certificate Ordinary [NSSCO] Level, and Grade 12: Namibian Senior Secondary Certificate Advanced Subsidiary [NSSCAS] Level) (Namibia. MoEAC, 2015). Table 1 shows the significant differences between these two curricula in the Junior Secondary phase, where this study was undertaken.

Table 1. The differences between the 2010 curriculum and the 2015 curriculum for the Junior Secondary phase

Aspects	The 2010 JS curriculum	The 2015 JS Curriculum
Exit grade	Grade 10	Grade 9
Type of examination at end of phase	Junior Secondary examination	Junior Secondary semi-external examination

Examiners	national markers, in Windhoek	subject teachers at schools

The level of content difficulty is/will be elevated across all promotional subjects in schools in the current curriculum. The current curriculum suggests that teaching should consider learners' prior knowledge as the point of departure. For this curriculum to have a coherent and concise framework that ensures excellent and consistent service delivery, it has defined goals, aims and rationale, learning and assessment, language policy, and curriculum management (Namibia. MoEAC, 2015).

Both the current and previous curricula have seven key learning areas through which teaching across phases takes place. A key learning area is defined as a "field of knowledge and skills which is part of the foundation needed to function well in a knowledge-based society" (Namibia. MoEAC, 2015, p. 14). These key learning areas are Languages, Mathematics, Natural Sciences, Social Sciences, Technology, Arts, and Physical Education. Natural Sciences is one of the key learning areas regarded as drivers of social transformation, as they are contributing to the foundation of a knowledge-based society. This key learning area strives to improve the scientific literacy of learners, which is achievable via understanding scientific processes, acquiring scientific knowledge, and developing scientific thinking (Namibia. MoEAC, 2015). In Namibia, Natural Sciences includes the following subjects: Environmental Learning (taught in the pre-primary grade), Environmental Studies (taught in Grades 1-3), Natural Sciences and Health Education (taught in Grades 4-7), Elementary Agriculture (taught in Grades 5-7), Life Sciences (taught in Grades 8-9), Agriculture (taught in Grades 8-12), Biology (taught in Grades 10-12), Physical Science (taught in Grades 8-9), Physics (taught in Grades 10-12) and Chemistry (taught in Grades 10-12). The study reported on in this thesis focuses only on the topic of chemical bonding in Grade 9 of the Junior Secondary Physical Science syllabus (as justified in Chapter 5 and 6).

The Namibian government is cognisant of natural resources that the country owns, which are regarded as enablers of national economic progression and improved living standard of its people (Namibia. MoEAC, 2015). As a result, the Physical Science syllabus was tasked with the purpose of improving the scientific skills and knowledge that are needed to explore the country's natural resources. The four main aims of the Physical Science syllabus are knowledge with understanding, values and attitudes, scientific skills, and democratic principles (Namibia. MoEAC, 2015). In Namibia, Junior Secondary Physical Science is a subject which combines chemistry and physics themes. The two chemistry themes are Matter and Energy, which is the area of research for this thesis; and Environmental Chemistry, where acids, alkalis (bases), metals, and non-metals are taught (Namibia. MoEAC, 2015). The only physics theme is Mechanics.

The Physical Science syllabus outlines two major expectations related to matter upon learners' completion of the Junior Secondary phase. First, learners are expected to complete the phase with an understanding that the world around them is made up of elements listed in the periodic table, and that these elements are arranged in groups and periods on the periodic table in order of their increasing atomic numbers (Namibia. MoEAC, 2015). Second, learners are expected to have an understanding that atoms of elements combine to form the building blocks of all materials in which the chemical bonding is either covalent or ionic, (Namibia. MoEAC, 2015). They are also required to have knowledge of properties and reactions of these elements in order to help them understand and illustrate both covalent and ionic bonding.

The Namibian Junior Secondary Certificate (JSC) examiners' reports reveal that Grade 10 learners perform consistently poorly at the national level when it comes to answering questions on chemical bonding (Namibia. MoEAC, 2014; 2015; 2016 & 2017). These reports inform us that the two major expectations of the Physical Science syllabus with regards to chemical bonding were not met at the end of the JS phase of both the previous and current curricula. It was frequently reported that the Namibian JS phase learners could not correctly explain, at the particulate level, how covalent and ionic bonding occur (Namibia. MoEAC, 2015). Specifically, these learners have difficulty illustrating both covalent and ionic bonding. Moreover, most of these reports revealed that the JS phase learners had difficulty writing correct chemical equations for chemical reactions. These reveal that the challenge of chemical bonding to Grade 10 learners has been prevalent in Namibia during the four years preceding this study (Namibia. MoEAC, 2014; 2015; 2016 & 2017), without being resolved. It is possible that this problem has its roots in Grade 9 chemistry, which prepares learners for chemistry in Grade 10.

Anecdotal evidence from my teaching experience as a Grade 9 and 10 Physical Science teacher in a school located in the northern part of Namibia is in agreement with the literature around the challenge of sense-making of chemical bonding by Grade 9 learners. For example, I have often observed learners incorrectly illustrating ionic bonding by drawing overlapping shells of metallic and non-metallic atoms instead of showing a transfer of electrons. Further, some learners incorrectly refer to atoms transferring electrons when asked to verbally explain a covalent bond, which actually involves the sharing of electrons. In my teaching experience, the majority of Grade 10 learners could not write correct balanced chemical equations for chemical reactions, while some write word equations when asked to write chemical equations, and vice versa. This difficulty among learners in making sense of chemical bonding, especially at sub-microscopic and symbolic levels of representation, is recognised internationally, and regarded as posing challenges to learning further chemistry topics (Hilton & Nichols, 2011; Nimmermark, 2014).

The study reported on in this thesis is a response to the above-mentioned challenge. It has explored the influences that a coordinated visual-verbal intersemiotic complementarity teaching approach has on Grade 9 Namibian learners' sense-making of chemical bonding. This study was informed by ideas drawn from literature about multimodality (Lemke, 1998; Cheng & Gibert, 2009), grammar of visuals (Kress & van Leeuwen, 1996), and intersemiotic complementarity (Royce, 1998). Learners' sense-making was appraised before and after the intervention to uncover changes due to the intersemiotic complementarity teaching intervention.

1.3 Problem statement and rationale

As discussed in Section 1.2, anecdotal evidence of my ten years of experience in teaching Physical Science reveals that the pedagogy of chemical bonding in Namibian schools, specifically in Grade 9, is a challenge, despite it being a central chemistry topic (Gilbert & Treagust, 2009; Hurst; 2002). This was confirmed by the JS examiners' reports for four recent consecutive years (Namibia. MoEAC, 2014; 2015; 2016 & 2017). The challenge is two-fold: chemical bonding being complex to learners, and the lack of suitable pedagogic approach to chemical bonding. I noticed that the complexity of this topic is not changeable as this is its nature; however, I reckoned that exploring a suitable pedagogic approach to it is possible. In Namibia, no study aiming to explore a suitable pedagogic approach to this topic was undertaken, hence indicating a knowledge gap. This prompted me to undertake an action research study exploring the influences of an intersemiotic complementarity teaching approach to the topic of chemical bonding. Undertaking this study was lead by the main research question: What are the influences of a coordinated visual-verbal intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding? The specific questions used to elicit data relevant to answering the main research question are as follow:

1. What are the visual and verbal demands that the curriculum makes on learners for the topic of chemical bonding?
2. What knowledge do Grade 9 Namibian learners have on the topic of chemical bonding after a traditional teaching approach?
3. How does a coordinated visual-verbal intersemiotic complementarity teaching approach shape Grade 9 Namibian learners' sense-making of chemical bonding?

The details regarding the merit of these research questions for this study, and how they were employed during the research process, are provided in Chapter 4.

Hurst (2002) posits that chemical bonding is an overriding core concept in chemistry because understanding it is an entry point to understanding other chemistry topics. Moreover, science learners' full understanding of chemical bonding and its processes lays a strong foundation for mastering chemistry (Hilton & Nichols, 2011). This signals that a lack of understanding of chemical bonding, a core chemistry topic, obstructs further learning of chemistry (Gilbert & Treagust, 2009). According to Levy-Nahum, Mamlok-Naaman, and Hofstein (2007), the chemistry-teaching community worldwide is dissatisfied with the degree to which learners make sense of chemical bonding. This was earlier revealed by Teinchert and Stacy (2002), who assert that students from all parts of the world lack a conceptual understanding of chemical bonding, hence a worldwide challenge.

Disregarding this knowledge gap may result in learners continuing to fail questions on chemical bonding (Talanquer, 2011), and subsequently result in a shortage of capable human resources who can explore the chemical nature of the country's natural resources (Namibia. MoEAC, 2015). This study was therefore conceptualised, aiming towards the possibility of closing of the said knowledge gap.

Studies conducted after the emergence of Johnstone's (1982) three levels of representation of chemistry concepts have supported the idea that the learners understanding chemical knowledge at these levels is an entry point to understanding chemistry. Even though numerous studies on these levels of representation of chemical knowledge have been conducted since their identification, none has focused on exploring the influences of a visual-verbal intersemiotic complementarity teaching approach to this topic – not even in Namibia despite this topic being reported by JS examiner's reports as poorly performed. This study is warranted by Talanquer (2011), who expresses that the visual language of chemistry has potential for helping students to understand chemical knowledge at these levels of representation, and by Royce's (2002) notion of a coordinated deployment of visual and verbal semiotic modes in making teaching and learning effective. The visual-verbal intersemiotic complementarity may be accomplished through combining the sense relations of ideational meaning-making resources of the visual and verbal semiotic modes (Royce, 2002). The meaning-making resources are the representations of the world around us, and the ideational is one that is most relevant to this study. The concept of *sense relations* is used by Halliday (1994) to refer to categories of lexical cohesion (further discussed in Chapter 2 and Chapter 3), which are the items of the verbal mode that enable a person to make sense of the meaning being conveyed through this semiotic mode. The viability of this cohesion on the coordinated visual and verbal semiotic modes is clarified by Royce (2002), suggesting that these sense relations are also useful in visual-verbal intersemiotic complementarity for making meaning.

The Namibian curriculum highlights that visuals play an increasingly important role in a country (such as Namibia) where transforming a society into being knowledge-based is the prime focus (Namibia. MoEAC, 2015). It suggests that learners should use a wide range of visual media and other sources of visual messages to access knowledge. This includes learners' work and formal assessment being done via mixed modes, such as oral and visual. However, guidance on how this should be achieved is not explicitly mentioned in this curriculum – leaving the teachers daunted due to unavailability of proper guidelines of implementation. I have realised that we (chemistry teachers) often employ the visual and verbal semiotic modes intuitively in teaching chemical knowledge – which is often helpful. This reaffirms the idea that visual-verbal intersemiotic complementarity is useful in pedagogy (Joyce, 2002; Talanquer, 2011), and the suggestion by the Namibian curriculum that teaching and learning should make use of visuals (Namibia. MoEAC, 2015).

Therefore, the ideas that the nature of chemical knowledge, such as chemical bonding, may be understood via analysing its levels of representation (Johnstone, 1982), and that coordinated visual and verbal semiotic modes may be employed in pedagogy (Talanquer, 2011; Royce, 2002), form a rationale for exploring the influences of a visual-verbal intersemiotic complementarity teaching approach to chemical bonding. This intersemiosis was achieved by coordinating the sense relations of the ideational meaning-making resources of coordinated visual and verbal semiotic modes. These meaning-making resources are discussed further in Chapters 2 and 3 of this thesis.

1.4 Significance of the study

In response to the knowledge gap mentioned earlier, this study has explored the influences of an intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding. The potential benefits of this study involve the possibility of finding a suitable pedagogic approach to teaching chemical bonding, informing curriculum review/development, and guiding the development and implementation of teacher training curricula. In addition to these, this study has the potential to improve my own pedagogic practice for chemical bonding and other chemistry topics.

Firstly, exploring the influences of a visual-verbal intersemiotic complementarity teaching approach may provide empirical evidence that the integrated use of the visual and verbal modes has the potential to enhance sense-making of chemical bonding. Secondly, curriculum review and development might draw from findings of this study with regards to how the visual and verbal modes can be used effectively in chemistry education. Thirdly, the findings of this study have implications for teacher training – enabling teacher training institutions to offer training to chemistry teachers on using visual-verbal intersemiotic complementarity as a pedagogic approach and making them (chemistry teachers) better equipped to help chemistry learners make sense of chemical bonding concepts. Other potential benefits of this study involve providing the foundation for future research into how science learners interact with multimodal materials, and building a positive attitude towards the non-verbal semiotic modes in both teachers and learners (Royce, 2002).

1.5 Thesis outline

This thesis comprises six chapters. Chapter 1 introduces the study, Chapter 2 presents the literature review, Chapter 3 provides the theoretical and analytical frameworks, Chapter 4 covers research design issues, Chapter 5 contains the discussion and presentation of findings, and Chapter 6 concludes the thesis with a summary of findings and the recommendations of the thesis. The last part of this thesis is the appendices. An outline of each chapter is provided below.

1.5.1 Chapter 1: Introduction

Chapter 1 provides the international and national context of school chemistry education in terms of the representational levels of chemistry, learners' challenges making sense of chemical bonding, and the rationale for why visual-verbal intersemiotic complementarity was investigated as a pedagogic approach to this topic. It also outlines the potential value of the study (action research). The chapter concludes by briefly highlighting to the reader the potential of a visual-verbal intersemiotic complementarity teaching approach for enhancing learners' sense-making of chemical bonding at the sub-microscopic and symbolic levels – the representational levels of this topic that are more challenging to learners.

1.5.2 Chapter 2: Literature review

Chapter 2 provides a review of literature on the topics that are relevant to this study. These topics are chemical bonding complexity and teaching approaches; the definition and expectations of chemical bonding according to the Namibian curriculum; Namibian learners' performance in assessments on chemical bonding; sense-making in science education; multimodality of scientific discourse; and visual-verbal intersemiotic complementarity. This chapter concludes by highlighting how views of various scholars on these topics have contributed to conducting this study.

1.5.3 Chapter 3: Theoretical and analytical frameworks

Chapter 3 discusses the two theories that underpin the study: social constructivism and Systemic Functional Linguistics. Social constructivism serves as a theoretical framework, whereas Systemic Functional Linguistics serves as an analytical framework. Justification for choosing these theories, and explanation on how they complement each other in the study, are provided in this chapter.

1.5.4 Chapter 4: Research design

Chapter 4 covers the following: research goal and questions, research methodology, research site and participants, data collection techniques, data preparation (such as transcribing and selection) and analysis, validity, ethical considerations, limitations of the action research study, and conclusion.

1.5.5 Chapter 5: Presentation of findings, analysis, and discussion

Chapter 5 includes the findings, the analysis and the discussion thereof. These findings include the curriculum's visual-verbal demands on representing chemical bonding knowledge, the Grade 9 learners' knowledge of chemical bonding after a traditional teaching approach, and the influences of the visual-verbal intersemiotic complementarity teaching approach on learners' sense-making of chemical bonding.

1.5.6 Chapter 6: Summary of findings, recommendations, and conclusions

This chapter contains a descriptive summary of qualitative findings. These are presented in sub-sections based on themes that have emerged from the analysis. Recommendations that are informed by the findings are then presented. The conclusion then ends the thesis.

1.5.7 Appendices

The last part of this thesis is the appendices. This is a list of items or materials that contain information needed to support the findings and analysis, and hence validating the conclusion drawn from the study. Their incorporation in the text makes the document poorly structured, and longer than necessary. These may include, amongst others, tables, diagrams, and results, as supportive evidence. This document has appendices lettered from A to U, and these include copies of ethical clearance approval letter, consent-seeking and consent letters, lessons plans, research tools used, tables of useful data, and a turn-it-in similarity report.

1.6 Conclusion

Central to this study is the fact that making sense of chemical bonding is a challenge to Grade 9 Namibian learners. This chapter has introduced the reader to the levels of representation of chemical bonding and related challenges, as discussed by Johnstone (1982). Moreover, ideas on intersemiotic complementarity have been reviewed for implementation in this study. This warrants exploration of possible pedagogic approaches to teaching chemical bonding in Namibia. The first step in attempting to contribute to filling the knowledge gap was to review literature that is relevant to this study, in order to inform the research design.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The overarching goal of this study was to explore the influences of a coordinated visual-verbal intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding. This was warranted by Namibian learners' difficulty making sense of chemical bonding, as well as by the potential pedagogic benefits of a visual-verbal intersemiotic complementarity teaching approach.

The sub-sections of this literature review include chemical bonding complexity and teaching approaches; the definition and expectations of chemical bonding according to the Namibian curriculum; the Namibian learners' performance in assessments on chemical bonding; sense-making in science education; multimodality of scientific discourse; and visual-verbal intersemiotic complementarity. Undertaking this review has improved my own understanding of the key concepts in the study, and has also informed the research design necessary for this study, as will be evident in Chapter 4.

2.2 Literature related to key concepts of the study

2.2.1 Chemical bonding complexity and teaching approaches

Chemical bonding is a chemistry topic that aids the overall understanding of chemical phenomena by students and scientists (Nimmermark, 2014). This understanding is attainable via knowledge of the chemistry of atoms, molecules, and ions of which substances consist (Gilbert & Treagust, 2009). The chemistry of these particles explains the behaviour and physical properties of the substances we use (Gilbert & Treagust, 2009). However, for students to understand these chemical phenomena is a challenge, as they often have ideas about chemical bonding that are incompatible with scientific perceptions (Ozmen, 2004). This incompatibility is due to understanding of chemical bonding involving abstract concepts that require both simple and complex explanation models (Harrison & Treagust, 1996). Some of these models include non-observable entities that are often accessible only via imagination (Gilbert & Treagust, 2009). These entities include atoms, ions, and molecules, as well as their behaviours. If learners' understanding of chemical bonding is inadequate, their subsequent understanding of chemical phenomena is hampered (Nimmermark, 2014).

Even though the knowledge of chemical bonding is considered to be accessible via the understanding of particular chemical concepts, this is often not achieved, as most learners cannot master these abstract chemistry concepts on their own (Gibert & Treagust, 2009). Addressing this challenge may consider the assertion that effective chemistry teaching can be influenced by the science teacher's ability to explain abstract and complex chemical concepts and phenomena to the learners (Treagust, Chittleborough & Mamiala, 2003). Hence, a teachers' inability to effectively convert concepts from their abstract forms into their concrete forms hampers students' learning of chemistry, as the subject is rich in these abstract concepts (Treagust, Chittleborough & Mamiala, 2003). Improving learners' sense-making in the topic requires teaching approaches that enable easy conversion of concepts from abstract to concrete forms.

Making the distinction between abstract and concrete forms may be enabled by considering ideas from Johnstone (1982). He initially categorised knowledge of chemistry as either real or representational. Real knowledge refers to the knowledge of things that exist, while a representation refers to conventional symbols and signs used to represent real chemical knowledge (Johnstone, 1982). According to Johnstone (1982), knowledge of things that exist is concrete, while knowledge of conventional symbols and signs is abstract. From these, he identified three levels of representation at which knowledge of chemistry is taught: macroscopic, sub-microscopic, and symbolic. The full understanding of these representational levels and their justified use in chemistry teaching by teachers can significantly improve learners' understanding of chemistry topics (Johnstone, 1982). These representational levels, their meanings, and their relationship to each other are illustrated in **Figure 1**.

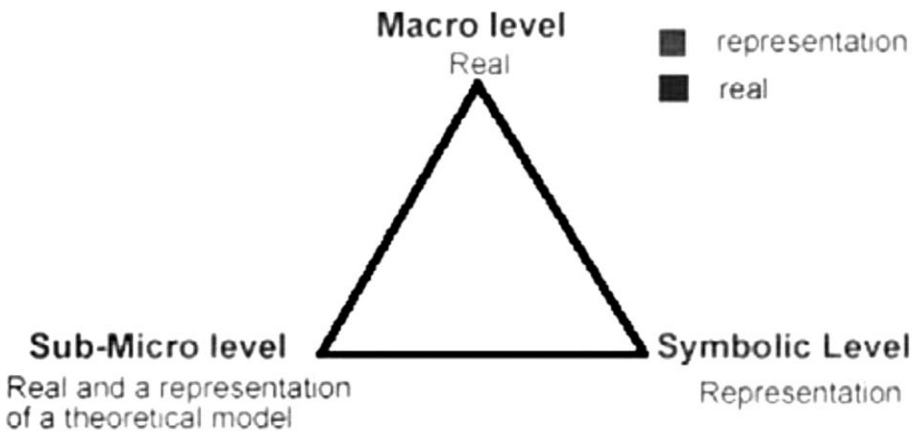


Figure 1. The representational levels of chemistry (Adopted from Johnstone, 1982)

According to Johnstone (1982), the macroscopic level of representation involves the representation of real, concrete, and observable chemical phenomena. This level of representation is characterised by teaching and learning of tangible, audible, and visible properties and behaviours of matter (Santos & Arroio, 2016). An example of this level of representation is explaining that limewater, scientifically known as calcium hydroxide solution, turns milky after carbon dioxide is bubbled through it. This is likely to be understood by most learners as they can see limewater changing from being colourless to milky (white). However, even the macroscopic level of representation may be challenging to students if suitable practical experiments are not prepared (Nelson, 2002). Nonetheless, as Figure 1 shows, the macroscopic representation is real because the colour change is observable. It is for this reason that learners usually understand knowledge at this level.

The sub-microscopic level of representation involves unobservable real structures and behaviours of microscopic particles of matter (Johnstone, 1982). This representation level is distinct from the macroscopic level in that it represents facts that cannot be observed, and learners are often confused by this (Harrison & Treagust, 1996). The explanation of what happens to limewater particles when carbon dioxide particles are blown through them is an example of this level of representation. The learners may be confused by this knowledge, as they do not see the particles of limewater and carbon dioxide, or how these particles react with each other. Gilbert and Treagust (2009) argue that this level of representation can only be accessed via imagination, which makes it more challenging than the macroscopic level. They suggest that while learners' understanding of this representational level may be achieved through language, this is not often accomplished, as language is sometimes imprecise. Imprecise language benefits from the use of the visual semiotic mode to help learners to understand knowledge at the sub-microscopic level of representation (Gilbert & Treagust, 2009). Gilbert and Treagust (2009) consider the visual mode as having the potential to depict aspects of the model of matter being explained to learners. Therefore, the visual semiotic mode coordinated with the verbal semiotic mode may be a suitable pedagogic approach required to address the challenge of understanding matter at the sub-microscopic and symbolic levels, the latter of which will now be discussed.

The symbolic level of representation involves the use of conventional signs, symbols, and chemical equations (Johnstone, 1982). The knowledge of chemical bonding at this level is distinct from the sub-microscopic level in that it is unreal. Johnstone (1982) clarifies that this level includes the allocation of symbols to atoms either as single particles or in groups, such as in ionic or molecular forms, of signs to represent the electrical charge of particles, and of subscripts to show the number of atoms in ionic or molecular particles. He adds that it includes letters in chemical equations to indicate physical states of entities. This level of representation is most challenging to students because it requires understanding of complex conventions used in symbolic forms (Johnstone, 1982). Writing a balanced chemical equation for the reaction between molecules of carbon dioxide and ions in limewater to produce calcium carbonate, which causes the milky colour, is an example of the symbolic level of representation as shown here: $Ca(H_2O)_2\ (aq) + CO_2\ (g) \rightarrow CaCO_3\ (s) + H_2O\ (l)$.

Among these three levels of representation, the symbolic level is most challenging, followed by the sub-microscopic level, with the macroscopic level being the least challenging (Johnstone, 1982). Understanding chemistry topics fully is achievable by obtaining chemical knowledge at the sub-microscopic and symbolic levels, because knowledge of chemistry is based mainly on these two levels (Kozma & Russell, 1997). However, accessing these levels of knowledge is often challenging to learners (Johnstone, 1982). Addressing the challenge of chemical bonding for learners might be informed by Johnstone's (1982) idea that invisible particles can be represented by using the visual mode of communication. Gabel (1998) argues that students have difficulty making links between the three levels of representation. This adds to the difficulty in learning chemistry. Since chemical bonding is an example of a challenging chemistry topic, Johnstone's (1982) idea of combining the visual and verbal modes for representing related phenomena was considered useful for my action research around the topic of chemical bonding in the Namibian context. The related curriculum will now be reviewed.

2.2.2 The definition and expectations of chemical bonding according to the Namibian curriculum

The complexity of chemistry topics, and the related challenge that they pose to learners as identified by Johnstone (1982), has also been noticed by the Namibian JS external examiners (Namibia, MoEAC, 2015). In Namibia, chemistry is a part of Physical Science in the Junior Secondary (JS) phase, and it comprises a number of topics, including chemical bonding (Namibia. MoEAC, 2015). The JS Physical Science syllabus' expectations for chemical bonding involve learners gaining an understanding of different types of chemical bonding, describing and distinguishing between covalent and ionic bonding, and relating chemical bonding to groups and periods of the periodic table. These expectations, however, are not usually met, as students struggle to understand chemical bonding concepts and processes (Namibia. MoEAC, 2015). This failure warrants exploring a novel pedagogic intervention for the topic of chemical bonding. Undertaking the intervention necessitated first reviewing the syllabus' objectives.

The Namibian Physical Science syllabus has both general and specific objectives. The general objectives are broad, and highlight what learners are expected to know or understand upon the completion of the topic (Namibia. MoEAC, 2015). For example, expecting learners to understand different types of chemical bonding is a general objective, because it is only achievable after types of chemical bonding are taught. Specific objectives state in detail, using action verbs (such as describe, list, identify, etc.), what learners are expected to do (Namibia. MoEAC, 2015). For example, expecting learners to describe and distinguish between covalent and ionic bonding is a specific objective, because it specifically requires them to give the details of, and the differences between, these two bonding types. Table 2 shows the general and specific objectives of the JS Physical Science syllabus for chemical bonding.

Table 2. General and specific objectives of the JS Physical Science syllabus on chemical bonding (Namibia. MoEAC, 2015, pp. 31-32)

Topic	**General objectives:** Learners will:	**Specific objectives:** Learners should be able to:
2.4 Chemical bonding	• understand the different types of chemical bonding	• describe and distinguish between covalent and ionic bonding as different types of bonding and relate bonding to position (group) of elements in the Periodic Table
2.4.1Covalent bonding (revised from Grade 8)	• know how to illustrate covalent bonding as the sharing of electrons when atoms combine	• describe how non-metal atoms combine with other non-metal atoms by sharing electrons in their outer shells with the result that both atoms achieve full outer shells
2.4.2 Ionic bonding /electrovalent bonds Note: • *electrons are indicated by crosses or dots*	• know how to illustrate ionic bonding as the transfer of electrons to form oppositely charged ions which attract electrostatically	• describe how the reaction between a metal and a non-metal results in the transfer of electrons from metal atoms to non-metal atoms so that both achieve full outer shells and form positive ions (cations) and negative

• *electrons from different atoms should be differentiated by crosses and dots* • *arrows should be used for electron transfer* • *transferred electrons should be indicated only once in the anion and not in the cation and the anion* • *only the outer shell will be indicated in the bonding sketch*		ions (anions) respectively • predict the positive and negative charges of ions (in terms of attained noble gas electronic structures) • define ions as atoms with a net electric charge due to the loss or gain of one or more electrons (e.g. cations have lost electrons and anions have gained electrons in order to attain noble gas structure) • draw Bohr structures of ionic compounds • explain ionic bonding as the electrostatic attraction between oppositely charged ions (cations and anions) • describe the lattice of an ionic compound as a regular arrangement of alternating positive and negative ions • write the formulae of ionic compounds including polyatomic ions (i.e. SO_4^{2-}; NO_3^-; CO_3^{2-}; NH_4^+; HCO_3^-; OH^-)

In addition to the general and specific objectives for chemical bonding in the Physical Science syllabus, the syllabus provides guidelines as to how learners are expected to illustrate concepts in the topic. These guidelines are provided for uniformity in how Physical Science teachers approach the topic as most learners in Namibia have difficulty illustrating chemical bonding (Namibia. MoEAC, 2015). For this study, this guideline needed consideration; because the study is based in Namibia, disregarding it might have negatively impacted on the validity of this study, and disadvantaged the learners in their examinations. The requirements of the syllabus, as provided by the Ministry of Education, Arts and Culture (2015, p. 32), include:

- "The nucleus has to be indicated, and a small line to the outside of an atom is drawn from it to write the number of protons and neutrons.
- Electrons have to be indicated by crosses or dots only.

- Electrons from different atoms should be differentiated by using dots and crosses.
- The overlaps of shells in covalent bonding should be used.
- All shared electrons in covalent bonding should be indicated in the overlap.
- Only the outer shells should be used in the bonding sketch of both ionic and covalent bonds.
- In ionic bonding, arrows should be used to indicate electron transfer from a metal atom to a non-metal atom.
- Transferred electrons should be indicated only once, in the anion, and not in both the anion and the cation."

It is possible that the way the syllabus expects chemical bonding to be taught contributes to the challenges faced by learners. For example, Gilbert and Treagust (2009) argue that interpretive frameworks developed by chemistry experts may cause novices to focus on incidental aspects of the representation used rather than on the main aspect. They argue that some curricula present meaningless features. It is possible that the Namibian JS Physical Science syllabus also presents meaningless features that have the potential to impact negatively on learners' sense-making of chemical bonding. Despite this possibility, this study does not defy the curriculum's specifications with regards to illustrating chemical bonding to learners, as that would have meant that learners' participation in the study would have disadvantaged them, thus raising ethical concerns.

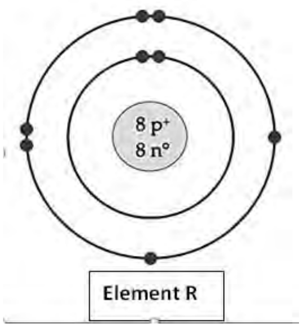
As evident from Table 2, knowledge of chemical bonding at the Namibian JS phase is represented mainly at sub-microscopic and symbolic levels, which Johnstone (1982) identifies as most challenging. This is noticeable, for example, in the stipulations made by the JS Physical Science syllabus on molecules and how they should be presented to learners (Namibia. MoEAC, 2015). Much of the chemical bonding knowledge in the Physical Science syllabus is sub-microscopic as it concerns microscopic particles of matter such as atoms, ions, and molecules that are non-observable. For instance, the Physical Science syllabus classifies molecules of covalent compounds as either diatomic or polyatomic. It defines a diatomic molecule as "a molecule made up of two atoms bonded together covalently", and a polyatomic molecule as "a molecule made up of more than two atoms bonded covalently" (Namibia. MoEAC, p. 31). Further, it classifies diatomic molecules as either homonuclear (made up of two atoms of the same elements) or heteronuclear (made up of two atoms from different elements). Examples of homonuclear molecules are H_2, O_2, N_2, and diatomic molecules of group 7 elements such as F_2, Cl_2, Br_2, and I_2, while examples of heteronuclear molecules are HF, HCl, and CO molecules. Polyatomic molecules such as CO_2, CH_4, H_2O, and NH_3 are heteronuclear, while O_3 and S_8 are homonuclear. Moreover, some aspects included in this knowledge are symbolic because there are symbols and subscripts used to represent ideas/information. This has the potential to add further difficulty to making sense of knowledge of chemical bonding, as these symbols and subscripts are usually complex to learners (Johnstone, 1982).

Knowledge at the sub-microscopic level, such as of molecules, and at the symbolic level, such as of formulae of compounds, covered by the Namibian Physical Science syllabus, may only be effectively accessed by students if they have developed mental models, as Nimmermark (2014) suggests. The syllabus also suggests that simple physical models may be used to illustrate both the Bohr structure of the first 20 elements in the periodic table, and that atoms bind to form molecules (Namibia. MoEAC, 2015). However, the syllabus does not discuss this in any further detail. As Johnstone (1982) suggests, physical models help to present the sub-microscopic level in a macroscopic way, in order to make chemical bonding concepts more explicit to learners. Therefore, this study also considered physical models by drawing from the perspectives of Social constructivism, since their use forms an aspect of the visual mode and, together with the verbal mode, might be used to mediate learners' meaning-making.

2.2.3 The Namibian learners' performance in assessments on chemical bonding

The Namibian JS examiners' reports revealed that the challenge of chemical bonding to Grade 10 learners continued in Namibia over four consecutive years (2014-2017) without being addressed. Despite these reports, and the suggestion by JS examiners for Physical Science teachers to put emphasis on this knowledge, this challenge was still noticed in the year 2018. This problem might have emanated from Grade 9, as that is where the introductory concepts are introduced. This sub-section of the literature review details the JS examiner's reports of how Grade 10 Namibian learners answered questions on chemical bonding for the four consecutive years prior to the beginning of this study. Previously, the examination for Grade 9 is marked at schools by subject teachers, while the examination for Grade 10 (referred to as the JS examination) is marked nationally in Windhoek by selected experienced markers; many of them are subject teachers, while others are education officers. These JS examiners' reports are provided to schools annually for teachers to address specific challenges that are identified by the national examiners. Since there are no (written) examiners' reports of how Grade 9 learners answer questions on chemical bonding, the review of literature for this study has focused on the JS examiners' reports for the 2014, 2015, 2016, and 2017 academic years. The details of the examiner's report for the year 2014 are in Table 3.

Table 3. The 2014 JS examiner's report of learners' performance on chemical bonding questions (Namibia. MoEAC, 2014, p. 255-258)

Knowledge of chemical bonding examined	Example of assessment questions	Question		% of Learners who scored full marks
Periodic table and atomic structure	The diagram shows the Bohr structure of element R.  Identify the elements represented by structure R.	1(a)	(i)	49.0
			(ii)	52.0
			(iii)	82.0
Identification of chemical bond type	Name the type of chemical bond formed between two atoms of element R.	1(b)	(i)	52.0
Illustration of ionic bond	Use the Bohr model to illustrate the bond between sodium and element R.	1(b)	(ii)	30.0
Defining a molecule	Define a molecule.	1(c)	(i)	4.7
Deducing formulae of ionic compounds	Deduce the chemical formula of the compound form when element R reacts with sodium.	1(c)	(ii)	11.7

Overall, the questions on the use of the periodic table in relation to an atomic structure were well-answered by the JS learners countrywide during the year 2014. Many of these learners demonstrated that they had no difficulty identifying the type of chemical bond between reacting elements. However, these learners showed that they had a limited understanding of molecules and ionic bonding, as only 4.7% and 30.0% of them respectively scored full marks on these questions. According to Johnstone (1982), this chemistry knowledge belongs to the sub-microscopic level of representation, because it concerns the *microscopic* particulate nature of matter that is explained using atomic, molecular, and kinetic concepts. The JS learners' difficulty with this knowledge of chemical bonding reported on in the 2014 examiner's report confirms the finding by Johnstone (1982) that learners have difficulty with chemistry knowledge at the sub-microscopic level of representation. Harrison and Treagust (1996) explain that this difficulty is often due to learners expecting atoms and molecules to be represented as concrete objects. This expectation resulted in learners having simplistic sub-microscopic understanding of chemical phenomena (Chittleborough, Treagust & Mocerino, 2005). It is therefore also possible that the Namibian JS learners' difficulty with the sub-microscopic level of representation is caused by them having such a simplistic view of matter.

Table 3 also shows that only 11.7% of learners scored full marks on the question that asked them to provide the formula of ionic compounds when given the name. This level of representation, according to Johnstone (1982), is symbolic because it focuses on making sense of and using representations such as chemical symbols, formulae, equations, and mathematical signs. Johnstone (1982) identifies this level of representation as challenging for learners because the symbols involved are difficult to understand. Gilbert and Treagust (2009) explain that difficulty with the symbolic level is due to its abstractness and non-experiential nature. According to Thadison (2011), most students memorise formulae, mainly from laboratory manuals, without ideas of what they mean or how they are used. It is possible that the 11.7% of Namibian JS learners that scored full marks on writing formulae have merely memorised the formulae without understanding them.

The challenge of chemical bonding to learners reported on in the 2014 examiner's report continued in year 2015 (Namibia. MoEAC, 2015). The details of the examiner's report on chemical bonding for the year 2015 are tabulated in Table 4

Table 4. The 2015 JS examiner's report of learners' performance on chemical bonding questions (Namibia. MoEAC, 2015, p. 236-239)

Knowledge of chemical bonding examined	Example of assessment questions	Question	Description of how the questions were answered
Periodic table	Element **D** is found in group 1 and in	1(a)	Poorly-answered

	period 1, While Element E is found in group 8 and in period 1. Question: Identify elements D and E.			
Identification of elements	Write down an element that exists as a diatomic gas at room temperature.	1(b)		Well-answered
		1(c)		Well-answered
Bond identification	State the type of chemical bond formed when magnesium reacts with oxygen.	1(d)	(i)	Well-answered
Explanation of bond between magnesium and oxygen	Explain how the bond in magnesium oxide is formed.		(ii)	Poorly-answered

Even though no descriptions of learners' responses in numbers or in percentages could be obtained from the 2015 JS examiner's report, the degree to which the learners attempted the questions on chemical bonding reveals their knowledge on the topic. The examiner's report reveals that the questions on chemical bonding that were asked in the year 2015 focused on knowledge that is represented macroscopically and sub-microscopically. For instance, questions on identification of elements and bond type test macroscopic knowledge, as answering them does not require knowledge of the particulate nature of matter, while the questions requiring explanation of the bond between magnesium and oxygen test for knowledge of these elements at their particulate level.

Overall, learners did not have much difficulty using the periodic table – they could correctly identify elements in the periodic table, with the exception of hydrogen being confused with helium (Namibia. MoEAC, 2015). They also distinguished between covalent and ionic bonding correctly. According to Johnstone (1982), accessing the knowledge of chemical bonding that belongs to the macroscopic level of representation is not a challenge to learners as they can experience it. These learners have experience using the periodic table, and many of them have even seen some of the elements from the periodic table.

As shown in Table 4, it was reported that the Namibian JS learners had difficulty explaining the bond between magnesium and oxygen atoms in terms of gain and loss of electrons (Namibia. MoEAC, 2015). They were expected to use concepts such as 'valency', 'electron transfer' and 'attaining a noble gas structure' when explaining this bond, which many of them failed to do. This failure confirmed that many 2015 Namibian JS learners also lacked the ability to represent chemical bonding sub-microscopically, a challenge previously pointed out by Johnstone (1982). The sub-microscopic nature of this knowledge is evident in that it concerns atoms and their sub-atomic particles, as well as related forces and behaviour.

The learners’ difficulty making sense of chemical bonding knowledge, especially at the sub-microscopic and symbolic levels, was still evident in 2016 (Namibia. MoEAC, 2016). The countrywide JS learners’ performance on chemical bonding questions in this year is tabulated in Table 5.

Table 5. The 2016 JS examiner’s report of learners’ performance on chemical bonding questions (Namibia. MoEAC, 2016, p. 244-245)

Knowledge of chemical bonding examined	Example of assessment questions	Question		Description of how the questions were answered
Periodic table	Identify the group number of chlorine.	2(a)		Well-answered
Bond type identification	Identify the type of bond formed between the two chlorine atoms.	2(b)	(i)	Fairly-answered
Illustration of covalent bond in a chlorine molecule	Use the Bohr model to illustrate the bond in a chlorine molecule.		(ii)	Poorly-answered
Writing a balanced chemical equation	Sodium can react with chlorine to form sodium chlorine (table salt). Write a balanced chemical equation for this reaction.		(iii)	Poorly-answered

The 2016 Namibian JS learners demonstrated knowledge of using the periodic table to access knowledge of chemical properties and behaviour of atoms of elements. This knowledge includes the ability to explain the relationship between the group number and the number of outer shell electrons, and between the period number and the number of shells of atoms of an element. It was also reported that many of these learners distinguished between metals and non-metals correctly – the knowledge needed for learning chemical bonding (Namibia. MoEAC, 2016). However, the 2016 JS examiner’s report revealed that many learners had difficulty using their knowledge of the periodic table to access knowledge of chemical bonding. As shown in Table 5, the question on identifying the type of chemical bonding (which is covalent) was answered moderately well, with some learners incorrectly answering as ionic. Even though the level of representation of this chemical knowledge is macroscopic, which is considered to be less challenging, some learners had difficulty distinguishing between metals and non-metals, the knowledge which is partly sub-microscopic. This may adversely affect their ability to access knowledge of chemical bonding, as this knowledge aspect is among the pre-requisites to gaining the knowledge of chemical bonding.

As earlier outlined by Griffiths and Preston (1992), these JS learners also had difficulty accessing chemistry knowledge at the sub-microscopic and symbolic levels of representation, possibly due to its abstractness and non-experiential nature. In 2016, this challenge was evident in learners having difficulty illustrating covalent bonding in a chlorine molecule and writing a balanced chemical equation for the reaction between magnesium and oxygen atoms (Namibia. MoEAC, 2016). Drawing bonding structures in any compound belongs to the sub-microscopic level of representation, as atoms and sub-atomic particles involved in bonding processes are non-observable, while writing chemical equations belongs to the symbolic level of representation as it involves using conventional symbols (Johnstone, 1991). The Namibian 2016 JS examiner's report revealed that many JS learners did not draw overlapping outer shells of the two chlorine atoms as instructed. It was also reported that only very few learners managed to correctly write the balanced chemical equation for the reaction between magnesium and oxygen. Hence, these revealed that understanding chemical bonding was still a challenge to the Namibian JS learners in 2016. Now a closer look at the learners' performance on this topic in the following year was then necessary. The countrywide JS learners' performance on chemical bonding questions in the year 2017 is in Table 6.

Table 6. The 2017 JS examiner's report of learners' performance on chemical bonding questions (Namibia. MoEAC, 2017, p. 226-228)

<table>
<tr><th>Knowledge of chemical bonding examined</th><th>Example of assessment questions</th><th>Question</th><th>Description of how the questions were answered</th></tr>
<tr><td rowspan="2">Periodic table</td><td rowspan="2">The table shows information of element P, Q, R, S, T and U.
<table>
<tr><td>element</td><td>Group</td><td>Period</td><td>Electron configuration</td></tr>
<tr><td>P</td><td>1</td><td>4</td><td>(i)…</td></tr>
<tr><td>Q</td><td>2</td><td>3</td><td>2,8,2</td></tr>
<tr><td>R</td><td>4</td><td>2</td><td>2,4</td></tr>
<tr><td>S</td><td>6</td><td>2</td><td>2,6</td></tr>
<tr><td>T</td><td>7</td><td>3</td><td>2,8,7</td></tr>
<tr><td>U</td><td>8</td><td>(i) …</td><td>2,8,8</td></tr>
</table>
(a) Complete the table by filling in</td><td>2(a)</td><td>Well-answered</td></tr>
<tr><td>(b)</td><td>Well-answered</td></tr>
</table>

	the missing information for (i) and (ii).			
Physical state of matter	Name the type of bond form when Q and S react.	(c)		Answered moderately
Writing formulae of ionic compounds	Write the correct formula for the compound formed from the reaction between element Q and element T.	(d)		Answered moderately
Bond type identification	Name the type of bond formed when element Q and element S react.	(e)		Well-answered
Illustration of covalent bond in carbon dioxide	Draw the Bohr diagram for the structure of a carbon dioxide molecule (outside shells only).	(f)	(i)	Answered moderately
Use of covalent compounds (carbon dioxide)	State two uses of carbon dioxide.		(ii)	Well-answered

The JS examiner's report for 2017 (Table 6) reveals that the challenge that chemical bonding posed to learners had not yet been addressed (Namibia. MoEAC, 2017). This report indicates that learners have done well in the following: usage of the periodic table; bond type identification; and stating uses of covalent compounds. With the exception of the use of the periodic table, this knowledge mainly concerns observable aspects of chemical bonding – the knowledge which Johnstone (1982) classifies as macroscopic, and describes as less challenging due to its experiential nature. Drawing from Johnstone (1982), this could be the reason why learners did not encounter difficulty when answering this question. However, some learners have shown that they had insufficient knowledge of chemical bonding related to physical states of matter, and illustrating covalent bonding, possibly because they consist of mainly sub-microscopic knowledge, as Johnstone (1982) suggests. In addition, learners countrywide have difficulty accessing knowledge of chemical bonding, which is symbolic, as Johnstone (1982) identifies. The examiner's report confirms this by mentioning that the question on writing the chemical formula of the compound formed after magnesium and chlorine atoms bonded was poorly answered.

Overall, these reports revealed the consistency of chemical bonding difficulty to Namibian JS learners, mainly at sub-microscopic and symbolic levels. To most chemistry teachers, including myself, addressing this challenge involves exploring pedagogic approaches that might enhance learners' sense-making of chemical bonding. The notion of sense-making in science education will now be considered.

2.2.4 Sense-making in science education

According to Solomon (1997), sense-making is an act of building a cognitive bridge that connects existing theories to empirical findings. He clarifies that sense-making can enable students to relate theoretical descriptions to what they found during experimentation or observation. Similarly, Zangori, Forbes, and Biggers (2013) define sense-making as the ability to draw links between theories and evidence. Furthermore, Crowder and Morrison (1993) articulate that sense-making is achievable via combining, seeking, and interpreting both theoretical knowledge and experiential knowledge. According to Vygotsky (1978), this process happens during internalisation of interaction from the inter-psychological space to intra-psychological space. Inter-psychological interaction happens between individuals, while intra-psychological interaction occurs with an individual's mind.

Achieving sense-making of science knowledge via linking scientific explanations to evidence is facilitated by helping students through the sense-making mental activities of cause, effect, and mechanism (Zangori, Forbes & Biggers, 2013). *Cause* involves students selecting or generating data that become evidence; *effect* has to do with ascertaining patterns of evidence; and *mechanism* means employing the patterns to propose explanations (Duschl, 2008). The combined cause-effect stage allows students to engage with real world phenomena in the form of data and evidence gathered. During this stage, students engage with a phenomenon of interest, work on it, organise and analyse data, and reflect on data collected. The mechanism stage provides the how and why questions for the observed real-world phenomena. At this stage, students construct arguments for how and why a phenomenon occurred, through which they come up with theoretical explanations for the phenomenon being studied. For one to ascertain if sense-making has taken place, indicators of sense-making should be considered.

Zimmerman, Reeve and Bell (2009), through analysing family sense-making practices in science centre conversations, devised a possible approach to sense-making that can also be applied in teaching to enhance sense-making. This approach involves interactions between individuals using communication modes that can attribute meanings to phenomena (Zimmerman et al., 2009). Zimmerman et al. (2009) assert that sense-making activities are dependent on and facilitated by tools such as language, technology, disposition, styles of talking, and artefacts. For this study, the intersemiosis of talk and visual artefacts (including models) has been selected for exploration into its influences on Grade 9 learners' sense-making of chemical bonding. Zimmerman et al. (2009) identify two sense-making influencers: individual and social. Individual sense-making influencers are factors dependent on, and developed and deployed by, individuals (Zimmerman et al., 2009). These include a range of prior knowledge, interests, and motives held by an individual. Social sense-making influencers are factors developed by and used in social settings. These are realised in social practices such as learner talk, material practices such as use of models and diagrams, and social networks such as interactions. Hence, social sense-making influencers are most relevant to this study, as they involve interaction between the teacher and the learners via coordinated talk and visual artefacts to facilitate learners' sense-making of chemical bonding. However, individual sense-making influencers are also worth considering in this study, as learners have to assimilate the knowledge independently after the visual-verbal intersemiotic complementarity teaching approach is employed.

Sense-making is associated with five indicators: perceptual, science fact-based, connecting and analysing, clarification, and nature-based (Zimmerman et al., 2009). The perceptual sense-making indicator involves making sense through perceptual activities such as identifying, counting, and/or describing scientific processes and behaviour of objects (Brandsford & Schwartz, 1999). The science fact-based sense-making indicator involves making meaning of scientific concepts and processes (Zimmerman et al., 2009). This sense-making indicator is observable through students' talk around abstract scientific concepts. The connecting and analysing sense-making indicator involves students demonstrating knowledge transfer from one context to another context (Brandsford & Schwartz, 1999). For example, students will make explicit and implicit comparisons and analogies to prior knowledge or experiences. The clarification sense-making indicator entails a student connecting scientific processes to real-life contexts (Brandsford & Schwartz, 1999). The nature-based ideas sense-making indicator involves students questioning or discussing how scientists discovered/explored the phenomenon being taught. In light of these, the perceptual sense-making indicator is least related to science knowledge (overlapping strongly with some everyday knowledge) and may indicate only low order scientific sense-making, while the nature-based sense-making is most related to science knowledge (most incompatible to everyday knowledge). The three other sense-making indicators have compatibility to everyday knowledge following the order in which they are listed above. The three mental activities of sense-making (cause, effect, and mechanism) are performed more in sense-making indicators that are more related to science knowledge than those which are more related to everyday knowledge. Hence, how students perform these sense-making mental activities contributes to ascertaining their sense-making of the topic being explored – thus considered in this study.

In summary, various studies on sense-making collectively provide insights into how learners' sense-making of chemical knowledge, such as chemical bonding, is enabled and assessed (Newman, Morrison & Torzs, 1993; Kronik, Levy-Nahum, Mamlok-Naaman & Hofstein, 2008; Zangori, Forbes & Biggers, 2013). First, defining sense-making as making links between theoretical explanations and evidence, and describing it as a cyclical process that requires interaction, informs teacher-researchers, such as myself, interested in enhancing sense-making in science education (Newman, Morrison & Torzs, 1993). Second, Zangori, Forbes and Biggers (2013) provide useful insights into connecting evidence and theoretical explanation which follows a series of steps: cause, effect and mechanism. Third, assessing five indicators of scientific sense-making, as discussed by Zimmerman et al. (2009), has the potential to ascertain whether learners' sense-making of any science topic has effectively occurred. Hence, the design of data collection and analytic tools in this study is informed by these ideas, as evident in Chapter 4.

2.2.5 Multimodality of scientific discourse

Multimodality, as used in the systemic functional approach to multimodal discourse analysis (SF-MDA), refers to the combined use of more than one semiotic mode in making meaning (Cheng & Gilbert, 2009). A semiotic mode is a "regularised set of resources for meaning-making…" (Kress, 2003, p. 1). Examples of these meaning-making resources are images, gesture, music, speech, and sound effects. Bock (2016) expands on this by pointing out that any material, either drawn from nature (such as feather, wood, or metal), or from cultural history (such as word, music or associated 3-dimensional object), can be a semiotic mode, provided it reflects regularities and follows an agreed-upon convention. For this study, the pedagogic approach chosen for exploration recognises the multimodality of scientific discourse.

Knowledge of individual semiotic modes and meaning-making resources in terms of their grammar and the role they play in communication might support effectively using multimodality in the pedagogy of science topics. The SF-MDA approach considers the affordances offered by many semiotic modes in terms of their ability to work in a complementary way to make meaning (O'Halloran, 2008). Lemke (1998) posits that the pedagogy of science is inherently multimodal. Cheng and Gilbert (2009) add that scientific meanings are commonly made by the "joint co-deployment" of two or more semiotic modes within one message (p. 56). This multimodal nature of science is realised in that its concepts "… are not defined by the common denominator of their representations, but by the sum, the union of meanings implied by all these representations … It is the nature of scientific concepts that they are semiotically multimodal…" (Lemke, 1998, p. 110-111). Furthermore, the multimodal nature of science concepts also requires outcomes and processes of science pedagogy to be multimodal (Lemke, 1998). This denotes that teaching, assessment tasks, and learners' responses in science should involve the use of more than one semiotic mode.

Cheng and Gilbert (2009) assert that different semiotic modes in science have different affordances, and address different specialised tasks. The coordinated use of these affordances and specialised tasks of different semiotic modes results in the combined effect – the meanings that science teachers and textbook authors intend (Kress, Jewitt, Ogborn & Tsatsarelis, 2001). Each meaning made by a certain semiotic mode can interact with and contribute to the meanings made by other semiotic modes (Kress et al., 2001). These different semiotic modes may carry similar meanings, or make meanings in a complementary way. Moreover, multimodality is multiplicative because it results in semantic expansion – the multiplication of meaning – due to each semiotic mode having a different semantic orientation (Lemke, 1998). Examples of this are evident in the complementary use of language and visual semiotic modes. Language has a typographical standpoint (concerned with legibility), while visuals have a topographical standpoint (concerned with visibility) of knowledge (Martin, 1992). Thus, a combination of these two communication modes results in more meanings being made than either mode alone.

Notwithstanding affordances offered by different semiotic modes, it has been noticed that some semiotic modes are more strongly recognised than others (Kress & van Leeuwen, 2006). For this reason, certain modes have been used frequently in both social and cultural works, at the expense of other modes that also have potential for making meaning. Language (both spoken and written) is more strongly recognised and used at the expense of other modes. In particular, its use has been consistently dominant over the use of the visual mode (Kress & van Leeuwen, 1996). After this dominance was realised, it was proposed that both verbal and visual semiotic modes should be used equally in order to stop privileging language over the visual mode, and ignoring the affordance offered by the visual mode (Siegel, 2006).

However, Royce (2002) asserts that making sense of knowledge necessitates an understanding of the meaning-making potential of the combined visual and verbal semiotic modes. He recommends that intersemiotic resources should be explored for pedagogic use.

In chemistry, the use of the verbal semiotic mode alone is no longer regarded to be as important or effective as when used together with the visual semiotic mode (Nugroho, 2009). Unsworth (2006) argues that when used alone, the verbal semiotic mode is an obstacle to making meaning due to two challenges: lexical (word related) difficulty, and grammatical (language rule) complexity. The lexical difficulty of chemistry is caused by high lexical density (many content words per clause or sentence) (Clay, 1971). This means many learners are not familiar with content words, as they are not used often in their everyday language. Grammatical complexity involves using language that may not be lexically dense, but grammatically complicated, making it a challenge to meaning-making (Clay, 1971).

Another challenge with chemistry language involves it being a *lingua-chemica* (Gilbert & Treagust, 2009). Lingua-chemica refers to the specialised language of chemistry, with its chemical terms and conventions only being known to and used by chemists. Gilbert and Treagust (2009) argue that chemistry students should be viewed as similar to students learning in a second language, who are expected to both learn the second language and use this same language simultaneously. To exacerbate this challenge, some students learn chemistry in a language of learning and teaching (LoLT) that is not their first language – a process that further impedes their making sense of chemistry topics (Sliwka, 2003). This is true in Namibia, where the majority of students learn content subjects, including Physical Science, in English, even though it is not their mother tongue (Namupala, 2013).

The challenge of using language alone in chemistry pedagogy for topics such as chemical bonding might be addressed by combining the verbal chemistry language with a range of visual representations (Gilbert & Treagust, 2009). This combined use of the verbal mode and visual mode helps to depict aspects of chemical models, while at the same time minimising the challenge of chemical language (Gilbert & Treagust, 2009). The range of visual representation includes graphs, diagrams, photographs, and charts. Since Pozzer and Roth (2003) posit that visual and verbal modes work complementarily in making meanings, it would make sense for science teachers to use this complementarity in a coordinated way when teaching chemistry topics such as chemical bonding. Most often, teachers rely on their talk for explaining chemistry topics because of its feasibility; not considering the affordances of the visual mode, which may require more careful lesson planning. However, this over-reliance on language is problematic, as it might cause confusion and misunderstanding for learners (Taber, 2001). The complementarity of the visual and verbal modes will now be discussed.

2.2.6 Visual-verbal intersemiotic complementarity

Intersemiotic complementarity is a concept developed from Systemic Functional Linguistics (SFL). It was employed by Royce (1998) to analyse intersemiosis between visual and verbal semiotic modes, and how this was applied in business magazines. SFL views language as a social semiotic through which meanings are made, dependent on their social context (Halliday, 1978). Four claims about language being a sense-making (meaning-making) resource are made in SFL (Halliday, 1978). These involve language being considered as functional, semantic, contextual, and semiotic. Firstly, language, in addition to it enabling communication, is functional because it shapes reality and is a resource for meanings (Halliday, 1978). Secondly, it is referred to as semantic because it is regarded as the maker of meanings. Thirdly, the contextual nature of language is evident from meanings being dependent on the social and cultural context in which the message is conveyed. Lastly, language is called a semiotic mode because meanings are selected from a series of options that constitute what the message means. Though SFL has traditionally been associated with the realm of language alone (Halliday, 1978), its perspectives provide a foundation for the development of intersemiotic complementarity, which considers other modes of communication for making meanings.

Developing intersemiotic complementarity was motivated by the perceived overreliance on language at the expense of other semiotic modes (Royce, 1998). It was also realised that confining communication to spoken or written language inhibits the learning process in schools (Royce, 1998). Other modes of making meaning were later recommended by Halliday (1984) for use in teaching to enable learning. Intersemiotic complementarity does not dismiss claims about, and functional levels of, language in SFL. However, it extends their vitality to other semiotic modes outside the realm of language (Royce, 1998). Kress and van Leeuwen (1996) realise that the visual semiotic mode is vital in communication and making meanings. They argue that confining pedagogic approaches to language deprives the meaning-making potential inherent in the visual mode, thus preventing further learning. Therefore, Royce (1998) draws from Halliday's (1978) SFL and Kress' and van Leeuwen's

(1996) ‘grammar of visual design’ to propose intersemiotic complementarity, which he describes as synergistic. By synergy, Royce (1998) means that the combined effect of two or more semiotic modes complementing each other is greater than any semiotic mode used alone. This has the potential to produce greater meaning for presenting to the recipients (such as learners) (Royce, 1998).

Visual-verbal intersemiotic complementarity adapts the metafunctional meaning-making resources of, and the claims about, language in SFL in order to be applied to other semiotic modes (Royce, 1998). Metafunctional meaning-making resources are general categories of meaning-making that are applicable in all uses of language (Halliday, 1985). These meaning-making resources include the ideational, interpersonal, and textual. From SFL perspectives, the ideational metafunctional meaning-making resource is defined as the representation of people’s inner and outer experiences and imaginations of the world around them (Halliday, 2004). The interpersonal metafunctional meaning-making resource refers to the meaning that comes as a result of an action that takes place between the speaker or writer and the hearer or reader (Halliday, 2004). The textual metafunctional meaning-making resource involves connectivity and cohesion between elements of the text (Halliday, 2004). The metafunctional meaning-making resources of intersemiotic complementarity, as illustrated by Royce (1998), differ slightly from those originally proposed by Halliday (1978). The difference between the two sets of meaning-making resources is that the latter employs visual and verbal modes combined, while the former concerns only the spoken and written semiotic modes.

The ideational (representational) meaning-making resource of the visual semiotic mode is the visual representation of knowledge that is experienced, perceived, or conceptualised by humans (Gilbert & Treagust, 2009). However, the ideational meaning-making resource of visual-verbal intersemiotic complementarity is defined as the integrated visual and verbal projection of experiential and logical content or subject matter that are lexico-semantically related (Royce, 2007). This is achievable through using six visual-verbal intersemiotic sense relations. These sense relations are repetition, synonymy, antonymy, meronymy, hyponymy, and collocation. The challenge with using these sense relations is that a deep understanding of how the visual and verbal semiotic modes work interdependently to convey the meanings is necessary. Due to the ideational metafunction being directly relevant to this study, it is focused on in subsequent chapters. A detailed discussion of the six sense relations is provided in Chapter 3.

The interpersonal and textual metafunctions, sometimes called meaning-making resources, also have the potential to make particular meanings in intersemiotic complementarity. The visual-verbal interpersonal resource of meaning-making refers to the interdependent relationship that exists between the viewer/listener and the message, through mood and modality (Royce, 2007). The textual resource of meaning-making refers to combined visual and textual ways of creating unified and coherent information for a viewer/listener to receive (Royce, 2007). However, the interpersonal and textual metafunctions are not directly relevant to the research questions in the current study, and so only the ideational metafunction was focused on.

In part, meaning-making of subject matter can take place when visual and verbal semiotic modes are allowed to work together (Kress & van Leeuwen, 1996; Royce, 1998, 2007). This coordinated use of visual and verbal semiotic modes allows semantic expansion, because each semiotic mode carries a part of the meaning of the entire message (Royce, 1998). As Royce (2007) suggests, a combination of visual and verbal semiotic modes enables meaning-making ideationally, interpersonally, and textually. The reason for focusing on only the ideational metafunction in this study is that the learners' experience of chemical bonding knowledge via the coordinated visual and verbal semiotic modes has the potential to enhance their sense-making of the topic.

2.3 Conclusion

The review of studies related to multimodality provides insights about how the co-deployment of various semiotic modes allows meanings to be made more effectively (Cheng & Gilbert, 2009). Additionally, the nature and the levels of representation of chemistry as discussed by Harrison and Treagust (1996), and the examiners' reports (Namibia. Ministry of Education, Arts and Culture, 2014, 2015, 2016 & 2017), guide the study regarding aspects of chemical bonding requiring particular attention. Moreover, the insights on sense-making, related pedagogic foci, and sense-making indicators discussed by various scholars have provided a means to explore how the teaching intervention in this action research study influences learners' sense-making of chemical bonding.

CHAPTER 3: THEORETICAL AND ANALYTICAL FRAMEWORKS

3.1 Introduction

According to Bertram and Christiansen (2015), a theoretical framework is a section in a research document under which theoretical explanations are provided regarding how and why a phenomenon occurs. It is also described as "a structure that guides the research by relying on a formal theory…constructed by using established, coherent explanations of certain phenomena and relationships" (Eisenhart, 1991, p. 205). Grant and Osanloo (2014) liken it to a foundation on which the study is built and supported, and which provides the means for philosophical, epistemological, methodological, and analytical approaches to the entire study. The theoretical frameworks in research enable the researcher to assess and refine the research goals, develop realistic and relevant research questions, select suitable methods, and identify potential validity threats (Maxwell, 2004).

The goal of this study was to explore the influences of a coordinated visual-verbal intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding. The choice of theories in this study was made based on two functional roles they play in framing the study, as suggested by Grant and Osanloo (2014) and Maxwell (2004). First, a theory may be chosen as a theoretical framework to provide basic explanations of the object of study (Maxwell, 2004). This role is comparable to the elevation plan of the house, where only the outside view of the house is provided (Grant & Osanloo, 2014). Second, a theory may play an analytic role in the study, and provide a detailed scheme of how a person specifically intends to research the topic (Maxwell, 2004). This role is comparable to a floor plan of the house, where interior details are clearly shown (Grant & Osanloo, 2014). In this study, social constructivism was chosen as the theoretical framework to provide general explanations on how teaching and learning occur through the semiotic modes, while Systemic Functional Linguistics was chosen as the analytical framework to inform the visual-verbal intersemiotic complementarity teaching approach.

3.2 Social constructivism

This study employs social constructivism as a theoretical framework to explore the influences of a teacher's coordinated use of visual and verbal semiotic modes on learners' sense-making of chemical bonding. Social constructivism was proposed by Vygotsky (1962), and posits that meanings are socially constructed through interactions, while learning is mediated by tools and signs. The theory recognises two social contexts that influence knowledge construction: the learners' historical development, and the nature of learners' interactions with others and the environment (Kim, 2006). Kim (2006) explains that a learner, throughout his/her life, learns, and learns through, symbol systems such as language. The theory postulates that learners' interaction with more knowledgeable others (MKO) helps them to acquire social meanings of important symbol systems, and then learn how to use them for further learning (Vygotsky, 1978). In schools, the MKO are subject teachers who know more about the content of their subjects than do the learners. However, the MKO can also be learners who have more experience and knowledge in the particular content than others. This is acknowledged in the Namibian Learner Centered Education framework that recognises learners' prior knowledge due to a significant role it plays in the teaching and learning processes.

3.2.1 Assumptions of social constructivism

The way in which reality, knowledge, and learning are viewed in social constructivism is different from the way they are viewed in other learning theories. Advocates of social constructivism view reality as constructed through society members' invention of properties in the world (Vygotsky, 1978; Kukla, 2000). They view reality as a human invention that is non-existent prior to construction. Knowledge is regarded as a human product that is socially constructed (Gredler, 1997; Ernest, 1999). The construction of knowledge happens when individuals interact with each other and the environment in which they live (Kim, 2006). This renders learning an active social process. According to Vygotsky (1978), the learning process of others also requires the involvement of more knowledgeable members of society (MKO). He explains that the role of MKO in the learning process is to render assistance to learning members of society. In this action research study, I, the Physical Science teacher, played this role in order to facilitate the learners' sense-making of chemical bonding – the learning activity which the learners cannot undertake unaided.

The construction of social meanings in social constructivism entails inter-subjectivity (Kim, 2006). According to Rogoff (1995), inter-subjectivity involves constructing meaning through shared understanding by individuals who have common interests and assumptions. This implies that negotiations among individuals shape and allow meanings and knowledge to evolve (Gredler, 1997). However, Kim (2006) alerts us to the fact that knowledge construction can be influenced greatly by the level of inter-subjectivity among the interacting members of the community. This implies that poor interaction between more knowledgeable others and those that learn complicates knowledge construction and learning. If there is poor interaction; for example, between the learners and the teacher as the MKO during science lessons; knowledge construction by learners may be hampered.

3.2.2 From intermental to intramental functioning

According to Vygotsky (1978), there are two dimensions of consciousness: the social dimension and the individual dimension. These are levels at which the human mind functions when working with knowledge. The social dimension of consciousness, also called intermental functioning, is considered primary, while the individual dimension of consciousness, also known as intramental functioning, is secondary (Vygotsky, 1978). However, due to the interchangeable use of the concept *intermental* with the concept *inter-psychological*, and the concept *intramental* with the concept *intra-psychological* functioning by different scholars, this study also uses each pair of these concepts interchangeably. Social constructivists believe that knowledge construction happens interdependently between the social and the individual contexts (Palincsar, 1996). Both social and individual contexts need to be understood on the basis of how their interdependence leads to effective knowledge construction by learners.

Wertsch (1998) described inter-psychological learning as the construction of knowledge involving two or more people interacting. This form of constructing knowledge is based on Vygotsky's (1978) Zone of Proximal Development (ZPD). Vygotsky (1978) believes that for learning to take place, the role played by MKO in aiding learners within the ZPD to reach the desired level of knowledge should be considered. The ZPD is described as the cognitive gap between the actual level of development, which is characterised by independent problem-solving, and the potential level of development, which is characterised by aided problem-solving (Vygotsky, 1978). In a classroom, the teacher (as the MKO) should first identify what learners can do unaided and what they can do with his/her support, before he/she plans how to help them. This help (referred to as scaffolding) is temporary, and has to be removed once the teacher sees that the learners can solve those particular problems independently (Vygotsky, 1978). In this study, intermental functioning was considered to enable the co-construction of chemical bonding knowledge between the chemistry teacher (myself) and learners.

Intra-psychological learning refers to learning taking place within the person's mind as he/she starts actively interacting with what he/she learnt to make sense of it (Vygotsky, 1978;

McRobbie & Tobin, 1997). Vygotsky (1978) argues that scientific concepts are not presented in ready-made form, but that they undergo interpretation by the human mind. Moreover, Daniels (2001) states that knowledge constructs are first formed through language and other semiotic modes inter-psychologically before they are refined at the intra-psychological level. Through intra-psychological functioning, students become able to decode and internalise the knowledge they acquired inter-psychologically (Vygotsky, 1986). Ajideh and Farrokhi (2012) further explain that students at the intra-mental level of functioning need no assistance from the MKO; they can deal independently with knowledge construction. Therefore, as suggested by Ajideh and Farrokhi (2012), students should be prepared for transcendence, which is the ability to apply learnt knowledge to a similar task.

In this study, the influences of the coordinated visual-verbal intersemiotic complementarity teaching approach were explored on both learners' inter-psychological and intra-psychological functioning. Learners were assessed on their transcendence.

3.2.3 Mediation of thinking by signs and tools

According to social constructivism, learning takes place through a mediatory process, which suggests that there should be means that aid the learning process (Vygotsky, 1978). Wertsch (2007) elaborates on mediation as being either explicit or implicit. Explicit mediation concerns aiding learning through the use of external objects, such as other people and signs (Wertsch, 2007). This mediation is often done with intention and awareness. Implicit mediation is described as internal, semiotic, and performed subconsciously (Wertsch, 2007). Wertsch (2007) posits that both forms of mediation happen on a daily basis, and play a significant role in learning. He postulates that explicit mediation precedes implicit mediation, as learning primarily begins with a person's interaction with more knowledgeable society members, following which assimilation of the knowledge into a person's cognitive structure takes place.

Mediation is carried out through the use of two main resources: tools and signs (Gillespie & Zittoun, 2010). While tools and signs are similar, due to the mediatory function they play during human communication, they differ in some respects (Vygotsky, 1997). Vygotsky (1997) makes a distinction between these two types of resources based on their use in human communication. Tools mediate human relation to the physical world and are associated with a change in the object of the activity, while signs mediate human relation to the mind and make no changes to the object of the activity (Vygotsky, 1997). By using a shovel as an example, Vygotsky (1997) explains that an object can be both a tool and a sign, depending on the role it plays at a particular time. He refers to a shovel as a tool if it is used to dig a hole, as it changes the shape of the ground. However, when the shovel is placed at the door, it becomes a sign, because it serves to remind the person that he needs to dig a hole.

The study of signs (semiotics) and the role they play in communication was initiated by an American pragmatist, Charles Sanders Pierce, in 1958 (Chandler, 2004). Pierce (1958) revealing the significant role played by signs in communication has impacted significantly on the way teaching and learning take place. The notion of semiotics and the use of signs in contemporary activities, including teaching and learning, have become highly influential, to the extent that ignoring them may result in inefficiency and ineffectiveness (Chandler, 2004).

According to Pierce (1958), there are three types of signs in general communication: symbolic, iconic, and indexical. Symbolic signs are those in which the signifier does not resemble what is signified. Examples of these signs include those used in language: punctuation, words, phrases, numbers, and sentences. For example, the word apple is a symbolic sign, as it does not resemble an apple in any form. Iconic signs are those in which the signifier resembles the signified by possessing some similar qualities (Pierce, 1958). These signs show a natural and physical relation to the signified, and are easy to understand because they do not require one to learn them. For example, a picture of an apple is an iconic sign because it imitates actual features of an apple. Indexical signs are those in which the signifier does not resemble the signified but has connotative features that communicate a particular message to the person (Pierce, 1958). Examples of these are signs representing thunder, or smoke. However, Pierce (1958) suggests that to enable effective knowledge construction, both arbitrary and physical features need consideration, suggesting that employing a range of signs types might be useful.

Based on aforementioned explanations, all three types of signs were considered during the teaching intervention explored in this study. This was done because the visual and the verbal mode used during the intervention employ these signs for communication. The facts that tools mediate learning (Vygotsky, 1978), and that various types of signs may work complementarily to enable effective communication (Pierce, 1958), have provided strong grounds for considering tools and signs in the intervention.

3.3 Systemic Functional Linguistics (SFL)

Many recent and current schools of thought on the use of language and other semiotic modes in communication employ insights that are derivatives of Halliday's (1978) Systemic Functional Linguistics (SFL). Earlier, Pierce (1958) defined semiotic resources as any form of activity, conduct, or process that involves signs, and their relation to meaning production. Later, Saussure (1966) defined semiotics as "a science that studies the life of signs within the society" (p. 16). Subsequently, various views on semiotics that drew from Saussure's (1966) definition emerged. These include the definitions of semiotics by Sebeok (1994) as "the antique doctrine of signs" (p. 5), and by Danesi and Santeramo (1992) as "the general science of signs and meanings" (p. vii). According to SFL, a semiotic is a system of signs that enables meanings to be made (Halliday, 1994). However, the only semiotic mode that was originally focused on as enabling meaning-making is language (Halliday, 1978). Consequently, language became regarded as the principal mode of communication, resulting in it being well studied and analysed in terms of its grammar and meanings (Royce, 1998).

Halliday (1978) claims that the nature of language as a semiotic system is defined by its multiple strata, where the most central stratum is the lexicogrammar. The choice of the term 'lexicogrammar' is influenced by the fact that language learning and learning through language require combined knowledge of its grammar and vocabulary (Halliday, 1994). Halliday (1994) explains that understanding the lexicogrammar is crucial, as it enables meaning construction from a sentence or a phrase.

The initial SFL view of semiotics was adapted from being "the general study of signs" to "the study of sign systems… the study of meaning in its most general sense" (Halliday, 1985, p. 3-4). The adapted description of semiotics contrasts with the notion that language (written and spoken) is the only semiotic system for meaning-making. Apart from written/spoken language, Halliday (1985) points out that there are other semiotic modes. Drawing from Kress and Hodge (1988), language is viewed as an ideology, suggesting that communication principles that are applicable to it may be applicable to other semiotic modes as well. This was later restated by O'Toole (1995), who describes language as offering "a powerful and flexible model for the study of other semiotic modes" (p. 150). He describes language as a paradigm, which can be applied to other systems of meaning-making. Kress and Hodge (1988) posit that communication in social settings must be stretched to accommodate all semiotic modes that have the potential to make meanings. These ideas need consideration for studies that are related to learners' sense-making of certain concepts via non-linguistic semiotic modes.

The strength of SFL is that understanding semiotics, including those that are non-linguistic, can be achieved by reviewing the three metafunctions. These metafunctions are reviewed on the role they play in communication and making meaning, as understanding them has the potential to explicate how other semiotic modes may be used effectively as teaching media. Since language is merely one of many systems for making meanings (Halliday, 1985), its principles may be applicable to other semiotic modes based on their metafunctions. Table 7 shows the terminology related to the metafunctions of semiotics.

Table 7. The terminology related to the metafunctions of semiotics (Adapted from Royce, 2007)

	SFL	**Subsequent studies**		
Author	**Halliday (1978)** (Systemic Functional Linguistics)	**O'Toole (1994)** (Language of Displayed Arts)	**Kress and van Leeuwen (1996)** (Reading images/Grammar of Visual Design)	**Royce (2007)** (Intersemiotic complementarity)
Metafunctions	Ideational	Representational	Representational	Ideational
	Interpersonal	Modal	Interpersonal	Interpersonal
	Textual	Compositional	Compositional	Compositional

According to Halliday (1985), the metafunctions of SFL operate simultaneously in making meanings in every language. He defines the ideational metafunction of SFL as a meaning-making resource that involves the representation of experience. This includes representing our experience of the world around and inside us. The interpersonal metafunction of SFL involves making meaning through action (Halliday, 1985). This involves the speaker performing a particular action from which the listener can formulate a meaning. The textual metafunction of SFL entails making meanings through relation to context (Halliday, 1985). These interpretations underwent adaptations in systemic functional multimodal discourse analysis (SF-MDA) to accommodate their viability in other systems of making meanings. Thus, the subsequent metafunctions and their interpretations differ slightly from those used by Halliday (1985).

Discussing analysis of the metafunctions of visual-verbal intersemiotic complementarity may warrant a reminder of why the combination of verbal and visual modes is preferable to the linguistic mode alone. Royce (1998) describes visual-verbal intersemiotic complementarity as resulting in semantic expansion. This means that it conveys expanded forms of meanings, from which users choose to make their own meanings when guided by the context. The combined visual-verbal semiotic modes results in semantic expansion because language and visual images have distinct orientations (Lemke, 2000). Language presents a typological view (types and symbols) of reality to listeners or readers through symbols, participants, and circumstances. The visual semiotic mode, on the other hand, presents a topological view (spaces and shapes) of reality, where knowledge formulation is guided by the degree of image display, such as the position and relative size of its component parts (Lemke, 2000). Lemke (2000) suggests that moving between typographical and topographical forms results in new organisational levels that provide space for new interpretations.

Accessing understanding of the intersemiosis of the visual and verbal semiotic modes (discussed earlier in this chapter) has the potential to reveal the synergy (expanded meaning) of intersemiotic complementarity, as described by Royce (1998). The ideational metafunction of visual-verbal intersemiotic complementarity is defined as meanings in both visual and verbal modes being lexico-semantically related (Royce, 1998; 2007). This suggests that words in the verbal mode and their equivalent items in the visual mode link to enable stronger meaning-making by the listener or viewer. This is usually realised through the sense relations of repetition, synonymy, antonymy, meronymy, hyponymy, and collocation. The interpersonal meaning-making resource involves meanings made in both visual and verbal modes through two sense relations: mood and modality (Royce, 1998; 2002; 2007). The textual (compositional) meaning-making resource involves making meanings from the texts and diagrams in a page; for example, texts and diagrams in a flipchart (Royce, 1998). This is achievable through the compositional sense relations such as information value, salience, visual framing, visual synonymy, and potential reading paths. Of these three meaning-making resources of intersemiotic complementarity, the ideational metafunction is the only one that is considered in this study, due to it involving experiential meaning.

Royce (1998) uses the concept of *verbal* to refer to written work, while this study uses it to refer to both spoken and written language, as teaching chemical bonding may not be confined to either of these alone. Chandler (2007) posits that written words are spoken words represented symbolically. Royce (1998) postulates that devising visual-verbal intersemiotic complementarity is enabled by first considering the sense relations. In this study, this accounts for the ideational metafunction. The ideational sense relations of visual-verbal intersemiotic complementarity are specific items used to relate the experienced knowledge and the logical content, or the subject matter expressed, in both visual and verbal modes (Royce, 2007).

The sense relation of repetition is defined as the reiteration of identical experiential meaning (Royce, 1998). In visual-verbal intersemiotic complementarity, this happens when a lexical item repeats the meaning represented in the visual message element, or vice versa. This has the potential for making multiplicative meaning. Royce (2007) adds that repetition can also arise through the use of lexical items that are products of inflexion or derivation. For example, the inflexion of the word 'oxidise' leads to 'oxidises', and a derivation from the word 'oxidiser' can be 'oxidant'.

If a case occurs where a similar experiential meaning is made in verbal and visual semiotic modes, a sense relation of *synonymy* is said to have occurred (Royce, 1998). This sense relation can be observed when the meaning in the lexical item is similar to (but not the same as) the meaning in the visual element, or vice versa. For example, an arrow drawn from a sodium atom's electron to a chlorine atom has a meaning similar to the phrase 'electron transferred from a sodium atom to a chlorine atom'. Even though the sense relations of *repetition* and *synonymy* are different from each other, I noticed that they are similar enough for their application in the coordinated visual-verbal modes to overlap, and thus complicate the analysis. Due to difficulty clearly distinguishing between these two sense relations in visual and verbal modes, the word 'similarity' was chosen in this study as an overarching term replacing the use of 'repetition' and 'synonymy'.

If two semiotic modes make the opposite experiential meanings, the particular sense relation involved is antonymy (Royce, 1998). This sense relation may be applied in cases where learners are likely to realise opposite meanings conveyed by either the visual or verbal mode. For example, an arrow indicating an electron being lost from a sodium atom has the opposite meaning as the lexical phrase 'electron gained' by a chlorine atom. The use of this sense relation is clearly useful for antonymous pairs such as 'gain' and 'lose'. However, the possibility for this sense relation to confuse the learners due to the opposite meanings it makes was foreseen, despite the suggestion by Royce (1998) that it may be useful. Efforts to avoid the learning difficulty that might be linked to this case in the study involved selecting knowledge items where this sense relation may be applied effectively and carefully coordinating the visual and verbal items of the knowledge taught.

The sense relation involved when the meaning is generated through the relationship between the general class of something and its sub-classes (termed hyponym and co-hyponyms respectively) is referred to as hyponymy (Royce, 1998). Either of the visual or the verbal semiotic modes can be presented as a general class of something to enable meaning to be made in the other semiotic mode. For example, if the Bohr diagram of the atom of an element shows two visible electrons in the outer shell (the diagram depicts the element as the hyponym), the teacher might state that this element belongs to group 2 of the periodic table (the teacher talk refers to group 2 of the periodic table as the co-hyponym). This in turn allows for more meaning to be made, such as that the element is a metal, it loses two electrons during bonding, and it has a valency of 2.

Royce (1998) defines meronymy as the cohesive relationship between the whole of something (termed super-ordinate*)* and its constituent part(s) (termed meronyms and co-meronyms). The Bohr diagram of a sodium atom can be considered as a whole visual message, with meronyms of lexical items such as nucleus, protons, neutrons, shells, and electrons. For the meaning to be carried across both modes, the lexical item 'sodium atom' has to be used as the whole verbal message, concurrently with its visual parts, such as the drawings of shells, protons, and electrons, and vice versa.

Halliday (1994) uses the word collocation, to refer to lexical items that have a tendency to co-occur. In intersemiotic terms, Royce (2007) defines collocation as when the item represented in one semiotic mode collocates, or has a tendency to be associated with, an item represented in another semiotic mode. This means that representing the message in one semiotic mode can have an expectancy relationship to the item in another mode. For example, a visible arrow pointing from a sodium atom to a chlorine atom may collocate with lexical items such as 'sodium cation' and 'chlorine anion'.

The review of visual-verbal sense relations of the ideational metafunction has illustrated that visual-verbal intersemiotic complementarity can be applied in teaching chemical bonding. This review has focused mainly on Royce's (2007) concept of intersemiotic complementarity, and Halliday's (1994) Systemic Functional Linguistics, which consider making of meaning by semiotic modes.

3.4 Conclusion

In summary, social constructivism and Systemic Functional Linguistics have proven useful as theoretical foundations for this study. Social constructivism posits that learner knowledge is non-existent prior to the active mental process of construction that occurs via mediation by the teacher using signs and tools (Vygotsky, 1978). SFL originally focused on language as the system of meaning (Halliday, 1985), but this view underwent adaptations in recognition of the various other modes of meaning-making. This resulted in the consideration of intersemiotic complementarity as a potential pedagogic approach aligned to the needs of teaching and learning chemical bonding in Namibia. These two theories consider signs to be crucial for learning. For this study, Royce's (2007) idea of visual-verbal intersemiotic complementarity emerged as the specific type that would offer the most value when considering the particular challenges posed by chemical bonding, as outlined in the earlier chapters. The design of the teaching intervention is thus strongly influenced by the perspectives derived from both social constructivism and Systemic Functional Linguistics in order to explore the influences of a visual-verbal intersemiotic complementarity teaching approach on learners' sense-making of chemical bonding.

CHAPTER 4: RESEARCH DESIGN

4.1 Introduction

This chapter initially presents the research goal and questions in Section 4.2, since they guide the data collection methods, instruments, and data analysis. The research methodology section of this chapter (Section 4.3) presents the research paradigm, methods, and outline of the action research study. A detailed explanation of the research site and sampling is provided in Section 4.4. The data collection techniques section (Section 4.5) explains the data collection instruments. These include document analysis, learners' pre-test, learners' post-test, structured lesson observation, and teacher's and learners' reflective journals. The chapter also discusses data preparation and analysis (Section 4.6), threats to validity and how they were addressed (Section 4.7), consideration of ethical issues (Section 4.8), and the limitations of the study (Section 4.9). The last part of this chapter is the conclusion, presented in Section 4.10.

4.2 Research goal and questions

4.2.1 Research goal

The goal of this study was to explore the influences of a coordinated visual-verbal intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding. In order to achieve this goal, a researchable question was developed. Three sub-questions were formulated from this, and these, together with the literature and theories informing this study, provided parameters for the research process.

4.2.2 Main research question

What are the influences of a coordinated visual-verbal intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding?

4.2.3 Research sub-questions

1. What are the visual and verbal demands that the curriculum makes on learners for the topic of chemical bonding? (answered via document analysis in action research Cycle 1)
2. What knowledge do Grade 9 Namibian learners have on the topic of chemical bonding after a traditional teaching approach? (answered via analysis of structured lesson observation, learners' reflective journals, teacher's reflective journal, and pre-test in action research Cycle 1)

3. How does a coordinated visual-verbal intersemiotic complementarity teaching approach shape Grade 9 Namibian learners' sense-making of chemical bonding? (answered via analysis of structured lesson observation, learners' reflective journals, teacher's reflective journal, and post-test in action research Cycle 2)

4.3 Research methodology

4.3.1 Research paradigm

The critical paradigm aims to bring about social change that will benefit groups with less power, or fewer chances or choices (Bertram & Christiansen, 2015). I will provide 2 broad reasons for why this paradigm is relevant to this thesis.

Firstly, I have noticed (from my 10 years' experience of teaching Physical Science) that chemistry teachers, including myself, in Namibian schools lack effective pedagogic approaches to chemical bonding. This possibly can be ascribed to teachers not being proficient in the language of learning and teaching (LoLT) as per a report in *The Namibian newspaper* (Kisting, 2011). This information was accessed after a nation-wide English Language Proficiency test (ELP) for teachers and principals conducted a few years prior to the beginning of this study, as mentioned in Chapter 1. Silvanus (2017) described the Lolt in Namibia as detriment to learners' sense-making. She realised this in learners begging the teacher to switch from English to Oshiwambo when teaching the topic of energy. She argued that lack of proficiency in the Lolt impedes understanding of technical terms applied in science – and science is incomplete without these terms.

Secondly, Namibian Grade 9 learners have been identified as experiencing a significant challenge in learning chemical bonding (Namibia. MoEAC, 2015). It is possible that this challenge can be attributed to two difficulties: complex chemistry knowledge, and chemistry language being incompatible with everyday language (Gilbert & Treagust, 2009). The complexity of chemistry knowledge is due to the abstract concepts used (Johnstone, 1982), as discussed in Chapter 2.

In view of the aforementioned challenges (teachers being unaware of effective pedagogic approaches, and Grade 9 learners having difficulty making sense of chemical bonding), it becomes clear that most chemistry teachers and learners in Namibia have a limited chance of success when teaching and learning chemical bonding, when compared to their English First Language counterparts in other countries. Teachers not successfully teaching chemical bonding can lead to learners having a lower chance of succeeding in chemistry, or pursuing chemistry careers (Johnstone, 1982). This action research study adopts a critical paradigm in an attempt to bring about a change to the unequal chances of success in Namibian school chemistry teaching and learning.

This study is qualitative in its approach, as it involves the collection of visual and verbal data (both of which are non-numerical), towards answering the research questions via verbal descriptions of the non-numerical results. However, quantitative data obtained from tests (pre-test and post-test) scores are included for descriptive purposes. This was informed by Teddlie and Tashakkori (2009), who confirm that qualitative studies may include quantitative description in order to answer the research questions more correctly.

4.3.2 Research method and outline

4.3.2.1 Research method

(a) Action research: Definition and goals, types and benefits

Various scholars define educational action research differently. Several definitions were reviewed, as they have informative research design implications. The definitions are similar in that they involve education action research being an action-and-reflection oriented process where practitioners (such as myself) review their own educational practice systematically and carefully in order to bring about a desired change in practice (Feldman, 1994; Ferrance, 2000). Further, Kemmis and McTaggart (1988) define it as a "form of self-reflective inquiry" conducted by participants in particular social contexts to improve the rationality and justice in their social and educational practices, and their understanding of these practices and situations in which these practices are undertaken (p. 5). Taking into consideration the similarities and dissimilarities of these explanation models, I resolved to define education action research as a systematic inquiry conducted by teachers, through a series of successive cycles, to know about, and improve a particular teaching practice or learning process. This activity has potential for bringing about a successful reform in the education arena (Guskey, 2000). For this study, I adopted an idea from Rossouw (2009) that stages (explained later in this section) in the first cycle may be repeated in the second cycle, with necessary adjustments only. The two primary goals of education action research, as identified by Ferrance (2000), are change in educational practice, and in professional development of participants.

Noffke and Stevenson (1995) point out that action research is specifically helpful to both pre-service and in-service teachers when exploring alternatives to current educational practices, which may enhance learning. Teachers who conduct education action research become reflective and inquiring practitioners in their classrooms (Fals-Borda & Anisur, 1991). Moreover, addressing questions that deal with educational matters at hand causes a teacher's practice to evolve, as he/she works on problems he/she identifies in a class or in the whole school (Ferrance, 2000).

Education action research provides the "first person trueness" of the case being studied (Candler, 2003). This means that findings of education action research accord with the actual state or condition of the case being explored. For instance, seeking evidence from learners about how they learn may result in collecting more factual information than when seeking it from secondary sources, such as documents published by other researchers. Additionally, action research *with* rather than *on* people provides full descriptions of situations (Candler, 2003). When action research is conducted with people, people become research participants rather than research objects, and they are more likely to provide rich and real data. This action research was conducted with learners in Grade 9 in order to obtain first hand data of how they make sense of chemical bonding before and after the coordinated visual-verbal intersemiotic complementarity teaching approach.

Ferrance (2000) identifies four types of action research. The first one is individual-teacher action research, because it is conducted by one teacher on a single classroom issue (Ferrance, 2000). The second type is called collaborative action research, where a group of researchers work collaboratively to explore a particular issue (Ferrance, 2000). The third type is referred to as school-wide action research and is applicable in research where the researcher targets the whole school (Ferrance, 2000). The last type is district-wide action research, which covers a large area such as a district or village (Ferrance, 2000). My study falls under the category of individual-teacher action research, because it explores the influences of a visual-verbal intersemiotic complementarity teaching approach on learners' sense-making of chemical bonding, in a single classroom (there was only one Grade 9 class at my school at the time of conducting this research).

(b) Individual-teacher action research: Benefits and challenges

Individual-teacher action research is conducted by a single teacher who focuses on finding a solution to a single classroom issue (Ferrance, 2000). The classroom issue may include classroom management, instructional strategies (such as an approach to teaching chemical bonding), use of teaching materials (such as visual-verbal materials in this study), and student learning (such as their making sense of chemical bonding). The process of individual-teacher action research begins with identification of an area or a problem of interest, before seeking solutions to it (Calhoun, 1994). As outlined in Chapter 1, the research problem in this study arose from anecdotal evidence, which was further supported by examiner reports and literature around the challenges posed by the topic of chemical bonding.

During individual-teacher action research, students may or may not be involved directly in the generation of alternatives and determination of effects (Calhoun, 1994). Further, action research practitioners may be supported by their supervisor or principal, instructor, or even parents. In this study, support was provided by my research supervisor, who provided guidance and critical feedback throughout the research process. Since my study was based at the school where I was teaching, further support was obtained from the school principal and a critical friend (details in Section 4.4). The principal has played a significant role by providing consent for the study to be undertaken at the school, and by informing teachers and learners that they could accord me the assistance that I required. A critical friend, according to Stenhouse (1975), is a chosen teacher who has agreed to work with and advise the teacher-researcher throughout the research process. In this study, the critical friend worked collaboratively with myself as the teacher-researcher and, in some instances, provided me with advice on the research process.

Ferrance (2000) states that individual-teacher action-research can benefit the teacher-researcher in numerous ways. The benefits include collecting relevant data (from learners), hence increasing validity of the study, when conducted with learners (Ferrance, 2000). I explained to learners that my presence, as their usual teacher, should not influence their participation in this study. According to Ferrance (2000), individual-teacher action research is also an opportunity for teachers to evaluate strategically and improve their own teaching practice. Other benefits of individual-teacher action research involve the teacher gaining confidence through reflection, improved thinking skills, developing efficacy of the teacher, willingness in the teacher to work with other teachers, and improving the attitude of the teacher towards change (Ferrance, 2000).

Feldman (1994) argues that changes caused by interventions, such as the improvement in the teacher's practice and understanding, are difficult to measure. However, as will be discussed in Chapter 6, the discussion of data collected via learners' reflective journaling has the potential to reveal the influences of the coordinated visual-verbal intersemiotic complementarity teaching approach to chemical bonding. The influences may be realised in learners' sense-making changes of chemical bonding. Calhoun (1994) argues that the change may affect only the chosen class group and not other class groups but since my teaching practice was informed by the study, the impact will shape my students' making sense of chemical bonding in subsequent years as well. This is aligned to the action research literature, which states that teachers, as reflective practitioners, conduct education action research to "accomplish personal, academic, occupational and professional growth" (Thomen, 2005, p. 820).

4.3.2.2 The outline and structure of individual-teacher action research

(a) Outline of action research cycles

Mc Kay and Marshal (2001) reveal that action research may be limited to only two cycles, where the second cycle is overlaid on the first cycle. The first cycle focuses on problem-solving interest and possibilities, while the second cycle focuses on the research interest and possibilities. Mc Kay and Marshal (2001) argue that both cycles are essential in action research in order to solve the problem identified, and to test the proposed method of solving the problem.

I have adopted ideas from Mc Kay and Marshal (2001) for the two cycles of the individual-teacher action research: the first cycle is for problem-solving interest and possibilities, and the second cycle is for research interest and possibilities. Each of the two cycles of the individual-teacher action research has four stages: observation, planning, implementation, and reflection (Mc Kay & Marshal, 2001). The first cycle is undertaken to inform the second cycle – findings from the stages of the first cycle inform the design of the stages in the second cycle towards addressing the problem identified, or to understand the issue being explored. This is accomplished by providing new insights, demands, and proposed proceedings that are significant to addressing the problem or issue that is identified (Steketee, 2004). However, Steketee (2004) postulates that observation is a natural precursor to action research for the provision of insights that are necessary for effectively conducting Cycle 1. While the second cycle (Cycle 2) may not have a specific observation stage, Steketee (2004) reminds us that observation may be considered throughout the action research process to identify and rectify constraints to accessing reality.

The problem-solving interest cycle (Cycle 1) allows the researcher to be aware of the real-world problem in order to elucidate ideas of relevance to the research (Mc Kay & Marshal, 2001). Stage 1 of this cycle is observation, which begins with initial identification of the problem, followed by reconnaissance and fact-finding. Reconnaissance and fact-finding involve the researcher finding information about the nature and context of the problem (Mc Kay & Marshal, 2001). This level is achievable by identifying people affected by the problem, key stakeholders in problem-solving, and the cultural and historical background of the problem. Stage 2 is the planning of the action, which is independent of the problem-solving approach. Rossouw (2009) describes this stage as considering ways of studying the issue of interest, resources needed to undertake proposed action, and accurate methods of collecting data. Other roles of this stage include deciding whether to involve others in carrying out the action (Elliott, 1991), describing the basic ethical system to be followed (Elliott, 1991), and estimating how, when, and how frequently the outcome will be assessed (Parsons & Brown, 2002). Stage 3 is the implementation of the planned action, and Stage 4 is the reflection, which guides planning the next cycle (Cycle 2).

The research interest cycle (Cycle 2) is conducted by the researcher who has an idea, an objective, or a question from Cycle 1 that s/he has to pursue (Mc Kay & Marshal, 2001). The observation stage of this cycle is research-based, where the researcher engages with relevant literature to clarify issues, and to identify relevant theories that may be explored to answer the research question (Mc Kay & Marshal, 2001). This information is useful during the planning stage of Cycle 2, to guide the implementation of the action. The implementation stage is followed by the reflection stage, where planned actions are evaluated to find out if they have addressed the problem or issue.

In this study, I adopted the ideas of Mc Kay and Marshal (2001) to begin Cycle 1 with the observation stage. This stage included initial identification of the problem, reconnaissance, and fact-finding. It enabled me to identify the problem of Grade 9 Namibian learners having difficulty making sense of chemical bonding. Reconnaissance and fact-finding around this problem included analysing the newly revised curriculum, reviewing four recent Namibian JS examiners' reports, observing traditional lessons on chemical bonding, and finding literature on possible teaching approaches for chemical bonding that had potential for improved sense-making by learners. These activities were undertaken to access information about the nature and context of the problem and were essential for planning both the traditional teaching cycle

(Cycle 1) and the intersemiotic complementarity teaching approach to chemical bonding (Cycle 2).

The observation stage of this study informed the planning stage by providing information on the pedagogy of chemical bonding, which is necessary for planning the action. This information includes the complexity of, the representational levels of, and the intersemiotic complementarity teaching approach to, chemical bonding, that were pre-requisites to undertaking the implementation stage. Since this action research involves teaching during the implementation stage, prototype lessons (lessons taught in a traditional way) were taught, as they reveal the nature of the problem (Feldman, 1994). These were the lessons (lesson plans in Appendix K) without visual-verbal intersemiotic complementarity. Teaching these lessons prior to the intervention was to ensure that changes brought about by the intervention would be noticeable. The implementation stage was followed by the reflection stage, which was the last stage undertaken in this cycle (Cycle 1).

Cycle 2 was designed to address the researcher's interest in exploring the intersemiotic complementarity teaching intervention. Like Cycle 1, Cycle 2 had four stages: observation, planning, implementation, and reflection. Contrary to Cycle 1, the planning stage was undertaken first, as the data to inform this stage were already obtained from Cycle 1. Hence, the observation stage of this cycle involved transcribing video clips, followed by analysing the transcripts of the lessons taught. The significant difference between Cycle 2 and Cycle 1 was that the benchmark lessons (lessons considering the intervention) taught during Cycle 2 included visual-verbal intersemiotic complementarity, while the prototype lessons taught during Cycle 1 did not. Table 8 outlines the two cycles of the action research used in this study.

Table 8: Outline of the two cycles of the action research

Cycle	**Research sub-question addressed**	**Stage 1** (Observation and analysis)	**Stage 2** (Planning)	**Stage 3** (Implementation)	**Stage 4** (Reflection)
1	1	• Lesson observation ✓ *Investigating learners' sense-making of chemical bonding*	• Design of 4 prototype lessons ✓ *2 lessons for each chemical bonding type:*	• Teaching 4 prototype lessons (lesson plans in Appendix K) ✓ *Prototype lessons*	• Pre-testing ✓ *Test includes visual and verbal features of chemical bonding*

		• Document analysis ✓ *Analysis of visual-verbal demands in the 2015 Grade 9 JS Physical Science syllabus and Physical Science textbook*	*covalent and ionic*	*include only the verbal mode*	• Reflective Journaling ✓ *By learners* ✓ *By the teacher*
2	2 & 3	**Stage 1** (Planning)	**Stage 2** (Implementation)	**Stage 3** (Observation)	**Stage 4** (Reflection)
		• Design 4 Benchmark lessons ✓ *2 lessons for each chemical bonding type: covalent and ionic bond* .	• Teaching 4 benchmark lessons (lesson plans in Appendix L) • ✓ *Benchmark lessons include visual and verbal features of chemical bonding*	• Lesson observation: ✓ *Observing learners' sense-making of chemical bonding*	• Journaling ✓ *By the teacher* ✓ *By learners* • Post-testing ✓ *Test includes visual and verbal features of chemical bonding* • Evaluation ✓ *Reviewing learners' journal answers* ✓ *Analysing learners' post-test answers and marks*

(b) Structure of the individual-teacher action research

The research method for this study was individual-teacher action research, as mentioned earlier in this chapter. Even though learners were important participants in this study, their role was not to take part actively in data collection. Instead, they were involved in this study as sources of data for how learners make sense of chemical bonding knowledge after a traditional teaching approach and after an intersemiotic complementarity teaching approach to chemical bonding. These data were obtained from them via observing their participation during the related Physical Science lessons, analysing their reflective journals, and evaluating their answers to pre-test and post-test questions. The duty of the critical friend was to provide support (see Section 4.4) to the teacher-researcher, but not to collect or analyse data directly.

The first cycle may or may not be guided by the problem-solving approach, and it may involve diagnosis (Mc Kay & Marshal, 2001). The first cycle of this study was not guided by the problem-solving approach, and it was analysed against the second cycle for determining the influences of the intervention on learners' sense-making of chemical bonding. Diagnosis during the observation stage happened via two instances: reviewing my previous experience of teaching chemical bonding, and analysing the Namibian JS examiners' reports, as discussed in Chapter 2. However, searching for ways to deal with the problem was undertaken by reviewing literature around the topics related to chemical bonding discussed in Chapter 2.

The second cycle involves testing variables in the problem-solving approach (Mc Kay & Marshal, 2001). In this study, it involved testing the influences of the coordinated visual-verbal intersemiotic complementarity teaching approach to chemical bonding. The two cycles (also referred to as a dual cycle) are not carried out independently, but are interlinked and contingent upon each other. They are described as "superimposed on each other", because each cycle has a significant role to play (Mc Kay & Marshal, 2001, p. 50). The dual cycle action research has advantages, as identified by Mc Kay and Marshal (2001). Firstly, it enables less experienced teacher-researchers to strengthen their interest in research. Secondly, it enables the teacher-researcher to identify real-world problems that need to be solved. This study has followed the steps of action for action research as shown in Figure 2. The dual cycle used in this study was adapted from that of Kemmis and Mc Taggart (1988). In this study, the observation stage was done at the beginning of Cycle 1 and after implementation during Cycle 2. This was done because beginning Cycle 2 is informed by the data collected during Cycle 1.

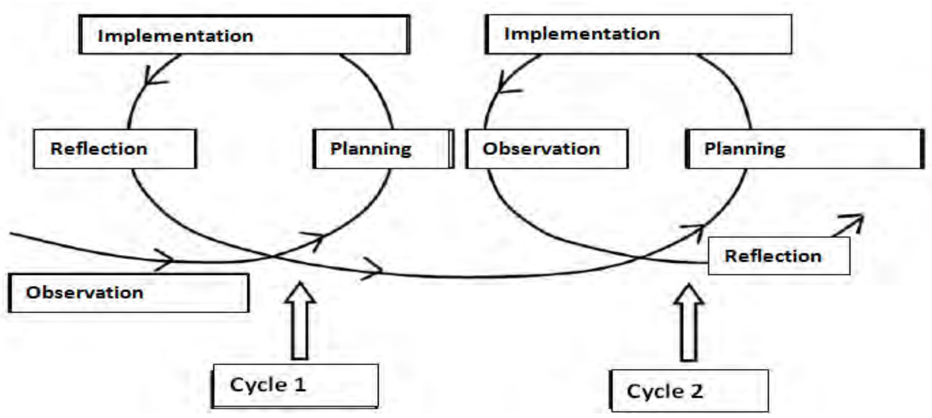


Figure 2. Steps of a two-cycle action research (Adapted from Kemmis & Mc Taggart, 1988)

Planning stage

In action research, planning involves a researcher analysing the data collected during reconnaissance and problem or situational analysis, to devise strategies that guide an action during the implementation stage (Dimitrov & Rumrill, 2003). Calhoun (1994) elucidates that the planning stage is informed by problem diagnosis, which can be done via pre-research observation, pre-testing, and interviewing the participants. The pre-research observation is undertaken via noticing, investigating, and scrutinising a case or situation prior to conducting a detailed study in order to inform planning (Calhoun, 1994). A pre-test is undertaken prior to an intervention to identify the people's baseline knowledge of the case (Dimitrov & Rumrill, 2003). For action research where planning is essential, pre-research observation, pre-testing, and consultation with the correct stakeholders are crucial aspects to consider.

Pre-research observation has occurred over the course of my 10 years' experience as a Grade 9 Physical Science teacher prior to conducting this study. It resulted in collecting anecdotal evidence of Namibian Grade 9 learners having difficulty making sense of chemical bonding, as discussed in Chapter 1 and 2. This evidence prompted the review of literature around the problem, and undertaking structured lesson observation that informed planning of prototype lessons (in Cycle 1) and benchmark lessons (in Cycle 2). Planning of prototype lessons did not consider the intervention (intersemiotic complementarity teaching approach), as these lessons were used as the baseline for ascertaining the influences the intervention has on learners' sense-making of the topic. Contrary to planning of prototype lessons, benchmark lesson planning considered the sense relations (discussed in Chapter 2) of a visual-verbal intersemiotic complementarity teaching approach to chemical bonding. Moreover, assessment of learners' sense-making of the topic was part of this stage in both cycles of action research. This was achieved by using sense-making indicators which are discussed in Chapter 2.

Implementation stage

The implementation stage involves employing the strategies developed during the planning stage (Kemmis & Mc Taggart, 1988). Implementation during the first cycle of action research may not be fully influenced by the plans, but it follows the traditional way of teaching (Kemmis & Mc Taggart, 1988). In this study, implementation during the first cycle of the individual-teacher action research did not consider visual-verbal intersemiotic complementarity teaching approach to chemical bonding, as it served as a baseline for the second cycle of the action research.

During the second cycle of education action research, benchmark lessons (lessons considering the intervention) are taught in order to determine the influences of the intervention on teaching and learning (Feldman, 1994). The second cycle of this action research had benchmark lessons (Appendix L), which considered intersemiotic complementarity as a pedagogic approach to chemical bonding.

Altricher, Posch, and Somekh (1993) remind us that the implementation stage should include reflection in order to open up options for action. This type of reflection is referred to as 'reflection-in-action' because it is done during the research and not only at its end. Reflection-in-action is enabled by observing any action or outcome during implementation (Altricher, Posch & Somekh, 1993). This type of reflection helps researchers to rectify faults that have the potential to affect the effectiveness of the planned action. Hence, reflection-in-action in this study was employed in order to tackle unexpected issues that might arise. This involved reflecting on how learners were making sense of the topic, as observed in their interaction.

Observation stage

Kemmis and Mc Taggart (1988) discuss that the observation stage involves identifying and documenting the effects that result from action taken. They assert that observation captures aspects or evidence that may enable a critical and sound reflection by the practitioner. Even though observation was first done during the implementation stage, I also considered having a specific stage for observation in order to collect relevant data. During this stage, I created a climate that enabled easy collection of valid evidence, as suggested by Kemmis and Mc

Taggart (1988). This was achieved by creating an environment that welcomed learners' participation so that participants felt at ease. Audet, Hickman, and Dobrynina (1996) describe learners' reflective journals as a vehicle that can provide evidence of learners' sense-making. Reflective journals are useful for collecting evidence because participants openly reveal their feelings about a particular issue (Audet, Hickman & Dobrynina, 1996). In this study, I used teacher's and learners' reflective journals as sources of evidence for how learners make sense of chemical bonding during both cycles. These reflective journals had guiding questions for eliciting sufficient and relevant data from the learners during the research process. Evidence of observation may be video-recorded or noted on paper for later review (Kemmis & Mc Taggart, 1988). I stored the evidence of how learners made sense of chemical bonding during each cycle in the form of notes and videos that I reviewed during data analysis.

Reflection stage

Reflection involves producing an acceptable understanding of an event or a situation (Quixley, 1997). This understanding is enabled by accurately identifying and describing what was happening during the implementation stage. Kemmis and Mc Taggart (1988) identify two aspects that action researchers reflect on: the results of the evaluation, and the way the whole action research project proceeds. Having drawn from this idea, I reflected on the data that I collected, and also on the action research that I carried out, as discussed in Chapter 5.

Reflection during the first cycle can lead to identification of problems that need to be addressed during the second cycle (Kemmis & Mc Taggart, 1988). Schon (1991) terms this *reflection-on-action.* This type of reflection is described as *retrospective*, as it takes place after an action or event. Conveniently, it can be undertaken by viewing videos and reading notes of the lessons taught (Schon, 1991). I employed reflection-on-action when viewing video recordings of the lessons and reading learners' and teacher's reflective journals of every prototype and benchmark lesson that I taught.

4.4 Research site and participants

4.4.1 Research site

This study was Namibian-based and conducted at a government school in Omusati Region in the northern part of the country; the school I have easy access to, because it is where I teach. The school had Grades from 1 to 9, with the total of 568 learners, and 24 teachers. I chose this site because it is a school where the learning problem, alluded to in Section 1.3, was identified – even though learners in other schools in Namibia and in other countries around the world might have the same problem. The school had no sufficient access to multimedia – learners and teachers converse dominantly via spoken and written forms of communication – and this could have links with the learning problem of the topic. It is possible that this challenge existed at this school for years before I started teaching there, as some Grade 8 and Grade 9 learners openly revealed their need of a teacher who can help them to understand chemical bonding upon my arrival. My introspection of this case revealed that the problem mainly lies with the traditional pedagogic approach being inappropriate, and hence, justice should be done to this pedagogic problem at this school.

The evidence related to the context of the school and the learning challenge discussed in Chapter 1 rationalises the choice of this school as a research site. Hence I decided that conducting this study at this school where learners have difficulty making sense of chemical bonding, as they do in other schools around the world, would be necessary and viable.

4.4.2 Sampling procedures and samples

Sampling involves choosing which people, events, settings, or behaviours are to be included in a study (Bertram & Christiansen, 2015). The type of sampling made use of in this study is purposive. Purposive sampling refers to the researcher specifically choosing people, groups, or objects to be part of a study for a particular purpose (Bertram & Christiansen, 2015). This type of sampling enables rich data to be collected from participants who have the needed information (Patton, 1990).

This study has purposively focused on learners in one Grade 9 class for three reasons. Firstly, anecdotal evidence from my 10 years' experience teaching Physical Science has revealed that learners experience difficulty in making sense of chemical bonding, as mentioned in Chapter 1. Grade 10 Physical Science learners' sense-making of chemical bonding is dependent on their Grade 9 sense-making thereof (Namibia. MoEAC, 2015). Grade 9 learners having the challenge of making sense of chemical bonding, mainly at the particulate level, was also evident in the JS examiners' reports (Namibia. MoEAC, 2014; 2015; 2016; 2017). This was realised by many learners countrywide answering JS examination questions related to atomic structure, behaviour, and bonding incorrectly for the past four years. Secondly, the Namibian Education Curriculum intended for Grade 9 to become an exit grade from the year 2018 (Namibia. Ministry of Education, Arts and Culture, 2015). This change is part of the curriculum review currently underway, as mentioned in Chapter 1. It involves moving some challenging topics and concepts that were previously a part of the Grade 10 syllabus (Namibia. MoEAC, 2010) to Grade 9. These include writing formulae of compounds under the topic of chemical bonding – an exercise that is reported as challenging to learners (Namibia. MoEAC, 2017). For the purpose of maintaining anonymity, neither the teacher's or learners' real names were revealed in the study. Instead, the alphabetical letter codes were used to indicate the learners that responded to certain questions aimed at contributing towards answering the research questions.

Moreover, I purposively chose the Grade 9 Platinum Physical Science textbook as the document to be analysed in order to collect data related to the visual-verbal demands the curriculum makes on learners' sense-making of chemical bonding. This was the only prescribed textbook available and used by learners at the school. Thirdly, one class was chosen because there was only one Grade 9 class group for this grade in the year 2018, which is when the data collection for the study was conducted.

The study has also purposively selected one science teacher who performed the work of a critical friend such as assisting me with video-recording during my lesson presentation. A critical friend is a partner who works with and advises the teacher-researcher throughout the research process (Stenhouse, 1975). The critical friend in this study was a Grade 8-10 Life Science teacher who has 2 years of teaching experience. Ideally, I would have chosen a chemistry teacher, but this was not possible since there was no other Physical Science teacher at the school. This teacher does hold a Bachelor of Education (Honours) degree from the University of Namibia. Apart from her science education qualification and experience, this teacher was chosen because she felt confident enough to provide critical feedback on my science lessons, and was available to have one-on-one post-lesson discussions with me. She provided written informed consent (Appendix C), after being provided with a letter outlining the role she was required to play (Appendix B).

4.5 Data collection techniques

Bertram and Christiansen (2015) define data collection as the collection of evidence or information needed to answer the research question. In this study, I collected data through a variety of tools, as shown in Table 8. Each of these will now be discussed.

4.5.1 Document analysis

Document analysis can be used by researchers to analyse existing documents in order to discover themes and patterns related to a phenomenon being studied (Bertram & Christiansen, 2015). This analysis is undertaken to elicit meaning, to enhance understanding, and to expand empirical knowledge of a particular case (Corbin & Strauss, 2008). Bowen (2009) describes this method as involving systematic reviews and evaluations of documents. This is achievable via examining and interpreting the data obtained from the document in question (Corbin & Strauss, 2008). These documents may include manuals, books and brochures, and organisational and institutional reports that were written or published without the researcher's input (Corbin & Strauss, 2008).

Steps in doing document analysis include accessing, selecting, appraising (making sense of), and synthesising the data in the document (Bowen, 2009). These data may come in the form of excerpts, quotations, or entire passages that need to be organised into themes and categories (Bowen, 2009). Document analysis in this study followed a similar pathway by first accessing the Grade 9 Physical Science syllabus for the 2015 national curriculum (Namibia. MoEAC, 2015), and the prescribed Platinum Physical Science textbook (Haimbangu, Poulton & Rehder, 2016). The next step involved selecting sections in these two documents that address chemical bonding: pages 30-32 of the syllabus and 76-81 of the textbook. This step was followed by appraising the data in terms of the visual-verbal demands made by this topic, in order to answer research question 1. The last step involved organising the data (from general and specific objectives) into themes and categories. The findings are discussed in Chapter 5, and informed the action research lesson planning.

4.5.2 Pre-test and post-test

According to Dimitrov and Rumrill (2003), research designs containing pre-tests and post-tests can be used in social science studies for the purpose of measuring changes in a chosen group of participants after the group is exposed to special treatments or interventions. They suggest that changes are determined by analysing influences of the intervention on the case being explored.

The pre-test is a test given to a group before the intervention or before exposure to a special treatment, to determine their baseline knowledge of something (Dimitrov & Rumrill, 2003). Calhoun (1994) defines it as a baseline test that is prepared to reveal the nature and/or causes of difficulty of a case. In this study, a pre-test was devised to assess how Grade 9 Namibian learners make sense of chemical bonding after a traditional teaching approach (the one not involving coordinated visual-verbal intersemiotic complementarity). This pre-test (Appendix S) was administered during the fourth stage of the first cycle (Cycle 1)**.**

A post-test is administered to a group after an intervention or after exposure to a special treatment, in order to determine the influences that have resulted from it (Dimitrov & Rumrill, 2003). The post-test (Appendix T) in this study was devised and then administered in the fourth stage of the second cycle (Cycle 2). The learners' responses to pre-test and post-test questions were compared to ascertain how the intervention influenced their sense-making of chemical bonding. The data generated are presented both descriptively and numerically in Section 3 of Chapter 5.

4.5.3 Structured lesson observation

According to Leary (2001), observation is a data collection method aimed at studying individuals or situations without interfering with their normal behaviours or natural contexts. He reveals that the aim of observation is to capture what can be learned from individuals or situations when they act in a natural way. Lofland (1971) asserts that data collection through observation helps within describing a situation in more detail.

Observation can be structured, unstructured, or semi-structured. According to Dyer (1995), structured observations are aimed at testing hypotheses or theories about specific behaviours or activities. They make use of pre-determined formats that guide the collection of desired data (Herbert, 2001). Unstructured observations focus on collecting any description of a situation (Dyer, 1995). This method of data collection is used to collect as much data as possible from a situation without following a pre-determined format and without focusing on specific theories or hypotheses (Herbert, 2001). A semi-structured observation is a combination of structured and unstructured observations, and it uses pre-determined formats to some extents (Herbert, 2001). While data collection via this method is guided by a theory, other aspects that have the potential to influence the results are also considered (Dyer, 1995).

This study has used structured lesson observation to explore influences of a visual-verbal intersemiotic complementarity teaching approach on sense-making of chemical bonding by Grade 9 learners. The structured lesson observation sheets (Appendix N) have been designed to discern sense-making changes for chemical bonding by specifically analysing changes in sense-making indicators/types. Wilkinson (2000) describes structured observations as requiring the use of codes to ease data collection and analysis processes. In this study, coded sense-making indicators were used to describe sense-making of chemical bonding by Grade 9

Namibian learners before and after the use of a visual-verbal intersemiotic complementarity teaching approach. The guiding questions were formulated to maintain the focus on the intervention. This made observation easier in both cycles of this action research.

4.5.4 Teacher's and learners' reflective journals

Reflective journals have been employed in various studies as instruments for capturing the participants' experiences of the settings or cases being studied (Olitsky, 2007). They can be written by teachers, learners or both (Olitsky, 2007). This study has employed both the teacher's and learners' daily journaling as data collection instruments for evidence of learners' sense-making of chemical bonding after the traditional and the visual-verbal intersemiotic complementarity teaching approaches were undertaken.

Gay, Mills, and Airasian (2009) explain that the teacher's reflective journal provides "first-hand accounts" of what is taking place in the classroom (p. 374). In order to obtain first-hand data on, and to get an overview of, the Grade 9 learners' sense-making of chemical bonding, this study involved daily reflective journaling by me as the teacher-researcher. These reflective journal entries were made by me after I taught each lesson.

Gay, Mills, and Airasian (2009) describe learners' reflective journals as providing teachers with "a window into students' worlds" and their "daily classroom experiences" (p. 374). Audet, Hickman, and Dobrynina (1996) describe learners' reflective journals as instruments that provide evidence of learners' sense-making of scientific topics or concepts. They add that learners' reflective journals publicise the learners' knowledge. However, it is argued that learners with no experience in writing reflective journals or learners with language barriers may not know what to write or how to express their thoughts via writing (Towndrow, Ling & Venthan, 2008). In consideration of this, I formulated guiding questions (Appendix P) for directing learners' responses towards providing the data that are relevant to the goal of this study.

4.6 Data preparation and analysis

In this study, I prepared the data prior to their analysis. Corbin and Straus (2008) define *data preparation* as the process of transforming raw data, prior to analysis, into insights that become useful information. It eliminates irrelevant data via selecting, reforming, and combining the data sets collected (Miles & Huberman, 1994). According to Corbin and Straus (2008), the data may be coded (using letters, words, or phrases) to ease the analysis process. The data collected in this study underwent preparation so that only those that were relevant would be analysed. This transformed raw data into being technically correct, consistent and tidy, and ready for analysis.

Qualitative data analysis entails a researcher identifying patterns, themes, categories, and regularities in data (Cohen, Manion & Morrison, 2011). Data can be analysed inductively, deductively, or through a combined deductive-inductive approach. Inductive data analysis involves generating patterns, categories, and themes from the raw data, whereas deductive data analysis involves the generation of specific data from the more general sets of data (Bertram & Christiansen, 2015). This study has employed a combined inductive-deductive approach to data analysis, since literature provided sense-making indicators, but it was also acknowledged that additional findings not previously mentioned in literature may emerge. Employing this approach to data analysis was considered in this study, as it allows specific data (learners' sense-making of chemical bonding through analysing sense-making indicators) to be collected from the learners, and also general data sets related to learners' sense-making of the topic to be formulated from them. Even though no analytical tools were devised for capturing unforeseen sense-making changes, other indicators of sense-making, such as the change in motivation, desire, and interaction of learners (Zimmerman et al., 2009), were considered for ascertaining whether coordinated visual-verbal intersemiotic complementarity influenced Grade 9 learners' sense-making of chemical bonding.

Teddllie and Tashakkori (2009) explain that qualitative studies do sometimes involve collecting quantitative data. The use of quantitative data in qualitative studies enables more meaningful data to be collected, which would lead to more authentic findings (Teddllie & Tashakkori, 2009). Hence, quantitative data in this study were also considered for analysis as numerical information (such as learners' test marks, percentage of learners answering a particular question etc.) cannot be ignored.

Learners' sense-making of chemical bonding was analysed according to sense-making indicators/types, as suggested by Zimmerman et al. (2009) and Brandsford and Schwartz (1999). These indicators of sense-making (adapted to take the form of the coordinated visual and verbal modes) include: perceptual (P), chemical bonding facts (CBF), connecting and analysing ideas (CA), clarification (Cl), and ideas about nature of chemical bonding (ICB). These sense-making indicators are realised in excerpts of learner talk, and in visuals. They are listed and defined in Table 9. The comparison of qualitative data of sense-making indicators during the first and second cycle of this action research was used to reveal details about the influences of the teaching intervention on the Grade 9 learners' sense-making of chemical bonding.

Table 9. Sense-making analytic framework (Adapted from Zimmerman, Reeve & Bell, 2009, p. 486)

Sense-making evidence	**Code**	**Sense-making indicator/type defined**	**Exemplar quotations from the data** (column to be filled after data collection)
Perceptual (descriptive)	P	Talk and visuals where learners identify, count, or describe concrete chemical bonding processes or objects observed	e.g. *atoms give away electrons, atoms given electrons, atoms combine, etc.*
Chemical bonding facts	CBF	Talk and visuals made by learners about abstract chemical bonding processes and objects.	e.g. *covalent bonding, ionic bonding, sharing and transfer of electrons, lose electrons, gain electrons, etc.*
Connecting and analysing	CA	Talk and visuals where learners make explicit and implicit comparisons and analogies to prior knowledge or experiences.	e.g. *cations and anions attract each other like charged objects attracting each other*.
Clarification	Cl	Verbal and visual explanations by learners about how atoms bond.	e.g. *how hydrogen and oxygen atoms bond to form water (hydrogen oxide) molecules.*
Ideas about nature of chemical bonding	ICB	Talk and visuals by learners about how knowledge of chemical bonding is discovered by scientists.	e.g. *microscopes are used to magnify the particles.*

4.7 Validity

According to Bertram and Christiansen (2015), validity in critical paradigms is the consideration of whether the data reflect the reality of a case being studied. They argue that some of the aspects that make studies devoid of reality are the fear of maleficence (harmful or unfavourable consequences of study) by participants, and the use of inappropriate data collection tools. I have addressed the fear of maleficence by highlighting to participants that the study is designed in the way that does no harm and causes no unfavourable consequences to them. For example, the pre-test and post-test scores were not recorded for use towards formal assessment for the participants' promotion to the next grade. According to Cohen, Manion, and Morrison (2011), validity threats caused by research tools can be avoided by using triangulation. They define triangulation as the collection of data by two or more methods. In this study, data were collected by various methods. These include document analysis, structured lesson observation, reflective journal writing by learners and the teacher, pre-testing, and post-testing. These tools were piloted with learners in Grade 8 (since there was only one Grade 9 class at the school) to test their reliability. Access to piloting these tools with Grade 9 at a different school was not available, as this was a hectic time for teaching – each teacher tries to finish the syllabus as the year plan. The pilot revealed the following: learners had difficulty understanding some guiding questions in reflective journals, and structured lesson observation sheets needed to be made more specific. These were addressed by making appropriate changes, such as explaining guiding questions for reflective journals in order for learners to understand them, and making small changes in the structured lesson observation sheets to specify what to look for when reviewing lesson recordings.

Merriam, Johnson, Lee, Kee, Ntseane, and Muhamad (2001) remark that validity of research can also be affected negatively if the researcher's positionality is not taken into account. They define positionality as the researcher's standing position in relation to research participants. These positions may include education level, social class, gender, and cultural dominance. I have addressed this validity issue by explaining to participants that my position as a teacher and them being learners should not influence the way they respond to questions, and by encouraging their free participation in the lessons through the creation of a welcoming and participatory environment, as alluded to earlier.

The validity threats can also be averted by member-checking (Bertram & Chritiansen, 2015) and the contributions by a critical friend (Stenhouse, 1975). The data collected were member-checked, by the critical friend and learners, in order to avoid any deviation from the learners' intended meanings that could have arisen as a result of misinterpretation by me as the teacher-researcher. In addition to the functions mentioned earlier, a critical friend can serve as a researcher's consultant during the research process (Stenhouse, 1975). Her core duties involve providing ideas to and assisting the researcher in order to help the researcher avoid bias. These were also highlighted in the aforementioned letter provided to the critical friend in my study, which outlined her responsibilities (Appendix B).

4.8 Ethical considerations

Ethics in the research context are moral principles that determine how research objects or participants (such as people, animals, and trees) should be treated (Bertram & Christiansen, 2015). Since this study involved participants who were minors (Grade 9 learners, aged between 13 and 18 years), voluntary participation of learners and informed consent was sought from both the learners (Appendix D) and their parents (Appendices E & F), with the option of participants being able to withdraw from the study without prejudice at any stage if they felt the need to do so. Signed consent letters were successfully received from all research participants and their parents (filed in a steel cabinet together with the other hard copies), and with electronic copies stored safely online. I explained the details of the study to both the participants and their parents in English and Oshiwambo (the first language of the local community served by the school). Participants were informed that their names would not be revealed in publications resulting from the study. However, it was also explained to them that anonymity of the school could not be guaranteed, due to the study involving action research, and my needing to discuss issues such as positionality arising from the participants being my own learners. Informed consent from the critical friend was also sought (Appendix B) and received (Appendix C).

Since this study was based at a government school, the informed consent to conduct it was sought and successfully received from the school principal (Appendices G and H) and the Regional Education Director of the Omusati Region (Appendices I and J). Moreover, the ethical clearance approval letter (Appendix A) received from Rhodes University Higher Degrees Committee has endorsed this study as abiding by ethical principles. Ethical issues related to plagiarism were avoided by acknowledging the works of authors that were significant in conducting this study. I achieved this by referencing different authors' quotes and ideas in the text, and by compiling and including a reference list at the end of this document. A Turnitin similarity report (Appendix U) confirming the originality of my work was obtained and appended in this document.

4.9 Limitation of action research study

This study is Namibian-based, focusing on a single class at one school, and thus represents the learning context of a specific class of learners that is not identical to that of learners in other schools, Namibian regions, or countries. Therefore, findings regarding the influences of a coordinated visual-verbal intersemiotic complementarity teaching approach on Grade 9 learners' sense-making of chemical bonding may not be generalised strongly to other learning contexts. Moreover, the results regarding the influences of a coordinated visual-verbal intersemiotic complementarity teaching approach might only apply to chemical bonding, and not to other topics or other subjects.

Despites the limitations highlighted above, this study was still considered worthwhile, as it has some potential benefits. Firstly, the study may discover the influences of a coordinated visual-verbal intersemiotic complementarity teaching approach that are helpful for learners' sense-making of chemical bonding. This motivates me to consider, and hence continually employ, this approach as a useful pedagogy for chemical bonding. Moreover, other Physical Science teachers who get access to findings of this study may test and employ this teaching approach for betterment of teaching and learning at their respective schools. Secondly, members of the curriculum review and development team may suggest that chemistry teachers use visual and verbal modes in their coordinated form, if they access the findings of this study and become informed that the abovementioned modes are useful in teaching. Third, studies on the influences of an intersemiotic complementarity teaching approach to other chemistry topics could be undertaken in the wake of this study, if positive results were obtained. Finally, this study has the potential to provide a foundation for future research into how science learners interact with multimodal materials, as intersemiotic complementarity draws from the perspectives of multimodality.

4.10 Conclusion

This chapter has elucidated means that were appropriate for undertaking this action research study. Mechanising these means was guided by the research goal and questions; as hinted on in Chapter 1 and explained in detail in this chapter; informed by the literature relevant to the study, and triggered by the feasibility of the study in the chosen research site and learning context. This study having been conducted by one researcher-teacher, being assisted by a critical friend, among a class of thirty-eight learners at the rural school in Omusati Region in the northern part of Namibia, supported the decision to name it an 'individual-teacher action research'. It provides a number of benefits, which include, among many others, bringing desired changes in education practices of the teacher (Feldman, 1994), which are parts of a focus of a critical paradigm that it took. In addition, it had the potential to address the learning challenges that were identified in learners who participated in the study. This action research study adopted a two-cycle approach, with each cycle having four stages, namely: observation, planning, implementation, and reflection. The techniques employed to collect data that correctly answer the research questions include document analysis, structured lesson observation, reflective journaling by the teacher and the learners, and pre- and post-testing of the learnt knowledge before and after employing the teaching intervention, respectively. This study was proactive to validity threats. This involved identifying possible issues that could invalidate the findings of the study, and the plans to avoid them. These include maleficence, where the learners were guaranteed against non-harmful or unfavourable consequences; the researcher's positionality in relation to research participants, where free participation was encouraged; and ineffectiveness of the research tools, averted by piloting these tools. Possible deviation from the participants' intended meaning by the researcher was also foreseen, and a remedy to it was member-checking – where participants verify their responses to the questions. The parameters within which this study worked were foreseen, and evaluated prior to conducting the study. These include, among others, the study representing the learning context of a specific group of Namibian learners, and the possibility of the influences of the intervention being applicable only to the chosen topic and subject.

CHAPTER 5: PRESENTATION OF FINDINGS, ANALYSIS, AND DISCUSSION

5.1 Introduction

This chapter presents the data, their analysis, and the discussion of findings aiming at answering the research questions. The data collection techniques used in this study involve document analysis, structured lesson observation, the teacher's reflective journals, learners' reflective journals, and pre-test and post-test, as detailed in Chapter 4. The choice of the data collection techniques was informed by the main research question and the research sub-questions, discussed in Chapter 4.

This chapter comprises three sections: the curriculum's visual-language demands of chemical bonding (Cycle 1); the Grade 9 Namibian learners' knowledge of chemical bonding after the traditional teaching approach (Cycle 1); and the influences of an intersemiotic complementarity teaching approach on learners' sense-making of chemical bonding (Cycle 2). This chapter ends with a brief conclusion of the findings and their discussion.

5.2 The curriculum's visual-verbal demands on chemical bonding (Cycle 1)

I employed document analysis as a method of collecting data about the visual-verbal teaching and learning demands for the topic of chemical bonding in the Namibian curriculum, as explained in Chapter 4. In this study, document analysis focused on the Grade 9 Physical Science syllabus (Namibia. MoEAC, 2015) and the Grade 9 Physical Science textbook to explore the demands they make on the use of a coordinated visual-verbal intersemiotic complementarity teaching approach on chemical bonding, because their documentation and publication are guided by the broad curriculum document. Therefore, this section contains results that were collected from these two curricular documents.

5.2.1 The Grade 9 Namibian Physical Science syllabus

The current Namibian Grade 9 Physical Science syllabus (Namibia. MoEAC, 2015) was developed from the broad national curriculum by the Ministry of Education, Arts and Culture (2015). It has a detailed description of the intended learning and assessment for Physical Science at the Junior Secondary phase (Namibia. MoEAC, 2015). According to this syllabus, Grade 9 Namibian learners are expected to have an understanding of only two types of chemical bonding: covalent bonding and ionic bonding, as discussed in Chapter 2. In this study, I analysed the general and specific objectives of the Physical Science syllabus related to chemical bonding to access knowledge of the visual-verbal demands the syllabus makes on the topic. The results of this analysis will now be discussed.

5.2.1.1 The consideration of visual and verbal semiotic modes by the Physical Science syllabus

Gilbert and Treagust (2009) highlight that the combined use of visual and verbal modes in chemistry teaching helps in depicting aspects of a given chemical model, which minimises the challenges of learning it. It was explicated that the visual language of chemistry helps students to understand the sub-microscopic and symbolic levels of representation, which are considered very challenging for students due to their abstractness (Pozzer & Roth, 2003; Talanquer, 2011). Despite these ideas, and the suggestion by the Namibian curriculum document for teaching to include oral and visual modes (Namibia. MoEAC, 2015), the Physical Science syllabus has not indicated directly how these two semiotic modes should be used in teaching and learning the topic of chemical bonding. However, it suggests to teachers that learners should be able to use action verbs that relate to the verbal mode, such as 'describe', 'define', and 'explain'. The specific objectives from this syllabus that suggest the use of action verbs by the learners on chemical bonding state that learners should be able to:

- "describe and distinguish between covalent and ionic bonding as different types of bonding and relate bonding to position (group) of elements in the periodic table;
- describe how non-metal atoms combine with other non-metal atoms by sharing electrons in their outershells with the results that both atoms achieve full outershells;
- describe how the reaction between a metal and a non-metal results in the transfer of electrons from metal atoms to non-metal atoms so that both achieve full outershell and form positive ions (cations) and negative ions (anions) respectively;
- predict the positive and negative charges of ions;
- define ions as atoms with a net electrical charge due to the loss or gain of one or more electrons;
- describe the lattice of an ionic compound as a regular arrangement of alternating positive and negative ions;
- and write the formulae of ionic compounds including polyatomic ions" (Namibia. MoEAC, 2015, p. 31-32).

The syllabus also suggests to teachers that learners should use visual representations such as 'drawing' and 'illustration' for both ionic and covalent bonding. For instance, it emphasises that learners should be able to “draw Bohr structures of ionic compounds” (Namibia. MoEAC, 2015, p. 32). In contrast, the syllabus does not provide guidelines to teachers on how these modes can be used together in a coordinated form for teaching the topic. This revealed the need to consult literature on how these modes may be coordinated, and subsequently, intersemiotic complementarity was identified and built into the overall study. Employing intersemiotic complementarity in pedagogy draws from the ideas of Gilbert and Treagust (2009). The idea states that coordinating visual and verbal semiotic modes for use as a pedagogic approach to chemical bonding has the potential to remedy the challenges of learning this topic. Hence, the information on the visual and verbal demands, accessed via analysing the Grade 9 Physical Science syllabus, has motivated the urge to plan and implement an intersemiotic complementarity teaching approach to chemical bonding.

5.2.1.2 The use of physical models in the Physical Science syllabus

In addition to using diagrams, the Grade 9 Physical Science syllabus suggests that visible models of particles that made up substances may be used. It states that teachers should “build models of atoms, mixtures and compounds by using little spheres of various sizes and colours” (Namibia. MoEAC, 2015, p. 35), when teaching topics related to matter. Pallant and Tinker (2004) suggest that physical models of atoms and molecules are another form of the visual mode considered effective in helping students predict or explain chemical phenomena at different representational levels. They assert that physical models help students relate the difference in states of matter to their motion and behaviour. The physical models help students use atomic and molecular interactions for explaining chemical phenomena they observe at the macroscopic level of representation (Pallant & Tinker, 2004).

I found that the Namibian Physical Science syllabus is silent on how exactly the physical models of atoms and molecules may be used in explaining chemical phenomena taught under the topic of chemical bonding. The details related to using of different coloured and sized spheres to represent particles is helpful but it does not adequately equip teachers with the ability to coordinate visuals and spoken or written words. This leaves sense-making of chemical bonding by learners a challenge. Hence, there was a need to also consider physical models at a more advanced level, as the visual mode, together with the verbal mode, in order to explore the influences of a coordinated visual-verbal intersemiotic complementarity teaching approach on learners’ sense-making of chemical bonding. In this study, using physical models together with the spoken and written language was considered to contribute to designing and implementing an intersemiotic complementarity teaching approach to chemical bonding.

5.2.2 Physical Science textbook

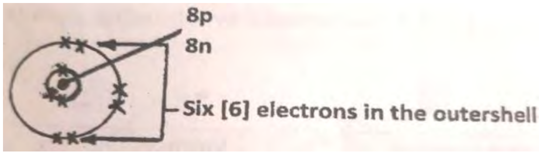
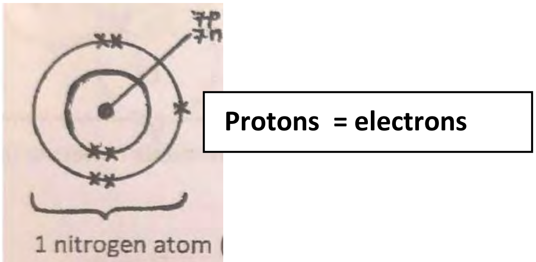
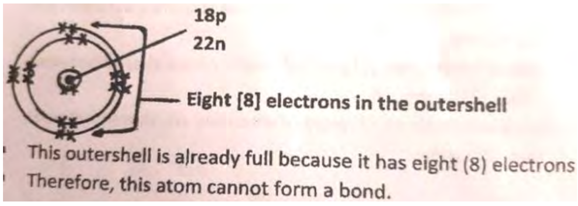
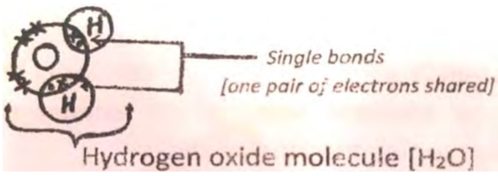
In this subsection, I present the visual-verbal requirements I have identified by analysing the visual and textual modes of representing chemical bonding used in or suggested by the Physical Science textbook. These requirements became insights that were employed during the planning stage of the second cycle of this action research study. The data presented in this subsection are based on how the Physical Science textbook has used the visual and textual modes in representing the two chemical bonding types: covalent and ionic. I needed this information to guide my preparing of learners' notes on chemical bonding in a way that considers coordinated visual-verbal intersemiotic complementarity. In this subsection, the nature of each of the two semiotic modes (visual and verbal) used or suggested for explaining chemical bonding in the textbook is first presented, before their combined use is discussed.

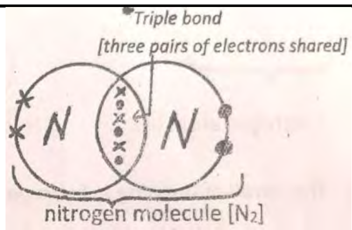
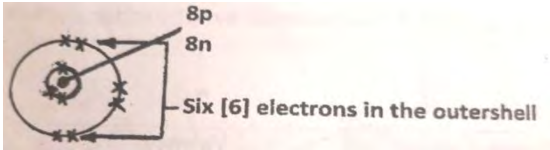
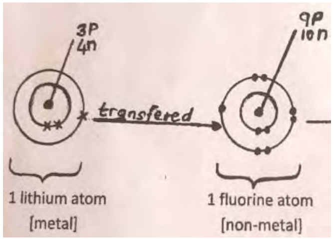
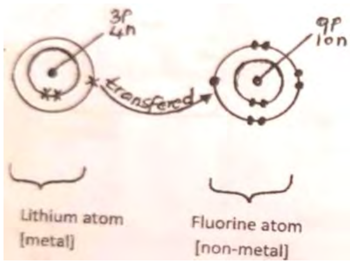
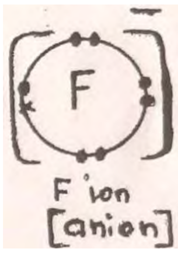
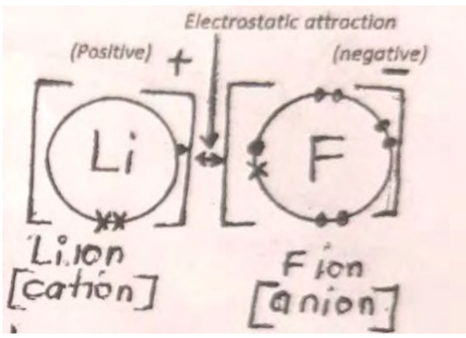
5.2.2.1 The visual-verbal requirements: Identified from language use in the textbook

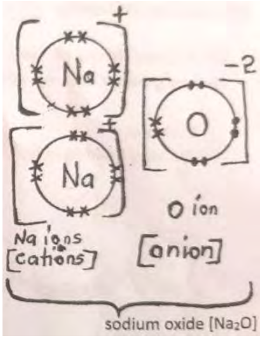
Drawing from Unsworth (2006), the use of either spoken or written language can be an obstacle to learning if used alone to make meaning, because it involves two challenges, as discussed in Chapter 2. These are lexical (words) difficulty and grammatical (language rule) complexity. *Lexical difficulty* refers to the learning difficulty that learners have due to high lexical density (many content words per clause or sentence), while *grammatical complexity* is the learning difficulty due to the complex grammar used (Clay, 1971). For this study, language use in the Physical Science textbook on the topic of chemical bonding was analysed, focusing on the lexical items and the grammar used.

The difficult lexical items and grammatically complex phrases that were identified from the textbook on the topic of chemical bonding are shown in Table 10. These items and phrases were identified in order to determine the corresponding visual-verbal requirements necessary for planning and implementing the coordinated visual-verbal intersemiotic complementarity teaching approach on the topic. The criterion used for considering words and phrases as difficult lexical items involved identifying technical concepts and processes of chemical bonding. These were the chemical concepts which have meanings that are incompatible to those in everyday English language, and that have the potential to hamper learners' understanding of the meaning of the sentence or phrase. The criterion used for considering phrases and sentences used in the textbook on chemical bonding as grammatically complex involved identifying phrases and sentences that are complicated and not commonly used in everyday English language, as they may negatively impact on learning of this topic.

Table 10. Difficult lexical items and grammatically complex phrases in the Physical Science textbook on chemical bonding and the visual-verbal requirements

Topic	Difficult lexical items	Grammatically complex phrases	Visual-verbal requirements	Code
Chemical bonding	complete/stable outer shell		labelled Bohr diagrams of atoms 	LD
	neutral atom(s)		labelled Bohr diagrams of atoms 	LD
		group 0 elements with little tendency to lose/gain electrons	labelled Bohr diagrams of atom an atom of a group 8 element. 	LD
Covalent bond		sharing of electrons between non-metals	labelled overlapping outer shells 	LO
	electron pairs		labelled Bohr diagrams of atoms	LD

			
	valence electrons	labelled Bohr diagrams of atoms 	LD
Ionic bond	electrovalent bond	labelled Bohr diagrams of atoms 	LD
	loss/ gain of electrons	labelled electron-transfer arrow 	LA
	cations and anions	labelled Bohr structures of ions  or 	LI
	electrostatic bond	labelled Bohr structures of ions 	LI

	net electric charge due to the loss or gain of electrons	labelled Bohr structures of ions 	LI

As shown in Table 10, analysis of language use in the textbook on the topic of chemical bonding has enabled identification of the visual-verbal requirements that were necessary for preparing the learners' notes. Using these notes was another entry to employing the visual-verbal intersemiotic complementarity teaching approach to chemical bonding. These requirements involve labelled Bohr diagrams (LD), labelled overlapping shells (LO), labelled electron-transfer arrows (LA), and labelled structures of ions (LI). I used these requirements for preparing learners' notes on chemical bonding that include both textual (in place of the verbal mode) and visual modes.

5.2.2.2 The visual-verbal requirements: Identified from diagrams use in the textbook

I found that explanations of chemical bonding in this textbook also make use of diagrams, which are visual representations. This is a response to the general objective of the Physical Science syllabus on this topic, which requires Grade 9 learners to illustrate the two types of chemical bonding. The syllabus specifies that diagrams must be used for illustrating Bohr structures of atoms of elements, and molecule and ion formation in covalent and ionic bonding respectively. This directly uses the visual mode to explain the models of electrons distribution, and atomic or molecular behaviour (Gilbert, Boulter, & Elmer, 2000). Moreover, diagrams develop learners' engagement during lessons, and self-motivation (Gilbert & Treagust, 2009).

Notwithstanding the idea that diagram use abolishes the dominant use of language over other semiotic modes and helps students with little or no background of chemical knowledge, they are viewed as difficult to interpret by students as they cause confusion (Chittleborough, Treagust, Mamiala, & Mocerino, 2005). This problem (confusion) may be due to the interpretation of diagrams requiring metacognition (Gilbert, 2005). Metacognition involves students navigating and assessing the images of chemical phenomena. This confusion may be avoided by labelling diagrams, as this facilitates learners' construction of accurate mental models (Gilbert, 2005).

I found that the Bohr diagrams of chemical bonding used in this textbook are not clear to the learners. Most of them are not labelled, requiring the teacher to explain them verbally, which is often not successfully achieved due to the barrier in communication. The Bohr diagram of a covalent bond in a water molecule formation, shown in Figure 3, is one of inexplicit bond diagrams found in the textbook. The verbal captions would have been used to provide details related to the process illustrated by the diagram. This may include words such as 'non-metals', 'valency' and 'share'. Moreover, indicating particles as atoms or molecules would have also given better understanding of the diagram by the learners.

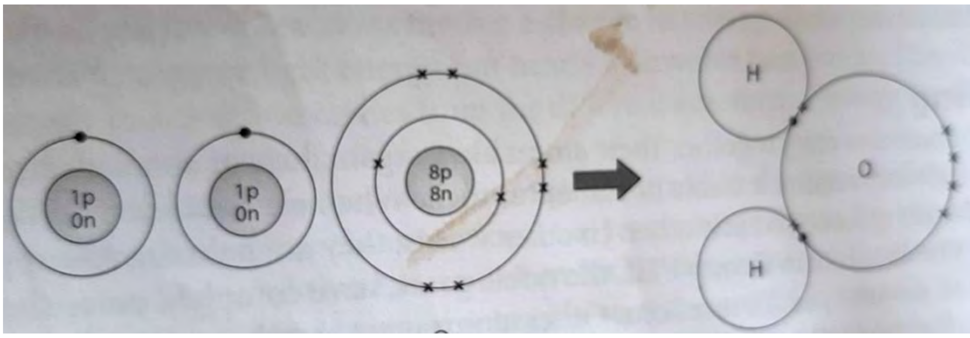


Figure 3. An inexplicit diagram of a covalent bond in a water molecule (taken from a grade 9 Physical Science textbook)

The low quality of bond diagrams, as per se, is not only identified in covalent bonding, but also in ionic bonding. The diagram in Figure 4 is evidence that ionic bond diagrams are also inexplicit to learners, especially those learning this bond type for the first time. Even though the electron transfer arrows labelled '$2e^-$' are drawn, more captions could have been done to provide needed details about the bond between magnesium and oxygen atoms. This could include words such as 'valency of magnesium is +2', 'valency of oxygen is -2' and 'atoms becoming ions after they lose or gain electrons'.

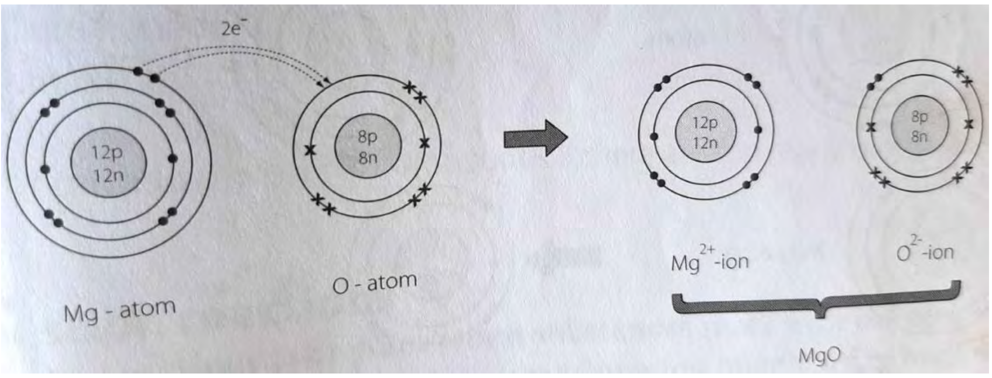
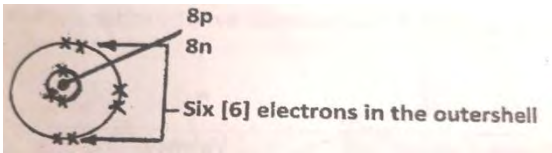
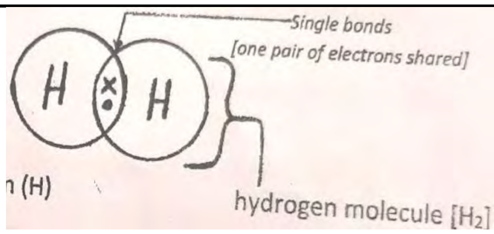
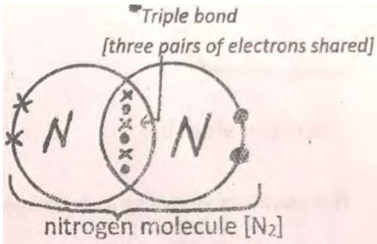
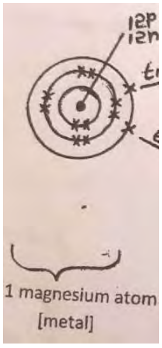
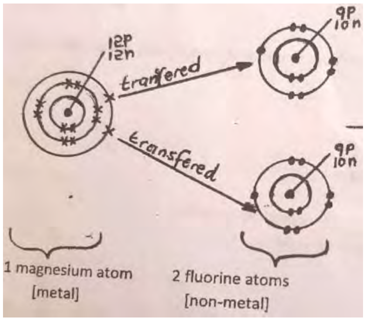
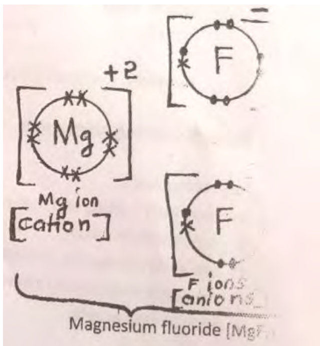


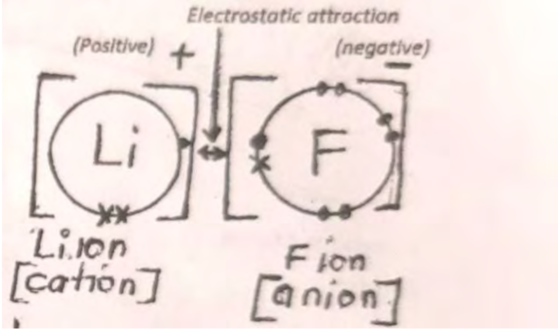
Figure 4. An inexplicit diagram of an ionic bond in magnesium oxide (taken from a grade 9 Physical Science textbook)

I attempted to rectify this problem by first identifying the bond diagrams that I considered as having potential to negatively impact the learners' understanding of chemical bonding, and secondly, identifying difficulties that learners might have in understanding these diagrams, before thinking of words that may be used to label these diagrams. I did this in order to inform planning and implementing the co-deployment of the visual mode with the verbal or written forms, as Chittleborough, Treagust, Mamiala, and Mocerino (2005) suggest. Table 11 shows the difficulty of chemical bonding diagrams in the textbook, and the visual-verbal requirements that were identified from the analysis.

Table 11. Difficulty of chemical bond diagrams in the Physical Science textbook and its visual-verbal requirements

Topic	Difficult knowledge of chemical bonding caused by bond diagrams	Visual-verbal requirements	Codes
Covalent bond	valency concept	labelled Bohr diagrams of atoms 	LD
	electron sharing rule	labelled overlapping shells	LO

			
	bond strength	labelled Bohr diagrams of atoms	LD
			
Ionic bond	valency concept	labelled Bohr diagrams of atoms	LD
			
	electron-transfer rule	labelled electron-transfer arrows	LA
			
	positive and negative signs assigned to ions	labelled Bohr structure of ions	LI
			
	bond strength	labelled Bohr structure of ions	LI



5.2.2.3 The textbook's overall visual-verbal requirements of chemical bonding

As indicated earlier, analysing the textbook was undertaken in order to identify the visual-verbal requirements of the topic, as an entry to planning and implementing an intersemiotic complementarity teaching approach to it. The overall visual-verbal requirements identified involve using labelled Bohr diagrams of atoms (LD), labelled overlapping shells (LO), labelled electron-transfer arrow (LA), and labelled structures of ions (LI). I used these requirements specifically when preparing chemical bonding notes for learners in order to present knowledge of the topic in the textual (in place of the verbal mode) and visual modes in a coordinated manner. These notes were the teaching materials needed for the coordinated visual-verbal intersemiotic complementarity teaching approach to the topic, which was employed during Cycle 2 of this action research.

5.3 Grade 9 Namibian learners' knowledge of chemical bonding after a traditional teaching approach (Cycle 1)

Before attempting to explore the influences of an intersemiotic complementarity teaching approach on learners' sense-making of chemical bonding employed during Cycle 2, I conducted Cycle 1 to ascertain the Grade 9 Namibian learners' knowledge of the topic gained after employing a traditional teaching approach to the topic. Cycle 1 played two roles that guided undertaking the intervention during Cycle 2: analysis of curricular documents (Grade 9 Physical Science syllabus and Physical Science textbook), and analysis of Grade 9 learners' sense-making of chemical bonding after employing a traditional teaching approach. The document analysis results were provided in Section 5.2. The knowledge of learners' sense-making of chemical bonding was accessed via three data collection techniques: structured lesson observation, the teacher's and learners' reflective journals, and the pre-test. The results accessed via these data collection techniques will now be presented.

5.3.1 Findings from structured lesson observation in Cycle 1

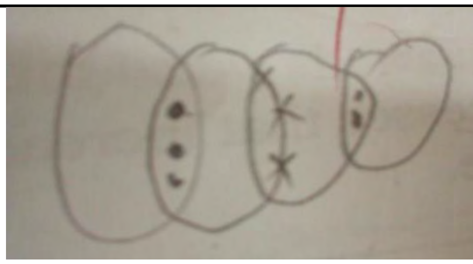
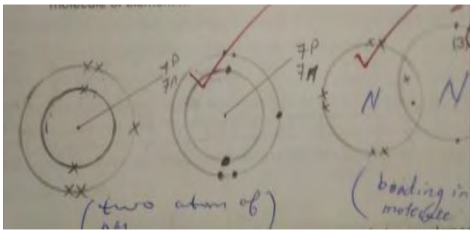
During the traditional teaching approach carried out in this study, structured lesson observation was undertaken in order to ascertain learners' sense-making of chemical bonding. This same method of collecting data was later employed during the intervention (using an intersemiotic complementarity teaching approach) in order to ascertain the learners' sense-making of the topic after every lesson taught.

In this study, structured lesson observation was undertaken with a focus on sense-making types/indicators as identified by Zimmerman et al. (2009). This assessment analyses the learners' ability to link theories to evidence, as Zangori et al. (2013) outline. These sense-making types, their codes, and their definitions are provided in Table 12. The excerpts of learners' talk and the visuals indicating their sense-making of chemical bonding knowledge observed during the traditional teaching approach are also shown in Table 12. These were categorised according to five sense-making types, which were evidence of how learners made sense of chemical bonding knowledge. These types are perceptual, chemical bonding facts, connecting and analysing, clarification, and ideas about the nature of chemical bonding sense-making. Analysis of excerpts of learner talk and visuals informed planning of the coordinated visual-verbal intersemiotic complementarity teaching approach undertaken during the second cycle of the action research. Further, these excerpts were also categorised according to the representational levels of chemical knowledge (chemical bonding) that are realised in them, in order to identify the level(s) that is/are problematic to sense-making. These representational levels are macroscopic (M), sub-microscopic (SM), and symbolic (S), as identified by Johnstone (1982).

Table 12. Sense-making evidence observed during traditional (prototype) lessons

Sense-making evidence	Code	Definition	Excerpts/drawings indicating learners' chemical bond knowledge and their representational levels (M, SM or S)	Descriptive code(s)
Perceptual (least aligned to scientific facts and	P	This is how talk and/or visuals are used by learners to identify,	*"carbon dioxide is a compound because it is made by two elements which is carbon and*	E, L & Sm

rules)		count, and describe concrete chemical bonding processes or objects observed.	*oxygen"* **(M)**	
			"covalent bond is bonding between a non-metal and a non-metal like carbon and oxygen of carbon dioxide" **(M)**	E & L
			"covalent substances are not conduct electricity" **(M)**	E & L
			*"covalent substances are not conducting electricity"***(M)**	E & L
			"ionic substances like salt we put in food don't dissolve in water… if you put salt in the pot of meat and water, you are not see it anymore" **(M)**	E & L
Chemical bonding facts	CBF	This is when students make talk and visuals about abstract chemical bonding processes and objects.	*"elements that are bonding is because they are in the periodic table to react"* **(SM)**	C & L
			Teacher's question: *"Do argon and fluorine bond? If yes, Why?"* Learner's answer: *"yes, because they all non-metals that share electrons and can form a covalent bond"* **(SM)**	C & L
			"a diatomic molecule is elements that found with +2" **(SM)**	C & L
			"sodium becomes an anion because it loses electrons" **(SM)**	C & L
			One learner's incorrect Bohr diagram of a carbon dioxide molecule:	C & V

				
			The Bohr diagram of a nitrogen (element X) molecule drawn by one learner: 	C, V & Sm
Connecting and analysing	CA	These involve talk and visuals used by students to make explicit and implicit comparisons and analogies to their prior knowledge or experiences.	Element Z (Aluminium) was indicated as an element in group three (3) and period three (3). The electron structure of its ion drawn by one learner was *"2: 8: 3"* **(S)**	C & L
			"sodium ion is positive because it gives away one electron in its outer shell to chlorine" **(SM)**	E & L
			"formula for magnesium oxide is MgO_2" **(S)**	C, L & Co
			"the formula for sodium carbonate is $NaCO_2$" **(S)**	C, L & Co
Clarification	Cl	These involve using talk and visuals to clarify how chemical bonding processes work and/or are applied in real life contexts.	*"the bond between carbon and oxygen is covalent is involve sharing of electrons between them"* **(SM)**	E & L
			"covalent compounds do not conduct electricity because all are non-metal" **(SM)**	C & L

			"the bond in ionic substances is very strong because a metal is also strong and it is strong" **(SM)**	C & L
Ideas about nature of chemical bonding (most aligned to scientific facts and rules)	ICB	These are talk and visual debates and discussions about knowledge of chemical bonding.	More learners were saying that *"lithium and oxygen share electrons"* while few were saying *"they cannot share because one is a non-metal while other one is a metal"*.	C & L

Descriptive codes of learners' excerpts of chemical bonding knowledge:

- E – sense-making enabled; C – sense-making constrained; L – lexical sense relation; V – visual sense relation; Sm – similarity; A – antonymy; Me – meronymy; H –hyponymy; Co – collocation

5.3.1.1 Evidence of perceptual sense-making (P)

Perceptual sense-making refers to learners' ability to identify, count, and describe concrete objects or processes of chemical bonding (Allen, 2002). In this study, this sense-making type was adapted to consider learners making sense of chemical bonding via visuals and talk combined. Among the sense-making types, this type is least aligned to scientific facts and rules (Zimmerman et al. 2009), as it involves learners using very basic skills to access scientific knowledge. However, Zimmerman et al. (2009) highlight that perceptual thinking can be one of the developing epistemic resources required by learners to share observations or knowledge of relevant scientific phenomena. They further elucidate that sharing of this knowledge between learners allows interaction to occur, which results in construction of new meaning.

Table 12 shows that learners have demonstrated a good understanding of chemical bonding knowledge that belongs to this sense-making type. However, all excerpts of learner talk and visuals illustrating this sense-making type of this kind of chemical bonding knowledge belong to the macroscopic level of representation, because much of the knowledge they portray is observable. These findings affirm Johnstone's (1982) point about learners having the least problems with the macroscopic level of representation, due to its tangibility.

I extracted only four excerpts of learners' talk for discussion. Learner J stated that *"covalent bond is bonding between a non-metal and a non-metal like carbon and oxygen of carbon dioxide",* while Learner H explained that *"carbon dioxide is a compound because it is made by two elements which is carbon and oxygen"*. This indicates that the perceptual sense-making of chemical bonding was enabled by the lexical sense relation of similarity. I realised this from the learners being able to *identify* the bond as covalent and *describe* it as taking place between non-metals. I also realised this sense-making in learners being able to *identify* carbon and oxygen as elements that make up carbon dioxide. Moreover, the learners being able to *count* in order to determine the number of elements that comprise carbon dioxide indicates their perceptual sense-making.

Two further excerpts of learners' talk indicating the perceptual sense-making were *"covalent substances are not conducting electricity"* and *"ionic substances like salt we put in food dissolve in water… if you put salt in the pot of meat and water, you are not see it anymore"*. The fact that learners could *describe* covalent substances as non-conductors of electricity and ionic substances as soluble in water indicates that their perceptual sense-making of this chemical knowledge was enabled. However, even though many of these learners have no problem with the perceptual sense-making, it was not concluded that sense-making of chemical bonding knowledge has successfully occurred, as this type is least aligned to scientific facts and rules due to it being accessible via basic scientific skills.

5.3.1.2 Evidence of chemical bonding facts sense-making (CBF)

Chemical bonding facts sense-making (CBF) involves students making talk and visuals about abstract chemical bonding concepts of chemical processes and objects. This implies that good understanding of abstract scientific words is a sign that sense-making of chemical knowledge is advancing. The frequent use of abstract scientific concepts in this type of sense-making makes it more aligned to scientific facts and rules than the perceptual sense-making (Zimmerman et al, 2009). Therefore, I analysed this sense-making type in this study in order to understand how learners cope with abstract scientific concepts and processes before and after employing the intersemiotic complementarity teaching approach. Overall, I observed that learners have little chemical bonding knowledge at this sense-making level – evident in them being unable to use abstract concepts and ideas adequately when explaining chemical phenomena.

I found that more than half of the class (more than 19 learners) had difficulty explaining the microscopic conditions that lead to chemical bonding. Learner W incorrectly explained that *"elements that are bonding is because they are in the periodic table to react"*. When asked to state, with a reason, whether argon and fluorine can bond, Learner A incorrectly answered that *"yes, because they all non-metals that share electrons and can form a covalent bond"*. These two excerpts of learners' talk reveal that learners lack the knowledge of chemical bonding occurring due to incomplete (unstable) outer shells of atoms of some elements. The learner expressing that argon and fluorine bond covalently because they are non-metals shows his mere understanding of this bonding type happening between non-metals. Though he could use the concept 'sharing', he did not think of argon being unreactive due to the full outer shells that its atoms have. This reveals that his knowledge of more abstract concepts and ideas (such as stable/complete outer shells; inert/noble gas) is limited.

Learner P defined a diatomic molecule as *"elements that found with +2"*. After a series of follow-up questions posed by the teacher, two possible reasons emerged for his failure to answer the question correctly. First, it is possible that this learner did not know either the meaning of the prefix *di-* or the meaning of the concept *molecule*, both of which are more abstract than perceptual. Second, this learner seemed to have interchangeably used knowledge of *diatomic molecules* with *charges on ions.* He could understand that the prefix *di* refers to two things, but ended up wrongly linking it to the charges formed during ionic bonding. Learner A correctly explained that a sodium atom loses one electron during its bond with a chlorine atom. However, he wrongly referred to an ion formed by a sodium atom as an *anion*, when he should have referred to it as a *cation*. I see this knowledge as constrained possibly by the verbal mode used and by it being sub-microscopic, as electrons are invisible to the naked eye.

The learners' inability to make sense of chemical bonding facts was also identified in their visual representation of chemical diagrams of a covalent bond in carbon dioxide and chlorine molecules. Though it was evident that some learners generally know that covalent bonding involves electrons sharing, specific difficulties could clearly be identified from the Bohr diagrams of carbon dioxide and nitrogen molecules they drew. For example, some of these difficulties could be identified from Learner F's incorrect bond diagram of a carbon dioxide molecule in Figure 5.

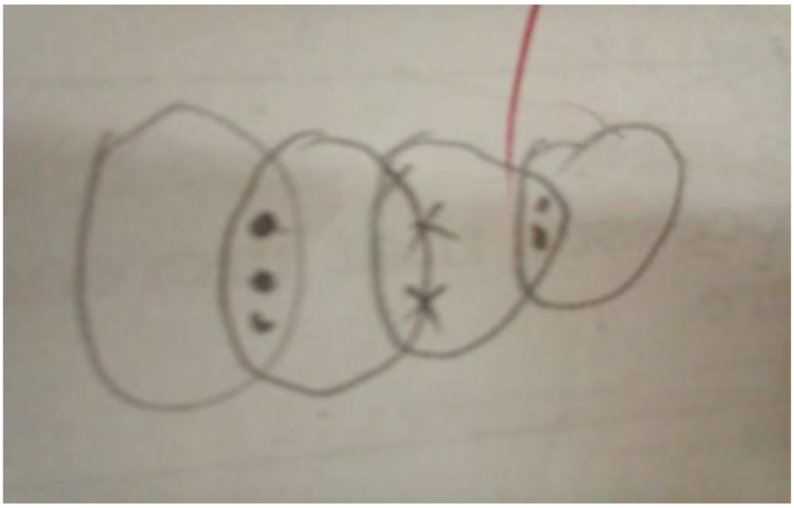


Figure 5. An incorrect bond diagram of a carbon dioxide molecule (drawn by Learner F after Cycle 1)

First, this learner shows lack of understanding of covalent bonding in carbon dioxide in the incorrect number of atoms he has drawn. The molecule of carbon dioxide (CO_2) actually consists of three atoms in total: one carbon atom, and two oxygen atoms. However, the Bohr diagram of a carbon dioxide molecule (Figure 5) drawn by this learner has four atoms instead of three. Second, the atoms in the molecule are not labelled, and the number of electrons shared is shown incorrectly. They could have labelled the atoms involved in the bond, as this would indicate their knowledge of atoms contained in a carbon dioxide molecule. This is good, because in Namibian schools, marks are also awarded for correct labelling of atoms in a molecule. Carbon atoms share four electrons because their valency is four, while oxygen atoms share two electrons because their valency is two. This knowledge is abstract, as learners do not observe a carbon dioxide molecule and so can access this knowledge only via the teacher's explanation. If the teacher used a physical model of a carbon dioxide molecule, this learner could have possibly constructed a more meaningful Bohr structure of a carbon dioxide molecule than the one in Figure 5.

Learner X's Bohr diagram of a nitrogen molecule (Figure 6) shows his more correct mental model of covalent bonding. However, the details of the bond diagram he drew show that his understanding of covalent bonding was still limited.

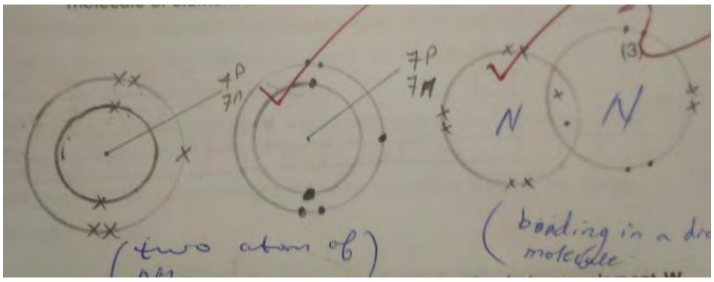


Figure 6. An incorrect bond diagram of a nitrogen molecule (drawn by Learner X after Cycle 1)

This learner showed that he understood that nitrogen is a diatomic molecule. This was shown in the two nitrogen atoms bonded together that he drew. He also knew that both atoms of nitrogen are non-metal and share electrons. His diagrams are correctly labelled, indicating his awareness of the need to show to the viewer/reader all atoms that make up a molecule. However, he lacks knowledge of the *valency* concept, and how it is applied to determine the number of electrons shared by two atoms that bond.

5.3.1.3 Evidence of connecting and analysing sense-making (CA)

Central to this sense-making type is students' ability to compare new knowledge to their prior knowledge (Zimmerman et al., 2009). This sense-making type involves high-level scientific skills. Thus, learners' knowledge of chemical bonding at this level reveals stronger sense-making of the topic compared to the perceptual or fact-based sense-making types.

Learner X indicated that the electron structure of an aluminium ion is *2:8:3,* not considering his prior knowledge of the atom of this element losing all three outer shell electrons when it becomes an ion. He should have described the electronic structure of an aluminium ion as being *2:8* only, as the 3 outer shell electrons have been transferred to atoms of a non-metal element. This indicates that his ability to construct the mental model of an atomic structure is constrained, possibly by the verbal semiotic mode that was used alone.

Few learners revealed understanding of the bond between sodium and oxygen atoms at the sub-microscopic representational level. Learner T stated and explained that the *"sodium ion is positive because it gives away one electron in its outer shell to chlorine"*. This explanation is correct; however, the fact that only a few learners could explain this bond correctly indicated that it needed consideration in the intervention cycle.

I noted the learners' difficulty deducing formulae of compounds, as many were struggling to write the formulae of magnesium oxide and sodium carbonate correctly. This was visible in some excerpts of learners' talk, such as *"the formula for magnesium oxide is* MgO_2*"* and *"the formula for sodium carbonate is* $NaCO_2$*"*. The representational level of this chemical knowledge is *symbolic*, as it includes, among others, the conventional *numbers* and *symbols*. The difficulty of this representational level of chemical knowledge was first identified by Johnstone (1982). Marais and Jordaan (2000) support the claim, explaining that this difficulty is due to learners' lack of understanding of the complex conventions used. Later, Gilbert and Treagust (2009) argue that the symbolic level of representation has to be more complex than the sub-microscopic level, due to numbers and symbols involved. I therefore thought that combining the teacher talk with visuals when teaching chemical knowledge, as Gilbert and Treagust (2009) suggest, may enhance learners' sense-making of chemical bonding at the symbolic level of representation. This supports the rationale for the intervention employed in Cycle 2 of the action research.

5.3.1.4 Evidence of clarification sense-making (Cl)

This sense-making type involves applying scientific skills ranked more highly than the P, CBF, and CA, as it requires learners to clarify scientific processes and objects. Making sense of chemical bonding for this sense-making type may include knowledge at the sub-microscopic level of representation, as understanding the chemical processes involved requires explanation of the particulate and kinetic nature of matter.

I attested that many learners could explain that covalent bonding involves electron sharing, while some had problems with this. This is evident from learner B's correct explanation that *"the bond between carbon and oxygen is covalent as it involves sharing of electrons between them"*. However, the learners seemed to have rote-learned this, as many mentioned 'electron sharing' but failed to show it correctly on their diagrams. They listed all physical properties of both covalent and ionic compounds; however, they failed to explain them by referring to the kinetic particle theory of matter. Explaining chemical bonding with reference to the kinetic particle theory of matter is sub-microscopic, as neither the particles nor their behaviour is observable. I realised this in the following excerpts of learners' talk: *"covalent compounds do not conduct electricity because all are non-metal"*, and *"the bond in ionic substances is very strong because a metal is also strong and it is strong"*. These excerpts revealed that some learners knew that covalent substances do not conduct electricity;

however, they lack adequate knowledge of this property as they could not explain it by referring to atoms in a molecule as still neutral. Explaining the bond strength in ionic substances by referring to the kinetic particle theory of matter was problematic, since no learner referred to the electrostatic attractive forces that exist between the oppositely charged ions.

Learners' ability to make sense of chemical bonding via clarifying it at the sub-microscopic level of representation was constrained, based on the results obtained from structured lesson observation (Appendix N). Hence, considering this level of knowledge in the intervention cycle (Cycle 2) was necessary.

5.3.1.5 Evidence of ideas about nature of chemical bonding sense-making (ICB)

This sense-making is achievable via learners debating and discussing science knowledge by referring to relevant scientific theories, laws, and principles (Zimmerman et al., 2009). In this study, this sense-making type was considered as more aligned to scientific facts and rules than previous sense-making types, as its reasoning is based on theories and principles of science.

In this study, almost all learners displayed challenges with this sense-making level. Many of them stated that *"lithium and oxygen share electrons"* – which is incorrect. They should have mentioned that a lithium atom transfers electrons to an oxygen atom, as metals have tendency to lose electrons, while non-metals have tendency to gain electrons. Very few learners supported the concept of *electron transfer* between the atoms of these two elements, reasoning that lithium is a metal while oxygen is a non-metal, and the electrons have to be *transferred* from lithium to oxygen atoms. In summary, I realised that learners' ability to apply the learned theories was very limited, and possible pedagogic approaches to enhance this needed to be explored.

5.3.1.6 Overall learners' knowledge of chemical bonding accessed via structured lesson observation in Cycle 1

Overall, I found that learners' sense-making of chemical bonding, accessed via structured lesson observation, was inadequate, as I had experienced in previous years. The findings include learners' knowledge of chemical bonding after employing the traditional teaching approach being mainly perceptual (based on what learners perceive), which is not sufficiently aligned to more abstract scientific reasoning; and predominantly macroscopic, as it mainly concerns concrete and observable entities and processes, which Johnstone (1982) describes as easy for learners to grasp. These findings have informed the design of the visual-verbal intersemiotic complementarity teaching approach undertaken during Cycle 2 of this action research study. Other methods of collecting data, such as reflective journaling (by the teacher and learners) and pre-testing (learners' answer scripts), were also administered for validation of these data, and for collecting data that cannot be collected successfully by using structured lesson observation.

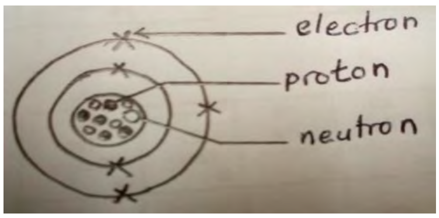
5.3.2 Findings from teacher's and learners' reflective journals in Cycle 1

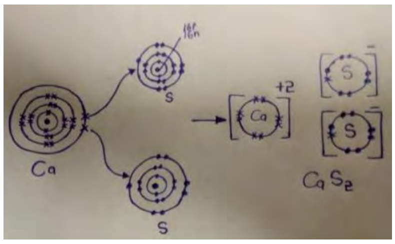
5.3.2.1 Sense-making evidence from the teacher's reflective journals

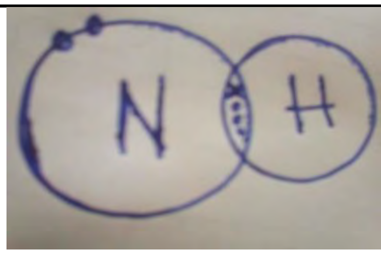
The teacher's reflective journal guide (Appendix O) was used in Cycle 1 to collect data related to how learners make sense of chemical bonding as a result of the use of the verbal mode during teaching. My choice of the teacher's reflective journal as a data collection tool in this study was informed by Gay, Mills, and Airasian (2009). They assert that reflective journals provide the researcher with first-hand data of the situation, making him/her more aware of the situation or case being studied. First hand data help the researcher to foresee the outcome of the intervention undertaken. I set the guiding questions in order to elicit details on whether learners' sense-making of chemical bonding knowledge had occurred or not occurred as a result of the semiotic mode used. I also used the guiding questions to maintain my focus (as a researcher) on data relevant to answering the research questions, and not on incidental aspects that may arise during the study.

The results on learners' sense-making of chemical bonding obtained via the teacher's reflective journal are recorded in Table 13. In this table, how learners made sense of knowledge of chemical bonding during the traditional (prototype) lessons was classified into five sense-making types, as was done with results of structured lesson observation. I further classified these sense-making types as either 'enabled' or 'constrained' by the sense relations of either the visual or verbal semiotic mode alone. This information was necessary for identifying knowledge of chemical bonding and the sense relation of visual-verbal intersemiotic complementarity that needed more consideration during Cycle 2 of this study.

Table 13. Evidence of chemical bonding sense-making and sense relations involved (From the teacher's reflective journals)

Sense-making type and definition	Enabled (E)/ constrained (C)	Lexical (L) /visual (V) sense relation involved	Description of chemical bonding knowledge learned or not learned (M – macroscopic, SM – sub-microscopic, S – symbolic)
Perceptual sense-making (P) – learners' talk and/or visuals involving identifying, counting, and describing concrete chemical bonding processes or objects observed.	E	L – similarity	Learners have correctly stated that metals are on the left and non-metals are on the right. (M)
	E	L – hyponymy	Some learners stated that the vertical columns are called groups and the horizontal rows are called periods on the periodic table. (M)
	E	L – antonymy	Most learners could distinguish between covalent and ionic bonding. (M)
	E	L – similarity	Some learners explained that ionic compounds are soluble in water, giving an example of table salt, which dissolves in watery foods. (M)
Chemical bonding facts sense-making (CBF) – learners' talk and visuals about abstract chemical bonding processes and objects.	E	L – similarity	Some learners identified protons as positive (+), electrons as negative (–), and neutrons as neutral. (SM)
	E	V and L – meronymy	Most learners could state that protons are in the nucleus, neutrons are in the nucleus, and electrons are in the shells, as shown in this diagram. (SM) 
	C	L – meronymy	One learner mentioned that protons are in the outer shell and they are equal to the period number, which is incorrect. (SM)
	E	L – meronymy	Most learners understand that an atom's first shell is full with two (8) electrons, the second shell with eight (8), and the third shell with eight (8). (SM)

	C	L – collocation	Some learners stated that protons are equal to neutrons, which is incorrect. (SM)
	C	L – collocation	Some learners said that neutrons are determined by subtracting the mass number from the atomic number, which is incorrect. (S)
	E	L – similarity	Some learners stated that different atoms should be represented with a dot or a cross. (S)
	C	L – similarity	Some learners could not distinguish between cations and anions. (SM)
Connecting and analysing sense-making (CA) – talk and visuals where students make explicit and implicit comparisons and analogies to prior knowledge or experiences of chemical bonding.	C	V – collocation	Many learners could not correctly draw the bond between calcium and sulphur atoms. One learner even drew two atoms of sulphur binding with a calcium atom, as illustrated below. (SM)
			
	C	L – collocation	Some of the learners who understand what valency is could not use it in writing formulae of compounds. (S)(SM)
	C	L – antonymy and collocation	Some learners could not identify ions as positive and negative. They kept debating that the atoms that lost electrons are negative while those that gained electrons are positive. (SM)
Clarification sense-making (Cl) – learners' talk and visuals about how chemical bonding processes work and/or are applied in real life contexts.	C	L – collocation	Almost all learners failed to explain why atoms of elements form a bond. (SM)
	C	V – collocation	One learner drew the bond in ammonia incorrectly, as shown below. (SM)

			
	C	L – collocation	About three quarters of the learners in the class could not explain electron loss from a sodium atom as being due to its instability in the outer shell. (SM)
Ideas about nature of chemical bonding sense-making (ICB) – learners' talk and visuals about how knowledge of chemical bonding is discovered by scientists.	C	V – antonymy	Some learners debated that atoms do not really bond, because no one could see the atoms with his or her naked eye. (SM)

(a) Evidence of perceptual sense-making (P)

As discussed in Chapter 2, perceptual sense-making (P) is the sense-making type where learners identify, count, and describe concrete objects or processes of chemical knowledge (Allen, 2002). It is least aligned to scientific reasoning due to it involving perceptual activities (identify, count, describe). As shown in Table 13, learners demonstrated a good understanding of chemical bonding knowledge that is accessed via perceptual sense-making. Moreover, knowledge aspects included in this sense-making type are mainly macroscopic, as they concern observable knowledge of chemical bonding. This concurs with the idea of Johnstone (1982) that learners have no learning problem with the macroscopic level of representation of chemical knowledge.

I realised that the learners' knowledge of chemical bonding categorised as perceptual was lexically accessed and expressed by learners during Cycle 1 of this study. The Systemic Functional-Multimodal Discourse Analysis (SF-MDA) approach suggests that this knowledge is accessible and/or expressible via the ideational meaning-making resource of the combined lexical and visual sense relations to produce expanded meaning (Royce, 1998; O'Halloran, 2008). The intersemiotic sense relations of the ideational meaning-making resource in this study involved similarity (adapted by combining synonymy and repetition), antonymy, hyponymy, meronymy, and collocation (as described in Chapter 2). Though I found that perceptual sense-making of this chemical knowledge had successfully occurred, I resolved to proceed with employing the coordinated visual-verbal intersemiotic complementarity sense relations of ideational meaning-making resources, as this sense-making type is least aligned to scientific facts, rules, and principles.

(b) Evidence of chemical bonding sense-making (CBF)

The difference between CBF and P is that CBF is realisable in learners either visually or verbally accessing or expressing abstract objects and processes of chemical bonding, while P involves learner talk and visuals that are based on what they perceive. Zimmerman et al. (2009) argue that sense-making involving abstract science facts and processes is better than the perceptual communication in enhancing meaning-making of scientific knowledge. Possibly, learners making sense of chemical bond knowledge via CBF may be obstructed by abstract concepts and processes. The teacher's reflective journals reveal that accessing this knowledge was possibly constrained by the verbal semiotic mode used during the prototype lessons. The main semiotic mode used for accessing and expressing this knowledge during Cycle 1 was the verbal semiotic mode. This supported the notion of an intervention involving another semiotic mode complementing the verbal semiotic mode, in order to explore the influences of their combined use on learners obtaining otherwise challenging knowledge.

I noticed that the challenging knowledge of chemical bonding categorised as CBF in this study was mainly sub-microscopic and symbolic. During this cycle (Cycle 1), I realised, through reflective journaling, that there were specific difficulties hampering learners' sense-making of chemical bonding knowledge classified as CBF, most of which is represented either sub-microscopically or symbolically.

I realised that the sub-microscopic knowledge of chemical bonding constrained by the verbal semiotic mode includes knowledge of the relationship between the periodic table and the Bohr structure, and between the Bohr structure and the ions of ionic compounds. First, learner X explained the relationship between the atomic structure of an element and the periodic table incorrectly by referring to *protons* instead of *electrons* in the outer shell. He explained that protons in the outer shell of an atom of an element are equal to its period number in the periodic table – which is incorrect, as protons are not located in the shells, but in the nucleus. In addition to the interchangeable use of these two concepts, this learner revealed his lack of understanding of how an atomic structure relates to the periodic table. He could, instead, have stated that electrons in the outer shell of an atom are equal to the group number but *not* equal to the period number. Second, many learners incorrectly explained that the number of protons is equal to the number of neutrons, while some even showed this misunderstanding in the Bohr diagrams they drew. Third, many learners failed to classify an ion correctly as a *cation* or an *anion*. They could have accessed this information from knowledge of the *positive* and *negative* signs shown on the ions, or from an imbalance of protons and electrons in a particular ion, but were not able to.

I noted that learners' difficulty with the symbolic level of representation of chemical bonding was also present when determining the neutron number using the mass number and the atomic number shown by the nuclide notation of an element in the periodic table. Some learners ended up knowing the opposite of what they are taught. They explained that the mass number must be subtracted from the atomic number to find the number of neutrons in an atom. This is incorrect, as subtracting the mass number from the atomic number gives a negative number – which is impossible for the mass number of an atom. This also shows that the symbolic level of representation of chemical bonding was challenging to these learners, and thus needed consideration during Cycle 2.

(c) Evidence of connecting and analysing sense-making (CA)

Connecting and analysing sense-making (CA) involves a learner making both explicit and implicit comparisons and analogies to prior scientific knowledge or experiences (Zimmerman et al., 2009). I therefore inferred that learners' prior knowledge (knowledge of using the periodic table) needed consideration in order to help learners to access chemical bonding knowledge easily. It is possible that learners who had difficulty making sense of chemical bonding at the CA level did not know how to use the periodic table – the knowledge taught in Grade 8 prior to teaching the atomic structure. Learners who make sense of the themes of scientific knowledge categorised as CA acquire more scientific skills than those who acquire them at the CBF and P levels. This is due to the fact that this sense-making type involves learners connecting the new knowledge to their prior knowledge.

The teacher's reflective journals I used in this study identified three knowledge aspects (also referred to as knowledge themes) of chemical bonding where learners' sense-making was categorised as connecting and analysing. These knowledge themes are ionic bonding drawing (IBD), valency (V), and ions (IN). The knowledge contained in these themes in this sense-making type was mainly sub-microscopic, as it concerns the non-observable, microscopic aspects of chemical bonding, as Johnstone (1982) explains. The traditional teaching approach undertaken during Cycle 1 was characterised by dominance of the verbal semiotic mode, as opposed to the visual-verbal intersemiotic complementarity teaching approach, which consists of related lexical and visual items combined. Learners' sense-making of chemical bonding knowledge belonging to these knowledge themes was possibly constrained by the traditional, verbal-only teaching approach employed during Cycle 1.

The teacher's reflective journals revealed that the learners' sense-making of chemical bond knowledge classified as IBD was constrained, as many did not draw the Bohr model of the bond between calcium and sulphur atoms correctly. Learner W drew a bond structure of two sulphur atoms bonding with one calcium atom instead of only one sulphur atom bonding with one calcium atom. Figure 7 shows the diagram he drew.

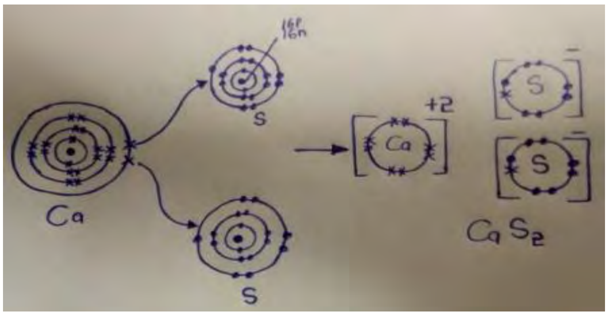


Figure 7. An incorrect Bohr diagram of a bond between calcium and sulphur atoms (drawn by Learner W during Cycle 1)

I realised that the bond diagram in Figure 7 was wrong due to the Bohr diagram of a sulphur atom being incorrect. This learner drew a sulphur atom with seven electrons in the outer shell, instead of the six that should have been present (due to this element belonging to group six in the periodic table). I therefore regarded this knowledge as inadequately learned by the learners prior to learning either ionic or covalent bonding. Therefore, I inferred that the learners' failure to illustrate the bond between calcium and sulphur correctly has a direct link to their failure to draw the Bohr structures correctly.

I also found that some learners could not deduce formulae of compounds by applying their prior knowledge of valency (V). Drawing from ideas of Johnstone (1991), knowledge of valency is sub-microscopic, as it concerns invisible microscopic sub-atomic particles (electrons) in the outer shell of an atom that are involved in bond formation. However, writing of formulae of compounds is symbolic, as it involves using conventional symbols (such as symbols of elements) and numbers (subscripts indicating the number of atoms) assigned to elements in a compound. Moreover, the reflective journals indicated that knowledge of valency and formulae writing was lexically expressed and accessed, indicating opportunity for it to be taught via more than one semiotic mode, as the Systemic Functional Multimodal Discourse Analysis suggests.

I noted that some learners' sense-making of ions (IN) was constrained, possibly by the verbal semiotic mode used during the traditional lesson presentation. This learning difficulty involves learners failing to identify ions as either positive or negative. They could distinguish between these two types of ions from the positive and negative signs they have, or from their imbalance (inequality) of protons (+) and electrons (-). This knowledge is sub-microscopic, as it concerns knowledge of microscopic particles (Chandrasegaran, Treagust & Mocerino, 2007). This warrants employing a teaching approach where ions are presented both verbally and visually to explore the influences this may have on learners' sense-making of ions as a concept in chemical bonding.

(d) Evidence of clarification sense-making (Cl)

The clarification sense-making (Cl) is realisable in learners being able to explain, and discuss possible application of, scientific processes in real life (Zimmerman et al., 2009). In this study, I adapted this sense-making type to refer to learners clarifying knowledge of chemical bonding, and its application in real life, via the combined use of visual and verbal semiotic modes. Learners' sense-making of this knowledge was ascertained by analysing verbal or illustrative explanations and comments made by learners when clarifying the nature and processes of chemical bonding after the teaching of prototype lessons used during Cycle 1. This sense-making type indicates a high level of scientific sense-making compared to the perceptual, fact-based, and connecting and analysing sense-making types, as Zimmerman et al. (2009) suggest.

I formulated three problematic knowledge themes, where making sense of knowledge was classified as clarification sense-making. This was made possible by analysing the learners' verbal and illustrative (visual) explanations of, and comments on, chemical bonding during the lessons. These themes involved chemical bonding knowledge (CB), covalent bond drawing (CBD), and electron transfer (ET). I regarded these themes as problematic as learners' explanations of, and comments on, the knowledge of chemical bonding were incorrect, based on the specific objectives of the Physical Science syllabus on this topic.

Learners were first asked to explain why atoms chemically bond. Even though I expected the majority of them to give the correct answer, I found that thirty-three out of thirty-eight learners could not do so. Some learners stated that atoms bond in order to form molecules, while others remained silent. The simple answer that learners were expected to give was that atoms bond in order to obtain stable (noble gas) electron structures. A high level of sense-making of this knowledge would have been observed if learners could further explain a noble gas structure as occurring when an outer shell of an atom has two electrons, if it is the first shell (closest to the nucleus), or eight electrons, if it is the second or third shell. Since these learners could not explain any of these either in the verbal or the visual mode, exploring the use of these modes coordinated in teaching this concept was a focus of Cycle 2 of this action research study.

Another problematic knowledge theme under this sense-making type that emerged from the learners' explanations and comments was covalent bond drawing (CBD). Figure 8 shows an incorrect bond diagram of an ammonia molecule, drawn by Learner M.

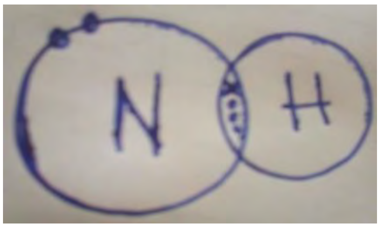


Figure 8. An incorrect Bohr diagram of a bond in an ammonia molecule (drawn by Learner M)

Even though the formula for ammonia was provided, many learners could not correctly draw the Bohr diagram of its molecule. Figure 8 reveals two skills missing in Learner M. First, the learner lacked understanding of the numerical subscript '3' that is found in the formula of an ammonia molecule (NH_3). This subscript means three hydrogen atoms bonded to one nitrogen atom. However, this learner did not understand it as he only drew one hydrogen atom instead of three hydrogen atoms. Second, this learner lacked knowledge of both valency of elements, and the attainment of a noble gas structure by atoms after bonding. Therefore, this indicates that the learner's clarification sense-making was constrained by the traditional teaching approach, as he was unable to clarify the bond when drawing the bond diagram of an ammonia molecule.

The third problematic knowledge theme I realised via journaling was electron transfer (ET). More than half of the learners in the class failed to explain the chemistry behind a sodium atom losing one electron during its bond with a chlorine atom. The correct answer I expected from them could include details such as an electron loss from a sodium atom is due to instability (outer shell not having a noble gas structure), and the attraction between the negative outer shell electron and the positive nucleus (an atomic core). Therefore, I inferred that the learners' knowledge of ET under this sense-making type is constrained and needed consideration in the intervention. This includes representing this knowledge in both diagrams and spoken words.

(e) Evidence of ideas about nature of chemical bonding (ICB)

The ideas about the nature of chemical bonding (ICB) involved learners debating, discussing, and reasoning using scientific facts, as Zimmerman et al. (2009) suggest. The ICB is most aligned to scientific facts among the five sense-making types. In this study, the analysis considered the concepts and processes of chemical bonding knowledge, and the levels of representation to which they belong. This was done to identify the representational level that would need more consideration than others during the intervention. The semiotic mode through which chemical knowledge was represented was also analysed to ascertain its relationship to learners' sense-making.

Possibly due to ICB being more aligned to scientific facts and rules compared to the other sense-making types, only very few learners' sense-making activities could be classified as such. It is possible that learners being insufficiently immersed in the sense-making types that are less aligned to scientific facts than this has contributed immensely to this condition. I noted that only a few learners stated that atoms bond, as no one could see them with his or her naked eye. These debates lack scientific support, as science provides explanations to this process mainly using microscopic knowledge. Moreover, the knowledge concerning atoms bonding is inherently sub-microscopic, as these particles cannot be seen with the naked eye. Since this communication was done lexically in Cycle 1, as shown in Table 13, the intervention has therefore planned teaching of this knowledge to be done both lexically and visually to explore the sense-making changes this would bring.

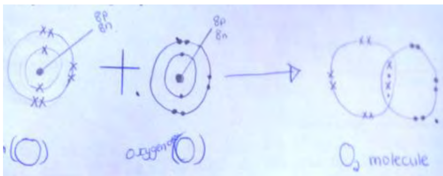
5.3.2.2 Sense-making evidence from the learners' reflective journals in Cycle 1

Learners' reflective journals were used during Stage 4 of Cycle 1 to elicit data required to answer research question 2. I formulated this question to ascertain the learners' sense-making of chemical bonding knowledge after a traditional teaching approach was employed. These reflective journals revealed knowledge aspects of chemical bonding knowledge that learners recalled, and those they thought were problematic to them during the traditional lesson presentations. Learners answered guiding questions after every prototype (traditional) lesson presentation. I administered this activity in order to ascertain knowledge of chemical bonding that learners gained during the first cycle of teaching in this action research.

The results obtained from this are tabulated in Appendix Q; presented in the form of excerpts of learners' talk and visuals from the reflective journals. These excerpts are classified as either gained knowledge or challenging knowledge of chemical bonding, depending on how learners described them in their reflective journals. I sorted the results into categories, from which I then generated knowledge themes. These knowledge themes are discussed, in this section, as either problematic or non-problematic, depending on the responses received. These themes are described in Table 14.

Table 14. Themes of chemical bonding knowledge derived from learners' reflective journals

Theme	**Examples from learners' reflective journals**	**Theme description**
Classification (C)	*"elements in the periodic table are classified as metals (left) and non-metals (right) that are separated by the line called zigzag line"*	The learners' ability to classify elements according to their groups and periods, and as either metals or non-metals
Bohr diagrams (BD)	*"I do not have any problem with drawing Bohr diagrams of the elements"*	The ability to draw atomic diagrams using the Bohr models that were developed by Niels Bohr
Electron arrangement (EA)	*"1st shell is full with 2 electrons, 2nd shell is full with 8 electrons and 3rd shell is full with 8 electrons"*	The learners' ability to locate electrons in shells of atoms using the 2:8:8 ratio, as suggested by the Namibian Physical Science syllabus
Chemical properties (CP)	*"the number of protons for oxygen is 8, because it has an atomic number of 8"*	The learners' ability to describe chemical properties of elements by referring to their atomic numbers, group numbers, and

		period numbers
Valency (V)	*" I am confused by the valency"*	The learners' knowledge of how valencies of elements are determined by using their group numbers in the periodic table
Chemical bonding (CB)	*"all atoms that do not have full outershell can form a bond…like oxygen* 	The learners' knowledge of elements that can form bonds by considering if the outer shell of an atom is stable or unstable
Bond differentiation (BDF)	*"I cannot know the difference between types of bonds"*	The learners' ability to distinguish between covalent and ionic bonds, with reference to electrons sharing or transferring, and whether the reacting elements are metals or non-metals
Electron sharing (ES)	*"I don't know which elements share protons"; "what happen if electrons are shared?"; "Why only non-metals share electrons?"*	The learners' knowledge of sharing of electron pairs between reacting non-metal elements
Covalent bond drawing (CBD)	*"when we draw ionic bonding, electrons should be shared and atoms will have eight electrons in outershell"*	The learners' knowledge of representing covalent bonding diagrammatically, including using all chemical symbols and signs correctly
Covalent bond types (CBT)	*"there are three types of bonding. covalent bond, ionic bond and metallic bond but we are not taught metallic bond. The teacher said it will be taught in grade 10 and 11"*	The learners' ability to classify a certain covalent bond as single, double, or triple by referring to the number of the shared pairs of electrons

Physical properties of compounds (PPC)	*"covalent substances do not soluble in water like fat"; "covalent compounds are not conduct electricity"; "covalent have low melting and boiling points"*	The learners' ability to state or list the physical properties of either ionic or covalent compounds by referring to the kinetic particle theory of matter
Bond strength (BS)	*"the bond in salt is strong because you cannot cut salt with a nice… I heard salt is ionic bonding and I did not forget it"*	The learners' ability to describe the bond strength in either covalent or ionic compounds as strong or weak by referring to charges between atoms in the compound
Ionic bond drawing (IBD)	*"in ionic bonding, electrons are transferred from metals to the non-metals to become full in the outershell"*	The learners' knowledge of representing ionic bonding diagrammatically, including using all symbols and signs correctly
Electron transfer (ET)	*"why non-metals are not give away electrons?"; "I don't know which atoms should give away electrons"; I think electrons must be shared between metals and non-metals"*	The learners' knowledge of electron transfer from metal atoms to non-metal atoms
Ions (IN)	*"sodium is giving electron to fluorine and become positive"; "lithium is a cation while fluorine is anion"*	The learners' knowledge of which atom becomes a positive or a negative ion following ionic bonding; of classifying ions as cations or anions; and of determining the charges the ions form
Electrical conductivity (EC)	*"Ionic materials conduct electricity and also they are hot easy but no for covalent bonding"*	The learners' knowledge of explaining the electrical conductivity in covalent and ionic

		compounds by referring to electrical charge or neutrality of atoms in a compound
Chemical formulae (CF)	*"the formula for aluminium oxide has many atoms, and we cannot even remember when our teacher wants us to deduce it from name"*	The learners' knowledge of deducing formulae of compounds by balancing the charges on ions in the molecule of a compound

The data in Table 14 were used as focus for the intervention (employing a visual-verbal intersemiotic complementarity teaching approach). The first step in this process was identifying particular concepts and processes of chemical bonding that require the coordinated use of the visual and verbal semiotic modes. Further, the themes in Table 14 were analysed in terms of the representational levels of chemical bonding knowledge to which they belong. These representational levels are macroscopic, sub-microscopic, and symbolic (as discussed in detail in Chapter 2). In this study, the idea of classifying knowledge of chemical bonding, a chemical knowledge, into representational levels in terms of the learning challenges they pose was informed by Johnstone (1982). The most challenging representational levels of chemical bonding are the sub-microscopic and symbolic, as the knowledge they concern is unobservable, complex, and abstract compared to the macroscopic level, which is least challenging due to it being observable, simple, and concrete.

I first arranged the results obtained from the learners' reflective journals into two groups: results on covalent bonds (collected after Lessons 1 and 2 of Cycle 1) and results on ionic bonds (collected after Lessons 3 and 4 of Cycle 1). Both sets of results sufficiently contributed to the planning and implementation of the intervention undertaken during Cycle 2 of this action research. Moreover, the results on how learners understood an atomic structure and its relationship to the periodic table were also analysed for planning purposes, as learners understanding these was a pre-requisite to them effectively learning both covalent and ionic bonding.

(a) Results on sense-making of covalent bonding (from Lessons 1 and 2 reflective journals)

The excerpts of learner talk and the knowledge themes of covalent bonding generated from analysing results obtained from the learners' reflective journals were classified as either gained knowledge (GK) or challenging knowledge (CK), based on how learners described them. Moreover, this chemical knowledge was classified as represented macroscopically, sub-microscopically, or symbolically; by considering the nature of learning it.

(1) Gained knowledge of covalent bonding (GK)

I found that not all knowledge aspects of covalent bonding were problematic to learners during Lessons 1 and 2 – the lessons without intersemiotic complementarity. This was indicated in many learners' reflective journals. Twenty learners stated that they had no problem using the periodic table, while twenty-seven indicated that they fully understood an atomic structure. In this study, knowledge of using the periodic table was categorised as classification (Cl), while knowledge concerning an atomic structure was classified as electronic arrangement (EA). This means that many learners could distinguish between metal and non-metal elements, being guided by the zigzag line separating them. Many of these learners could use the Bohr model to correctly illustrate atoms of the first 20 elements in the periodic table. This revealed that they knew the details about an atom, such as electron arrangement in the different shells.

Both clarification and electron arrangement are basic concepts of matter, and hence pre-requisites to understanding chemical bonding, and other chemistry topics. The classification of elements in the periodic table is symbolic, as it involves numbers and symbols, as Johnstone (1982) explains. For a learner to understand the periodic table he/she should have knowledge of the meaning of the group and period numbers, and the atomic and mass numbers. A learner also needs to know the symbols of the first 20 elements, because elements are represented by chemical symbols in the periodic table. Even though the learners who indicated they understood the periodic table did not provide details, they might have understood the role played by knowledge of the group and period numbers, and the atomic and mass numbers, in illustrating the Bohr structures of atoms. An electron arrangement is represented sub-microscopically, as the shells and electrons it concerns are not observable by learners. This knowledge was not a strong focal point in the intervention, but it was not ignored, as failure to access it could inhibit learners' effective sense-making of chemical bonding.

Few learners indicated that they understood chemical bonding (CB). This was first seen in nine learners explaining that *"atoms bond to have full outer shells"*, and that *"atoms with full* *outer shells do not form bonds"*. Some of them used helium as an example to explain that some atoms do not bond due to their full outer shells. Secondly, I noticed that ten learners indicated that valence electrons are those in the outer shells of atoms. However, they could not explain how this knowledge is applied when calculating the valency (V) of an element. Valency refers to the combining power of an element. This means the capacity of an atom to lose, gain, or share electrons in an outer shell. Learners' lack of this knowledge revealed that their knowledge of valency (V) was limited, may have impacted negatively on their sense-making of chemical bonding, and thus needed consideration in the intervention cycle. Thirdly, one of the sixteen related learners' responses reads *"during covalent bonding electrons are shared in pairs between non-metal…"*. This indicates that their knowledge of electron sharing (ES) was adequate as per the expectation of the Namibian Physical Science syllabus (Namibia. MoEAC, 2015). However, since only sixteen learners made reference to electron sharing when explaining covalent bonding, the implication was that an intervention needed to consider this knowledge theme as well.

Learners also indicated that they had knowledge of covalent bond types (CBT), and physical properties of compounds (PPC), as described in Table 14. The representational level of CBT is sub-microscopic, as the atoms and the electrons it concerns are not observable. The level of representation of PPC is macroscopic, since physical properties of compounds are observable. I noted that ten learners indicated in their reflective journals that a covalent bond can be classified as single, double, or triple, depending on the number of electron pairs that two atoms share. This revealed that they had knowledge of the three types of covalent bonds, since they could list them all, though they did not explain in detail or give examples of molecules with single bonds. Fifteen learners demonstrated a good understanding of the physical properties of compounds. This could be due to them being able to observe these properties, as Johnstone (1991) suggests. Many of these learners mentioned that most covalent substances are insoluble in water, possibly because many useful materials in their environment are products of covalent bonding, and they experience that these materials do not dissolve in water. Learner J mentioned a plastic bottle as a covalent substance (material) that does not dissolve in water, even though he could not mention the non-metals that make up a plastic bottle.

(2) Challenging knowledge of covalent bonding (CK)

The knowledge of covalent bonding that this study describes as challenging was also elicited from the learners' reflective journals. In this study, the term 'challenging' has been adapted from its daily use to describe the knowledge of chemical bonding that learners do not understand, or that they struggle to make sense of. The themes that emerged as challenging, based on the learners' description of their knowledge of chemical bonding, were further categorised into two groups: knowledge of the periodic table and atomic model, and knowledge of covalent bonding. Table 15 shows the knowledge themes included in each of these two groups.

Table 15. Themes and groups of covalent bond knowledge from Cycle 1 learners' reflective journals

Themes	Group
Classification (C)	Periodic table and atomic model knowledge
Bohr diagrams (BD)	
Chemical properties (CP)	
Valency (V)	
Bond differentiation (BD)	Covalent bond knowledge
Covalent bond drawing (CBD)	
Covalent bond type (CBT)	
Electron sharing (ES)	
Bond strength (BS)	

The themes in the first group (periodic table and atomic model knowledge) are considered to be pre-requisites of understanding the second group (covalent bonding knowledge) in this study. This grouping of chemical bonding knowledge was done to report analysis of the findings to the readers easily and in a comprehensible way.

(2.1) Periodic table and atomic model knowledge

I discovered from the learners' reflective journals that, for several learners, knowledge of using the periodic table in relation to the atomic model was insufficiently gained during Lessons 1 and 2 of Cycle 1 in this action research. This revealed a learning difficulty of chemical bonding, as the periodic table is regarded as a source of information required for efficient learning of chemistry (Gilbert & Treagust, 2009). Two learners indicated that they had a problem with classification (C). This suggests that they did not know the difference between groups and periods of the periodic table – even though this topic was the first to be taught in Grade 8. It is possible that this problem might have hindered their ability to understand an atomic model – the knowledge that precedes learning of chemical bonding. The challenge of the atomic model was also revealed by two learners who stated that they did not know how to draw the Bohr diagrams of atoms. This learning challenge demanded the intervention to also consider learners' knowledge of the periodic table, as learners would not understand chemical bonding without being able to sufficiently access knowledge of the periodic table.

An excerpt from Learner C's reflective journal reads *"I don't understand chemical properties"*, while eight others indicated that they do not understand what valency means. Gilbert and Treagust (2009) highlight that an atomic structure has links with the chemical properties of elements in the periodic table. They elaborate that complete knowledge of an atomic structure includes an ability to determine the valency of an atom of an element, and subsequently, its chemical properties, such as the reactivity. Drawing from this idea, the reason behind learners not understanding chemical properties of elements is linked to their lack of understanding of atomic structure and valencies. According to Johnstone (1982), the knowledge of both chemical properties and valencies of elements is represented sub-microscopically, as these phenomena are real, but invisible.

(2.2) Covalent bonding knowledge

According to Gilbert and Treagust (2009), the covalent bonding model is knowledge required for learners to understand chemical bonding. However, based on the learners' responses to journal questions during Cycle 1, it was evident that learners have gained this knowledge insufficiently during the traditional teaching approach to the topic. I gained this information by analysing how they described knowledge of chemical bonding in their reflective journals.

Knowledge themes related to covalent bonding that emerged as problematic to learners are as follows: bond differentiation (BD), electron sharing (ES), and covalent bond drawing (CBD). Firstly, Learner W stated that she had difficulty distinguishing between types of chemical bonding. Secondly, eight other learners reported not understanding the concept of electron sharing. Thirdly, seven learners complained that drawing covalent bonding was very difficult.

Addressing these challenges may require two processes: analysing knowledge themes in terms of their representational levels, and planning ways to incorporate the sense relations of a coordinated visual-verbal intersemiotic complementarity approach when teaching covalent bonding. My analysis revealed that knowledge of chemical bonding included in these knowledge themes is dominantly sub-microscopic, as atoms, their electrons, and their behaviour are real and invisible phenomena of chemical bonding. It was possibly due to the representational nature of this knowledge, as Johnstone (1991) suggests, that many learners struggled to make sense of it. Gilbert, Boulter, and Elmer (2000) suggest that addressing the challenge of learning about microscopic entities may be undertaken by using coordinated visual-verbal modes of communication. Thus, I resolved to teach knowledge of chemical bonding under these problematic themes via these two modes combined in order to explore their influences on learners' sense-making of the topic.

Other problematic themes of covalent bonding knowledge that I identified from the learners' reflective journals were covalent bond types (CBT) and bond strength (BS). Five learners indicated a problem with identifying the type of covalent bond formed when two atoms bond. I noticed this as some learners lacked understanding of the meaning of scientific concepts such as single, double, and triple bonds – the terms that reveal the number of electrons shared between any two atoms bonded covalently. Four learners indicated that the bond strength concept confuses them. In essence, they lacked understanding of what determines bond strength. This revealed that they were not aware of attractive forces that exist between the positive sub-atomic particles (protons) and the negative sub-atomic particles (electrons) of atoms that bond together in a molecule.

My analysis revealed that the level of representation of these two chemical phenomena (CBT and BS) is sub-microscopic, as explaining them makes use of the electron sharing concept, and the theory of proton-electron attraction. Protons, electrons, and their behaviour (movement, attraction, and repulsion) are real but invisible (microscopic) phenomena of chemical bonding. The idea of representing knowledge of microscopic entities using a coordinated visual-verbal mode, as Gilbert et al. (2000) suggest, might be applicable to knowledge of covalent bonding. Therefore, I drew from SF-MDA to employ the sense relations of visual-verbal intersemiotic complementarity to explore their influences on sense-making of this knowledge in the intervention. These sense relations were similarity, hyponymy, meronymy, antonymy, and collocation. As Gilbert et al. (2000) suggest, I used these sense relations in the form of the verbal mode (in both spoken and written forms) coordinated with the visual mode (in both two-dimensional [diagrams], and in three-dimensional [physical models] forms).

(b) Results on sense-making of ionic bonding (from Lessons' 3 and 4 reflective journals)

The learners' knowledge of ionic bonding was also classified into two groups: gained knowledge (GK), and challenging knowledge (CK). Each knowledge group was subdivided into knowledge themes based on how learners described ionic bonding in their reflective journals. The knowledge included in these themes was analysed in terms of the levels of representation of chemical knowledge. The information gained from this analysis was useful for planning the second cycle of this action research study which was visual-verbal oriented.

(1) Gained knowledge of ionic bond (GK)

I noticed, from the learners' reflective journals, that some learners had no problem understanding certain concepts and processes of ionic bonding. However, I found that there were more learners who did not understand concepts and processes of ionic bonding knowledge than those who understood them. Overall, this means that learners' sense-making of this chemical knowledge was ineffective, and teaching it via a traditional approach was inefficient, as discussed in detail in this subsection.

After I analysed learners' answers to the guiding questions in the reflective journals, three knowledge themes of ionic bonding (as described in Table 14) that were not problematic to some learners emerged. The chemical knowledge included in these themes is sub-microscopic, as it concerns non-observable entities and behaviour. These themes were electron transfer (ET), ionic bond drawing (IBD), and ions (IN). Therefore, how learners described knowledge of ionic bonding in their reflective journals has also contributed to informing the intervention.

In this cycle (Cycle 1), three learners revealed in their reflective journals that they have no problem with electron transfer (ET) – the knowledge that is a pre-requisite to learning ionic bonding. I discerned this information from the following excerpts I extracted from the learners' reflective journals: *"you need to know the rule of outer shells and the atoms that lose or gain electrons to understand ionic bonding"; "metals transfer electrons to non-metals" and "metals transfer some valence electrons".* I classified ET as sub-microscopic, since the electrons involved in this process are real but invisible, making it a challenge for learners to understand them. Atkins (2005) outlines that electron transfer is a core idea in chemical education that learners need to understand. Thus, learners failing to understand the electron transfer concept would have difficulty gaining chemical knowledge in general. The fact that only three learners could say something about electron transfer in their reflective journals suggested the need for it to be considered in an intervention.

Three learners indicated that drawing an ionic bond (IBD) was not a problem to them, though the rest were silent on this. I noticed this from the following excerpts: *"I understand drawing ionic bonds by transferring electrons in the outer shell"; "I know that electrons are transferred from metals to non-metals"* and *"we used arrows which show electrons travel from a metal to a non-metal"*. It was possible that some learners who did not mention anything about IBD did not understand it because they forgot about it or considered it unnecessary. Since many of the learners did not say anything related to IBD, I considered this knowledge type for the intervention in order to find out if there would be any change (decrease/increase) in the number of learners understanding this knowledge. This knowledge is part of chemical knowledge that is taught via the sub-microscopic level of representation – the knowledge that is regarded as challenging. Learners accessing this chemical knowledge allows their micro-macro thinking of ionic bonding to develop (Ben-Zvi, Silberstein, & Mamlok, 1990). Micro-micro thinking refers to when learners are able to link observable phenomena to unobservable phenomena of chemical knowledge (Johnstone, 1993). Through this thinking, learners discover the connection between chemical properties and structures of matter – which allows them to use the sub-microscopic level of representation to explain the macroscopic phenomena.

Excerpts from three learners' reflective journals about ions (IN) read as follows: *"sodium gives electrons to fluorine and becomes positive"; "lithium is a cation while fluorine is an anion";* and *"cations are positive and anions are negative"*. This means that only a few learners understood IN. This knowledge is also sub-microscopic, as the ions involved are microscopic particles of matter.

I discovered that learners generally have no problem with macroscopic knowledge of ionic bonding. I deduced this from excerpts drawn from their reflective journals. Six learners indicated that they understood the physical properties of ionic compounds. This knowledge of chemical bonding is macroscopic, as the properties of ionic compounds, such as electrical conductivity, solubility in water, and the state at room temperature, are observable. Some excerpts drawn from the learners' reflective journals were *"ionic compounds can dissolve in water, such as table salt"*, and *"ionic substances have strong bonds".* These attested that some learners understood this chemical knowledge, as these excerpts regarding ionic compounds are correct. However, it is possible that these learners had limited knowledge of the properties of ionic compounds, as none of them could explain it by referring to the kinetic particle theory of matter which concerns ionic substances dissociating into ions when dissolved and oppositely charged ions attracting each other.

In summary, I attest that some knowledge aspects of ionic bonding were known by Grade 9 Namibian learners after a traditional teaching approach; however, much of this knowledge is macroscopic, due to its observable nature. Unfortunately, the macroscopic knowledge of ionic bonding that the Physical Science syllabus (Namibia. MoEAC, 2015) recommends for teaching is far less than the sub-microscopic and symbolic knowledge. I therefore conclude that learners did not gain sufficient knowledge of ionic bonding from a traditional teaching approach. Therefore, using verbal explanations together with visual explanations, as suggested by Treagust, Harrison, and Venville (1998), to explore their influences on the learners' sense-making of ionic bonding, was warranted in this study. The knowledge themes of ionic bonding that needed consideration due to insufficient learning included ET, IBD, and IN, as they concern knowledge of unobservable particles and processes.

(2) Challenging knowledge of ionic bonds (CK)

With the exception of a few learners describing ionic bond knowledge as not problematic, I found that most learners experienced challenges with this knowledge. Many of the knowledge themes on the topic emerged as problematic to learners. In this study, these knowledge themes were further categorised into two groups: fundamental knowledge and detailed knowledge of ionic bonds. The fundamental knowledge introduces ionic bonding to learners, and it comprises knowledge themes such as classification (C), electron transfer (ET), and valency (V). The detailed knowledge of ionic bonding focuses on specific knowledge aspects of ionic bonding, and includes knowledge themes such as ionic bonding drawing (IBD), ions (IN), electrical conductivity (EC), and bond strength (BS). The learners' description of the knowledge of ionic bonding is now discussed based on these emergent themes and their categories.

(2.1) Fundamental knowledge of ionic bonding

Learner E revealed that he has a problem with classification (C). An excerpt from his reflective journal reads: *"I don't know the groups and periods needed to draw ionic bonds"*. I discerned that this learner, and possibly others, did not know the role played by periods and groups in the periodic table in determining the bond type. Moreover, five learners indicated that they had difficulty with the transfer of electrons (ET). Some of their excerpts include *"why do non-metals not give away electrons?"*; *"I don't know which atoms should give away electrons"*; and *"I think electrons must be shared between metals and non-metals"*. These proved that the learners' chemical knowledge related to ET, and subsequently the knowledge that ET leads to, was insufficiently gained during traditional teaching of ionic bonding.

Further chemical knowledge that was viewed as fundamental to sufficiently attaining knowledge of ionic bonding was valency (V). Valency is an abstract concept in the chemistry language that has impeded learning of school-level chemistry for decades (Gilbert & Treagust, 2009). Gilbert and Treagust (2009) claim that knowledge of valency is vital for explaining mutual attraction between the bonding electrons and the atomic core (nucleus), as well as the role it plays in deducing chemical formulae of ionic compounds. However, I noticed that learners lacked understanding of the concept of valency after analysing eight learners' reflective journals. Learner Y wrote: *"valency electrons confuse me when teacher explains"*. Other learners also made it clear that the concept 'valency' does not make sense to them. Learner F requested that the teacher tell him where the valencies are found in an atom, as he is only aware of electrons, protons, and neutrons in Bohr structures, not valencies. This shows that the learners did not successfully gain the fundamental knowledge of ionic bonding.

(2.2) Detailed knowledge of ionic bonding

The themes of this knowledge category that emerged as challenging, from analysing the learners' reflective journals, include ionic bond drawing (IBD), ions (IN), electrical conductivity (EC), and bond strength (BS). These knowledge themes were analysed to access learners' sense-making of knowledge of ionic bonding in detail. Many learners indicated that they had difficulty gaining knowledge of ionic bonds included in these themes.

Three learners revealed that they could not correctly represent ionic bonding diagrammatically. This indicates that chemical knowledge related to drawing ionic bonds (IBD) was not sufficiently gained by these learners, and possibly by other learners in the class. Moreover, learners faced challenges when accessing knowledge of ions (IN). I realised this from five learners who stated that they do not know exactly what the word 'ion' means. Some of these learners wrongly spelled the word as 'iron'. Though this could just be a spelling problem, it is also possible that these learners could not differentiate between the word 'ion' (an atom that has lost or gained electron(s)), and the word 'iron' (a transition metal element in the periodic table). These findings confirmed the view that students often display a limited understanding of chemical processes due to their abstractness, as suggested by Chandrasegaran, Treagust, and Mocerino (2007). Moreover, the problem of learners using words interchangeably was earlier identified by Treagust and Chittleborough (2001). They highlight that learners often follow their own views when learning chemical knowledge. Therefore, I viewed the problem of learners having difficulty accessing IBD and IN as serious, and requiring a well-thought out intervention.

Another knowledge theme of ionic bonding that I identified as challenging was electrical conductivity (EC) of ionic compounds. Electrical conductivity concerns the ability of a material to allow charges to pass through them. For example, dissolved or molten salts have good electrical conductivity. An excerpt showing this problem was extracted from Learner A's reflective journal. It reads: *"why do ionic substances pass electricity while covalent substances do not pass electricity?"* This excerpt indicates that the learner wanted an explanation of how electrical conductivity occurs in substances. According to the Physical Science syllabus, electrical conductivity is only possible in ionic substances when dissolved or molten (Namibia. MoEAC, 2015). This conductivity is enabled by oppositely charged ions that are scattered in a solvent such as water (Namibia. MoEAC, 2015). Learners are supposed to gain this knowledge, as it helps them to understand electrical conductivity of ionic substances. This knowledge is sub-microscopic, as ions causing this phenomenon are too small to be seen with the naked eye.

I found that the knowledge of ionic bonding categorised as bond strength (BS) was also challenging to learners. According to Gilbert and Treagust (2009), bond strength is dependent on the mutual attraction between the valency electrons and the cores of atoms in a molecule. The Namibian JS Physical Science syllabus describes BS as determined by an attraction between the positive protons in a cation and the negative electrons in an anion. The opposite net electrical charges of ions in ionic compounds result in their strong attraction, and this subsequently holds them together firmly, forming a strong bond between them. Unfortunately, these learners could not provide this explanation in their reflective journals.

Two learners asked questions related to it: firstly, *"why do ions attract?"*, and secondly, *"why are ionic compounds strong?"*.

The knowledge of deducing chemical formulae (CF) of ionic compounds was identified as challenging to the learners during this cycle. The remarks made by eight learners about chemical formulae of ionic compounds revealed this learning difficulty. Some learners' excerpts that stimulated a need to consider CF in an intervention included *"I do not understand how to use formulas of compounds"*, and "*I don't know how to find charges needed to deduce a formula of a compound"*. These excerpts revealing that learners have difficulty making sense of CF confirmed the findings of Chandrasegaran, Treagust, and Mocerino (2007) on formulae writing. The findings include students having a tendency to memorise chemical formulae of compounds as they appear in chemistry textbooks, without linking their formation to the numerical upper scripts (charges) on the chemical formulae or symbols of ions. Chemical formulae of compounds and numerical upper scripts of their ions are symbolic, as they contain chemical symbols of elements, numbers indicating the number of atoms/ions, and the positive (+) or negative (-) signs indicating the number of electrons lost or gained by an ion.

(c) Aggregate results on learners' knowledge of chemical bonding (accessed from the reflective journals)

As discussed earlier in this sub-section, the results collected include gained and challenging knowledge of chemical bonding types. The analysis of this knowledge in terms of its representational levels confirmed the findings of other scholars (Gabel, 1998; Tan & Treagust, 1999) that learners hardly make sense of chemical knowledge, especially that which is sub-microscopic and symbolic. This conclusion was reached by analysing the teacher's and learners' reflective journals to elicit the learners' sense-making of chemical bonding knowledge.

Overall, it was confirmed that many of the learners found gaining knowledge of chemical bonding challenging. Some of them clearly mentioned in their reflective journals that they did not understand certain concepts and processes of chemical bonding. Many excerpts from the learners' reflective journals indicated that knowledge of chemical bonding that was more problematic to learners was mainly sub-microscopic, which was also identified by journaling by the teacher. It was also discovered that learners had difficulty understanding symbolic knowledge of chemical bonding. Very few cases where learners had difficulty understanding the macroscopic knowledge of this topic were identified. I therefore realised that learners easily grasp knowledge of chemical bonding that is macroscopic, as it concerns observable objects and processes of matter.

The reliability of these data was confirmed by the insights of Gay, Mills, and Airasian (2009), and Audet, Hickman, and Dobrynina (1996). Firstly, the results from the reflective journals unveil the learners' general classroom experience (Gay, Mills & Airasian, 2009). In this study, learners expressing how they understood chemical bonding during teaching of traditional lessons revealed their classroom learning experience to the teacher-researcher. Secondly, learners' reflective journals provided evidence of sense-making of science topics (Audet, Hickman & Dobrynina, 1996). How learners attempted to explain certain chemical bonding concepts, and how they critiqued the lesson presentation, revealed that they had a problem making sense of the topic. Therefore, this method of collecting data contributed abundantly to ascertaining the learners' sense-making of chemical bonding after a traditional approach to the topic was employed. I used this information for designing and employing the second cycle of this action research study.

5.3.3 Findings and results of the pre-test

Following a series of four prototype lessons taught in Cycle 1, a pre-test was undertaken prior to beginning Cycle 2 of this action research study in order to ascertain the Grade 9 learners' knowledge of chemical bonding. Being aware of the Grade 9 learners' knowledge of chemical bonding was a guide to designing the intervention undertaken in Cycle 2. The results of this pre-test were later compared with those of the post-test (undertaken at the end of Cycle 2) in order to ascertain the influences of a visual-verbal intersemiotic complementarity teaching approach on the topic. In this subsection, I present the data under two headings: (a) learners' responses to the pre-test questions, and (b) the pre-test results.

5.3.3.1 Findings: learners' responses to the pre-test questions

The learners' responses to the pre-test questions (Appendix S) are discussed in relation to how learners were expected to answer them. In this sub-section, the learners' answers are discussed following the questioning order used in the pre-test. Numerical data describing how a number of learners attempted each question were used as additional information revealing learners' sense-making of the topic.

(a) Question 1 (The relationship between the atomic structure and the periodic table)

This question tested the learners' ability to identify the group and the period number of an atom of an unidentified element by analysing its Bohr diagram. This element was sulphur. Two marks were allocated to this question. Though this question did not test any of the specific objectives on the topic of chemical bonding in the Physical Science syllabus, it was asked because an atomic structure, and its relationship to the periodic table, were described by Gilbert and Treagust (2009) as an introduction to other basic chemistry concepts, such as bonding of elements and molecular/ionic structures of compounds – the topics under focus in this study.

From a total of thirty-eight learners, sixteen could not identify either the group or period number of an element from the Bohr structure drawn. The information that this Bohr structure was for a sulphur atom was not provided, in order to test if they could identify its group and period number by looking at its number of shells the and number of electrons in the outer shell. I noticed that many of them had an incorrect perception of this relationship. Some interpreted a group number as equal to the number of shells, and a period number as equal to the number of electrons located in the outer shell. Many answered that this atom belongs to an element in group three and in period six. Others answered that the group number of this atom is sixteen. These answers were all incorrect and revealed that these learners had little fundamental knowledge of chemistry, which could be the factor negatively impacting their sense-making of chemical bonding.

(b) Question 2 (The relationship between atoms and molecules and bonding processes)

I asked this question to test the learners' knowledge of an atom-molecule relationship and the activities taking place during the bonding processes. Four marks were allocated to this question. I realised that many learners did not score all the marks for this question, although I considered it not to be challenging.

Question 2(a), 2(b), and 2(c) tested the learners' ability to distinguish between atoms and molecules. These questions were challenging, as thirty-three learners did not score all the marks allocated for them. Many of them incorrectly referred to a single circle as a molecule and a group of circles joined as an atom. The correct explanation would have been that a single circle represents an atom and a group of circles jointed together represents a molecule.

Question 2(d) tested the learners' knowledge of concepts used in covalent bonding as opposed to ionic bonding. There were four words (atom, molecule, share, and transfer) given for the learners to identify the one that correctly described a covalent bond in a hydrogen oxide (water) molecule. They were expected to choose the concept 'share' to describe the overlapped outer shells with electrons contained between them. However, instead of doing this, fifteen of them chose the concept 'transfer' – a concept that is only applicable to ionic bonding. A few learners misunderstood this question, as they gave concepts that were not on the list. Some of these words were hydrogen oxide, outer shell electrons, and oxygen. Other learners did not attempt to answer this question. I therefore found that the learners' low proficiency in English – a Language of Learning and Teaching (LoLT) in Namibian schools – contributed to the problem. Hence, I resolved that addressing this problem may be possible if teaching of chemical bonding is done via the visual mode integrated with the verbal mode for the meaning to be clearer to learners.

(c) Question 3 (Bond type identification)

The learners were provided with a skeletal Bohr structure of a chlorine molecule (Cl_2) for them to identify the type of chemical bonding it showed. This structure had visible overlapped shells, which collocate with the lexical item 'covalent bond'; the answer to this question. Four marks were allocated to this question; however, only five learners earned full marks. Many of them who correctly identified the bond as covalent could not explain their answer correctly. I discovered that they guessed, since they had only learned two types of chemical bonding: covalent and ionic. Nine of them incorrectly reasoned that the protons shared by the two atoms indicate a covalent bond. This showed that they were aware that the concept 'share' is applicable to covalent bonding, though they confused protons with electrons.

The second question (Question 3(b)) asked learners to state the side of the zigzag line in a periodic table where this element is located. Fifteen of them answered that it is located on the right side of the periodic table – which is correct. Seven learners were more correct, as they also reasoned that the sharing of electrons only happens between atoms of non-metal elements, which are located on the right side of the periodic table. This showed that more than half of the learners in the class had knowledge of the periodic table following a traditional teaching to chemical bonding. However, some of those who correctly identified the element as located on the right of the zigzag line could neither support their choice nor give explanations that were relevant to the question. It is possible that they guessed and were fortunate that the answer they gave was correct.

(d) Question 4 (Determining the charge of ions)

I set this question to test the learners' knowledge of charges formed when atoms lose or gain electrons. I allocated three marks to this question. In Question 4(a), a simple Bohr structure of a magnesium atom with two electrons in the outer shell was provided to the learners. They were subsequently asked to identify the charges formed when this atom becomes an ion. Unfortunately, only seven learners scored full marks on this question. Among the remaining thirty-one learners, only eight correctly identified the charge as positive or wrote a magnesium ion as Mg^{+2}. Moreover, many of them failed to support their answers. Other learners gave answers that were completely incorrect, while still others did not attempt to answer the question. Therefore I noticed that knowledge of chemical bonding related to charges was not sufficiently accessed by learners, and thus required consideration in the intervention cycle.

In Question 4(b), I tested the learners' knowledge of the metallic nature of a magnesium atom – they had to decide whether magnesium was a metal or a non-metal element. Sixteen of thirty-one learners managed to correctly classify a magnesium atom as a metal. Many of the remaining learners classified it as a non-metal, while very few learners identified it as a metalloid – both of which are incorrect. Hence, this demonstrated that learners did not master knowledge of using the periodic table, which includes classifying elements as either metals or non-metals.

(e) Question 5 (Ionic bond and its bond strength)

This question was set to explore the learners' knowledge of ionic bonding. This knowledge was represented via the visual mode in the form of a bond diagram of sodium fluoride. Two marks were allocated to this question. Twenty-eight learners did not score full marks for this question, revealing that their sense-making of ionic bond knowledge was inadequate.

Question 5(a) required learners to identify a feature on the diagram that showed that the bond in sodium fluoride is ionic. Though there were many features on this diagram revealing that the bond is ionic, the most identifiable one was an arrow pointing from a sodium atom to a fluorine atom. This arrow is similar to the lexical item 'transfer', which is only applicable to ionic bonding. Many learners gave incorrect answers to this question. Some of these include one proton transferred, sodium fluoride, compound, and covalent bonding. A few learners did not attempt to answer this question. I realised that many of these answers were incorrect due to using the word ‘feature’, which some learners did not know. This resulted in them giving answers that were not related or relevant to the question.

Question 5(b) tested learners’ knowledge of bond strength in ionic compounds. Learners who scored full marks explained that opposite charges between sodium and fluorine ions create an electrostatic attractive force, which results in a strong bond formation. However, many learners gave wrong answers, such as ‘transferred electrons’ and ‘atom losing protons’. These answers are incorrect, as the transfer of electrons does not directly explain bond strength, even though they have a causal relationship. This relationship involves electrons being transferred from an atom of a metallic element to that of a non-metallic element; changing it from being a neutral atom to a positively charged ion due to it having more protons, which are positively charged, than electrons, which are negatively charged. Some learners did not attempt to answer this question. The two arrows on the bond diagram, one showing a transferred electron and one showing an electrostatic attraction between the two ions, did not make sense to them. Possibly, the word ‘transfer’ should have been written alongside a one-way arrow to further indicate that an electron is transferred from a sodium atom to a chlorine atom – a feature that indicates ionic bonding. This suggested for this intervention that caption is another form of visual and verbal modes combined that would be helpful in addressing this learning difficulty.

(f) Question 6 (Ions, names, and formulae formed in ionic bonding)

I formulated this question to test the learners’ sense-making of chemical knowledge related to ions, and names and formulae of ionic compounds. It included a diagram of a sodium atom transferring one electron to a chlorine atom. I allocated four marks to this, and found that twenty-seven learners failed to score full marks.

Even though it was explained that cations are atoms that have lost electrons while anions are atoms that have gained electrons, nineteen learners could not correctly state the type of ion formed by a sodium atom when it loses one valence electron. Nineteen learners correctly mentioned that sodium atoms form cations, but they did not support their answers. This showed that they guessed this answer. However, when asked to write down the name of a compound formed from the reaction between sodium and chlorine, thirty learners wrote *'sodium chloride'* – which is a correct answer. This shows that most learners have no problem deducing names of compounds from the given names of the reactants. However, I found that twenty-six learners had difficulty writing correct formulae of ionic compounds formed when elements react. Some of the incorrect formulae of sodium chloride written by these learners include $NaCl_2$, H_2O, Na_2Cl_2, Na_2Cl, and Na. The correct formula for this compound is NaCl. This is because the net electrical charge of ions in this compound is 0.

(g) Question 7 (Distinguishing between covalent and ionic bonding)

This question had two Bohr diagrams, one for a covalent bond in hydrogen chloride, and another for an ionic bond in sodium oxide. Question 7 (a) explored learners' abilities to distinguish between the bond types, with reference to outer shell electrons and bond strength. Four marks were allocated to this question, and twenty-one learners scored full marks. Twenty-two learners correctly stated that electrons in hydrogen chloride are shared, while in sodium oxide they are transferred. On bond strength, thirty-two learners correctly described the bond in hydrogen chloride as weak, and in sodium oxide as strong. However, when asked to complete the bond diagram in sodium oxide, fifteen learners failed to do so correctly. Even though more learners distinguished between covalent and ionic bonding correctly, the fact that they struggled to correctly illustrate the bond in sodium oxide means that their chemical knowledge was inadequate.

5.3.3.2 The learners' pre-test marks

The learners' pre-test results are recorded in Table 16 to show the marks scored by each learner. Knowledge of their scores in the pre-test contributed to the researcher's awareness of their sense-making of chemical bonding after employing a traditional teaching approach. In order to maintain the participants' anonymity in this study, I used letter codes (L1, L2, L3…) instead of learners' real names. For the purpose of making analysis easy, I calculated the learners' performance in percentages (%) and recorded them in this table. I also provided the learners' highest score, lowest score, and mean score, in order to ascertain the average knowledge that the Grade 9 learners had on the topic after a traditional teaching approach.

Table 16. Pre-test results

Learner	Marks scored (Total marks: 25)	Percentage (%)

L1	20	80
L2	19	76
L3	19	76
L4	18	72
L5	18	72
L6	17	68
L7	17	68
L8	16	64
L9	16	64
L10	15	60
L11	15	60
L12	15	60
L13	15	60
L14	15	60
L15	14	56
L16	13	52
L17	13	52
L18	13	52
L19	12	48
L20	12	48
L21	12	48
L22	12	48
L23	11	44
L24	11	44
L25	11	44
L26	10	40
L27	9	36
L28	9	36
L29	9	36
L30	8	32
L31	7	28
L32	7	28

L33	5	20
L34	5	20
L35	2	8
L36	2	8
L37	2	8
L38	2	8
Highest score	**20**	**80**
Lowest score	**2**	**8**
Mean score	**12**	**48**
Total score	**466**	

As shown in Table 16, the three measures of central tendency (highest score, lowest score, and mean score) revealed that the learners' performance in the topic of chemical bonding was low. Despite a splendid performance of 80% by L1, the data indicate that L35, L36, L37, and L38 performed poorly, as their performance was below 10%. The percentage mean score of 10% also revealed that many learners had difficulty answering questions on chemical bonding. This poor performance in the pre-test concurred with the sense-making evidence collected by other methods that the Grade 9 learners at this school had limited knowledge of chemical bonding. This informed undertaking a teaching intervention on this topic. The result of carrying out a teaching intervention on this topic is reported on in the next section (Section 5.4).

5.4 Intersemiotic complementarity: Influences of coordinated visual-verbal semiotic modes on learners' sense-making of chemical bonding (Cycle 2)

The influences of the coordinated use of the visual and verbal modes of an intersemiotic complementarity teaching approach were explored in this study during Cycle 2, as referenced in earlier chapters (Chapters 1 and 2). Research exploring the visual-verbal demands of the curriculum on chemical bonding, and the learners' knowledge of the topic following the traditional teaching approach, was undertaken prior to conducting this intervention, and it has significantly informed it.

The research revealed three problematic knowledge aspects related to Grade 9 learners' learning of chemical bonding. First, learners had very limited knowledge of chemical bonding after a traditional teaching approach. Much of the knowledge they possessed after this approach was related to general chemical bonding, as it is mainly macroscopic, due to it concerning observable chemical phenomena. Second, the semiotic mode mostly used in a traditional teaching approach is the verbal semiotic mode. The problem with using this semiotic mode was that it did not sufficiently resolve Grade 9 learners' difficulty with the sense-making of chemical bonding knowledge. This learning difficulty was made worse by the use of English, which is currently the Language of Learning and Teaching (LoLT) in Namibia, but which many Namibian learners are not fluent in. The challenge with the LoLT in Namibia was also identified in teachers after a nationwide English Language Proficiency test (ELP) was written (Kisting, 2011). This means that using the verbal mode alone for teaching chemical bonding would not eliminate this learning challenge. A visual semiotic mode was then coordinated with a verbal semiotic mode to explore the influences this would have on learners' sense-making of the topic in the wake of this. Third, the visual semiotic mode was rarely used for explaining chemical bonding to learners, except in cases where drawing a bond diagram is directly stated in the syllabus.

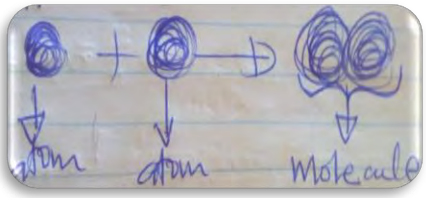
In this cycle (Cycle 2), the coordinated use of visual and verbal modes was achieved via using diagrams and physical models as visual items together with the spoken/written words as lexical items. Written words were used in cases where using spoken words was impossible, such as preparing learners' notes on chemical bonding. This coordinated use was achieved by using the ideational sense relations of visual-verbal intersemiotic complementarity in teaching the topic of chemical bonding to Grade 9 learners in four lessons. In order to explore the influences of this teaching approach on learners' sense-making of chemical bonding, I analysed the sense-making types involved when learners make sense of this topic. I collected these data via structured lesson observations, the teacher's and learners' reflective journals, and the post-test. The learners' marks in the pre-test and post-test were also compared to explore the influences of this intervention on learners' sense-making of the topic through analysing the difference in the performance.

5.4.1 Findings from structured lesson observations

I undertook structured lesson observation in this cycle (Cycle 2) to gauge sense-making of chemical bonding by Grade 9 learners, as I did in the first cycle (Cycle1). I did this in order to determine how learners' sense-making of the topic in Cycle 1 and Cycle 2 differs. The same sense-making types, their codes, and definitions that were used in Cycle 1 were still applied in Cycle 2. This was done in order to make a fair comparison of sense-making of the topic between these two cycles. The excerpts of how learners made sense of chemical bonding knowledge during an intersemiotic complementarity teaching approach are shown in Table 17. The codes were still used to provide detailed descriptions of the learners' excerpts.

Table 17. Sense-making evidence observed during the traditional (benchmark) lessons

Sense-making evidence	Code	Definition	Excerpts/drawings indicating learners' chemical bond knowledge and their representational levels (M, SM, or S)	Descriptive code(s)
Perceptual sense-making (least aligned to scientific facts and rules)	P	This is how talk and visuals are used by learners to identify, count, and describe concrete chemical bonding processes or objects observed.	*"compounds are formed if elements combine together"* **(M)**	E
			"covalent bond is between non-metals and ionic bond is between metals and non-metals" **(M)**	E
			"elements that we find in group 8 do not bond" **(M)**	E
			*"Helium does not bond because it is in group 8"***(M)**	E
			*"ionic compounds have high melting and boiling points means they do not melt and boil well if you heat them"***(M)**	
Chemical bonding sense-making	CBF	This is when students make talk and visuals about abstract chemical bonding processes and objects.	*"before atoms bond they are called atoms but after they bond together we say they are a molecule"* **(SM)** *"such as this one:*	E & Sm



"diatomic molecules are made from the same atom that are two" **(SM)** E & Sm

"e.g. if two atoms of oxygen bond together, they form a molecule called a diatomic molecule. Like this one…

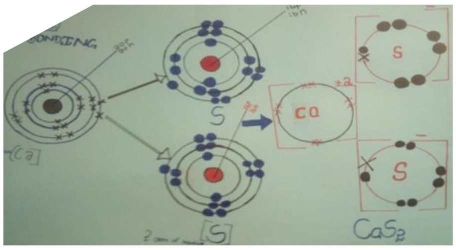
" **(SM)**

"bonding is when atoms of elements that have incomplete outer shells bind to have full outer shells" **(SM)** E

"valency electrons are the electrons in the outer shell that are take part in the bond" **(SM)** E

"cations are atoms that lost electrons while anions are atoms that gained electrons" **(SM)** E

Connecting and analysing sense-making	CA	These involve talk and visuals used by students to make explicit and implicit comparisons and analogies to their prior knowledge or experiences.	*"oxygen can bond because it has only six electrons in the last shell, because it needs two electrons again"*  **(SM)**	E, & Sm
			"elements that are have full outer shells are in group 8 because they all have eight electrons in outer shells" **(SM)**	E
			"Helium cannot bond because it has two electrons in outer shell and it is also found in group 8" **(SM)**	E
Clarification sense-making	Cl	These involve using talk and visuals to clarify how chemical bonding processes work and/or are applied in real life contexts.	*"in bonding atoms lose, gain or share electrons to attain a noble gas electron structure"* **(SM)**	E
			"covalent bonding is when non-metal atoms share electrons to have full outer shells" **(M) & (SM)**	E
			"each atom of oxygen in an oxygen molecule shares two electrons because their valency is -2". This learner referred to his drawing below:  **(SM) & (S)**	E, & Sm

			"the valency electrons are shared in pairs in the shells which are overlapped" **(SM)**	E
			"single bond has one pair, double bond has two pairs and triple bond has three pairs of electrons shared between any two atoms" **(SM)**	E
			"ionic bonding is transferring valency electrons from metal atoms to non-metal atoms" **(SM) & (M)**	E
			"the valency of potassium is +1because it belongs to group 1 because all elements in group 1 have the valency of +1. **(S)**	E
			(a)*"calcium atom has the valency of 2 which means it transfers two electrons to sulphur atoms when they bond as it is shown in this diagram:* (b)  *"* **(SM) & (S)**	(a)- E & (b)- C
			"atom of calcium is now having a full outer shell when it transferred two electrons to sulphur atoms" **(SM)**	
Ideas about nature of chemical bonding sense-making (most	ICB	These are talk and visual debates and discussions about knowledge of	Some learners were debating about this model:	(a)- C & (b)- E

aligned to scientific facts and rules)	chemical bonding.	 Some said (a) *"it is a bond in a water molecule, because there are three atoms",* while others said (b) *"it is a bond in carbon dioxide because there are three atoms with double bonds"* **(M) & (SM)**

Descriptive codes of learners' excerpts of chemical bonding knowledge:

- E – sense-making enabled; C – sense-making constrained; Sm – similarity; A – antonymy; Me – meronymy; H – hyponymy; and Co – collocation

A significant sense-making shift showing an improvement was identified from Cycle 1 to Cycle 2. This shift was realised after comparing excerpts of learners' talk and drawings of chemical bonding phenomena (covalent and ionic bonding). Firstly, many excerpts of learner talk and drawings taken from Cycle 1 lessons revealed chemical knowledge to be constrained, while many of these from Cycle 2 lessons revealed it to be enabled. Secondly, many of the excerpts and diagrams from Cycle 1 lessons were less aligned to scientific sense-making, while many of those from Cycle 2 were more aligned to scientific sense-making. Another evidence of this sense-making shift was noticed in learners engaging in discussions and debates that were more aligned to science during Cycle 2 lessons than during Cycle 1 lessons. Further details regarding this shift, based on the results of my analysing the excerpts of learner talk and diagrams in relation to each sense-making type, will now be presented.

5.4.1.1 Evidence of perceptual sense-making

The fact that perceptual sense-making involves learners identifying, counting, and describing concrete objects and processes of science knowledge, and is considered to be least aligned to science (Allen, 2002), does not imply that sense-making of chemical knowledge is absent. Instead, it implies that sense-making of the topic is inadequate. Many excerpts of learner talk from Cycle 2 lessons were still perceptual, even though sense-making of the topic had generally improved. Moreover, excerpts belonging to this sense-making type from Cycle 2 lessons were not many as those from Cycle 1 lessons – indicating that the intervention brought improvement to learners' sense-making of the topic.

Excerpts of learner talk belonging to this sense-making type in Cycle 2 were identified in learners perceiving concrete knowledge of chemical bonding during the lessons. Learner D explained that *"compounds are formed if elements combine together",* while learner Qb stated that *"a covalent bond is between non-metals and an ionic bond is between metals and non-metals"*. These excerpts are correct and indicate that learners understood compounds as products of two or more elements bonding.

Many other excerpts of learner talk that revealed the learners' perceptual sense-making are related to the reactivity of elements (whether certain elements can bond or cannot bond), and the physical properties of compounds. These were discerned from the following excerpts of learner talk observed during the lesson: *"elements that we find in group 8 do not bond…"*; *"Helium does not bond because it is in group 8"*; and *"ionic compounds have high melting and boiling points meaning they do not melt and boil well if you heat them"*. Chemical bonding being impossible with group 8 elements (including helium), and ionic substances having high boiling and melting points, are correct chemical bonding phenomena; however, learners might have rote-learnt this. The sub-microscopic explanation of this chemical knowledge considers electron structure, as the reactivity of an element is determined by the stability of its atoms (electrons in outer shell) – this explanation is more aligned to scientific sense-making, which learners are supposed to portray.

Despite these excerpts being least aligned to science, I discerned that the learners' sense-making of chemical bonding has improved, as fewer learners in Cycle 2 portrayed perceptual sense-making than in Cycle 1 – more learners proceeded to the next level of sense-making of this chemical knowledge.

5.4.1.2 Evidence of chemical bonding facts sense-making

The sense-making of chemical knowledge belonging to this type is more aligned to science, and noticeable in learners using abstract chemical concepts when explaining science phenomena, such as chemical processes and objects (Zimmerman et al., 2009). I found that the number of learners making sense of chemical bonding facts was higher in Cycle 2 than in Cycle 1. I noticed this in many learners using more abstract scientific words in Cycle 2 than in Cycle 1. This confirms the idea that the coordinated visual and verbal semiotic modes have potential to enhance sense-making of science knowledge (Zimmerman et al., 2009). Two themes of chemical bonding knowledge that have attracted the researcher's attention include the relationship between atoms and molecules, and the bonding process.

(a) Atoms and molecules relationship

First, sense-making of this knowledge was identified from Learner R stating that *"before atoms are bonded they are called atoms but after they bond together we say they are a molecule"*. He illustrated his idea with a rough bond diagram, shown in Figure 9.

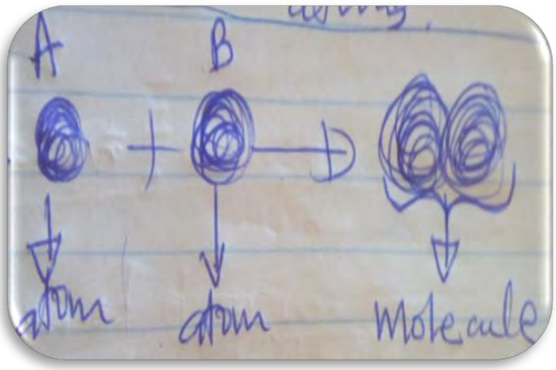


Figure 9. Learner R's diagram of atoms forming a molecule (observed during a Cycle 2 lesson)

The knowledge of the relationship between an atom and a molecule was evidently a challenge to students. This knowledge is classified as *intra-molecular*, as it concerns what constitutes a molecule and the processes happening within it (a molecule) (Gilbert & Treagust, 2009). This challenge can be addressed via using multiple representations, such as the combination of the verbal mode and physical models (Gilbert & Treagust, 2009). The combined visual and verbal modes in the form of diagrams, models, and spoken words, used during this cycle (Cycle 2) enhanced learners' sense-making of this topic. It is also possible that the physical model of a molecule, which could be dismantled into separate models of atoms, has made the explanation of the relationship between atoms and molecules clear, and has subsequently resulted in improved learners' sense-making.

Second, many learners correctly identified a diatomic molecule from other molecules. This was noticed in Learner Gd saying *"diatomic molecules are made from two atoms that are the same... example if two atoms of oxygen bond together, they form a molecule called a* *diatomic molecule".* Her correct Bohr structure of a diatomic molecule formed by two oxygen atoms is shown in Figure 10.

Figure 10. Learner Gd's correct bond diagram of a diatomic molecule formed by oxygen atoms (observed during a Cycle 2 lesson)

This excerpt of learner talk and the diagram (Figure 10) confirmed the finding that the learners' sense-making of the relationship between atoms and molecules, which are abstract concepts of chemical bonding, was enhanced due to the intervention. The two overlapped Bohr diagrams of oxygen atoms are similar in every respect, except that electrons in one atom are indicated with crosses, while in the other atom they are indicated with dots. These therefore confirm that sense-making of the relationship between atoms and molecules had taken place.

(b) Bonding processes

The chemical knowledge gained by learners that is classified as bonding processes in this sense-making type includes the definition of bonding, explanation of valencies, and description of ions. I accessed these data by analysing excerpts of learner talk about processes of chemical bonding that are related to this sense-making type.

Gilbert and Treagust (2009) suggest that a clear definition of chemical bonding should be provided to learners for them to determine if an element is reactive or unreactive. Learners' understanding of a bonding process was identified in Learner M saying *"bonding is when atoms of elements that have incomplete outer shells bind to have full outer shells".* This excerpt was selected because it was clearer than others, as many learners had difficulty expressing their ideas in English. The phrase 'incomplete outer shells' is abstract in two ways. First, the everyday meaning of the word 'incomplete' is not directly the same as its scientific meaning. The scientific meaning of this word involves an outer shell of an atom not fully occupied by the maximum number of electrons it can hold, while its everyday meaning refers to an activity or event unfinished or partially done. Second, the word 'outer shell' can only be understood by a person who has knowledge of electron arrangement in shells in an atom.

Considering excerpts of learner talk about valency in this study was informed by Gilbert and Treagust (2009). They assert that knowledge of valencies of elements is essential for determining the number of electrons involved in a bond, and for deducing and explaining the formulae of compounds formed from chemical reactions. I realised that twenty-two learners understood the valency concept, as they used it when explaining bonding. Among them was Learner F, who said *"valency is the electrons in the outer shell that take part in the bond"*. This indicates that they were aware that only some valence electrons (outer shell electrons) may be involved in a bond – and they are called valency. It is therefore possible that learners having this knowledge would have no problem either explaining chemical bonding or deducing the chemical formula of a compound.

Learner Z attempted to distinguish between cations and anions by saying *"cations are atoms that lost electrons while anions are atoms that gained electrons"*. She further explained that cations are mostly formed by metals, as they have the tendency of losing electrons, while non-metals form anions, as they mostly gain electrons. Accessing this knowledge is crucial, as it is one of the specific objectives in the Namibian Physical Science syllabus. This concurs with Gilbert and Treagust (2009), who assert that knowledge of ions, including their behaviour, contributes to a deeper understanding of the mechanism involved in the chemical reaction between metals and non-metals. Hence, learners would likely experience fewer problems understanding chemical reactions once they have acquired this knowledge.

5.4.1.3 Evidence of connecting and analysing sense-making

As Zimmerman et al. (2009) highlight, sense-making of science knowledge is recognisable in learners making references to past experiences or learned knowledge. Learners who are competent in making sense of science knowledge at this level demonstrate a high order of scientific sense-making. This evidence of sense-making was noted as occurring more frequently in Cycle 2 than in Cycle 1. I accessed these data by analysing excerpts of learner talk and diagrams. The learners were drawing from the knowledge of atomic structures, which they learned in the previous grade (Grade 8), when explaining objects and processes involved in chemical bonding.

Many learners employed prior knowledge of chemical bonding by drawing from knowledge of electron arrangements in shells of atoms, and of the stability of the noble gas structures, which they learned in Grade 8. The Grade 8 syllabus indicates that learners should be able to "outline that electrons are arranged in shells around the nucleus and explain that noble gases have full outer shells and therefore have stable electronic structures" (Namibia. MoEAC, 2015, p. 14). The results show that the participant learners recalled this knowledge, and were able to link it to their explanation for why and how ionic bonding takes place. Learner B said *"oxygen can bond because it has only six electrons in the last shell, because it needs two electrons again"***.** The Bohr diagram of an oxygen atom (Figure 11) he drew shows the details.

Figure 11. An electron arrangement in an oxygen atom (provided by Learner B in Cycle 2)

Both the learner's excerpt and the Bohr diagram in Figure 11, indicate that this learner was able to use his prior knowledge of electron structure to explain bonding. He has shown awareness of the fact that the first shell of an element is complete if it has two electrons, while the second and the third shell are complete if they have eight electrons. He explained that the outer shell for an oxygen atom is the second shell, which only becomes full once it has eight electrons. Learner R explained that *"elements that have full outer shells are in group 8 because they all have eight electrons in outer shells"*. He also explained that helium is the only element in group 8 without eight electrons in the outer shell of its atom, because it has only one shell with the maximum of two electrons. These excerpts show that the learners' sense-making of chemical bond knowledge became more aligned to science during Cycle 2 than during Cycle 1.

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5.4.1.4 Evidence of clarification sense-making (Cl)

The learners' sense-making of chemical bonding knowledge regarded as clarification is recognisable in learners clearly explaining chemical processes and objects (Zimmerman et al., 2009). This sense-making type is the second most aligned to science, based on the work of Zimmerman et al. (2009). During Cycle 2, the number of learners making sense of chemical bonding at this level was fifteen, compared to seven in Cycle 1.

Three sub-topics of chemical bonding (general chemical bonding principles, covalent bonding, and ionic bonding) have been identified as understood better by many learners after Cycle 2 than after Cycle 1. In all these sub-topics, the excerpts of learner talk have shown that sense-making via clarifying chemical bonding concepts has improved due to using the visual-verbal oriented teaching approach. This was enabled by different affordances that are offered by the visual and verbal semiotic modes in intersemiotic complementarity, as Crisp and Sweiry (2006) suggest.

(a) General principles of chemical bonding

Overall, I found that many learners (thirty-four) could clarify general chemical bonding processes correctly. I accessed this datum from excerpts of learner talk. Learner F said *"in bonding atoms lose, gain or share electrons to attain a noble gas electron structure"*. Twenty-one learners supported his ideas, with two of them explaining that chemical reactions would not exist if all atoms had full outer shells. Nineteen learners agreed with the teacher predicting that life would not exist in a world without chemical reactions because life is also a product of biochemical processes taking place in all living organisms.

The learners reasoned that atoms of noble gases have full outer shells, resulting in no reactions with other elements. They drew from their knowledge of atomic structure that an atom that has eight electrons in the outer shell will not react with any element because its outer shell is fully occupied by electrons. Though three learners could not explain this, thirty-four learners possessed this knowledge, which indicates that their sense-making related to clarifying general principles of chemical bonding has been enhanced as the result of the intersemiotic complementarity teaching approach used.

(b) Covalent bonding

The learners' ability to clarify covalent bonding was identified by them explaining that the sharing of electrons between non-metal atoms during a covalent bond results in noble gas electron structures for the elements that are bonding. A noble gas structure occurs when an atom has the maximum number of electrons it can hold in its outer shell. Learner N used oxygen atoms as an example by explaining that each atom shares two electrons because its valency is -2. His drawing is shown in Figure 12.

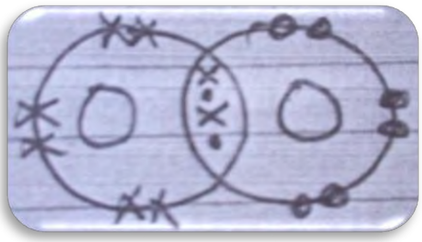


Figure 12. A diagram illustrating electrons shared between two oxygen atoms (provided by Learner N)

(c) Ionic bonding

I also observed learners' sense-making of chemical bonding during Cycle 2 in learners correctly clarifying objects and processes of ionic bonding. Learner B said *"ionic bonding is transferring valency electrons from metal atoms to non-metal atoms"*. An excerpt from Learner T says *"the valency of potassium is +1 because it belongs to group 1 because all elements in group 1 have the valency of +1"*. The notable aspect from these excerpts is learners referring to atoms *losing* and atoms *gaining* some valence electrons when explaining ionic bonding. This is central to understanding ionic bonding, as a learner cannot score marks for explaining this bond type without referring to electrons lost or gained by an atom. I also noticed that these learners understood that metals lose electrons while non-metals gain electrons. A second excerpt (by Learner T) also revealed that the learners were able to identify the valency of specific elements by referring to their groups in the periodic table. This knowledge is also required by learners to understand ionic bonding.

While many learners managed to explain the process of ionic bonding in calcium sulphide, a pair of learners drew an incorrect Bohr diagram of the bond in this compound. They correctly explained that a *"calcium atom has the valency of 2 which means it transfers two electrons to sulphur atoms when they bond"*. However, their bond diagram of this compound (Figure 13) was incorrect, as it showed one calcium atom transferring two electrons to two sulphur atoms when they should have drawn one sulphur atom gaining two electrons form one calcium atom, because calcium has a valency of +*2*, while sulphur has a valency of -*2*. They should have determined the valency of sulphur from its group number by subtracting eight from the group number in order to guide them when determining the number of electrons it gains.

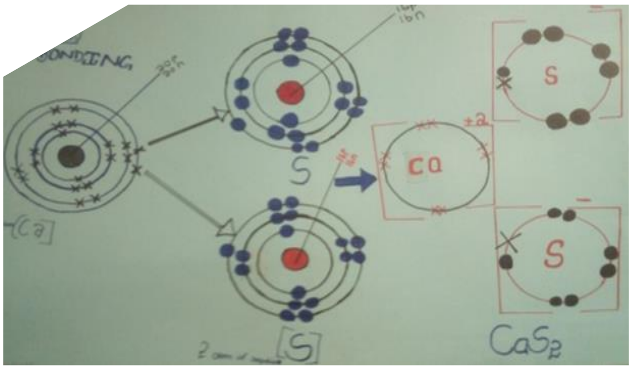


Figure 13. An incorrect Bohr diagram of calcium sulfide (drawn by two learners during a lesson in Cycle 2)

Figure 13 shows that the bond diagram of calcium sulphide drawn by these learners was incorrect due to their difficulty drawing a correct Bohr diagram of sulphur atoms. Illustration of atomic structures using the Bohr model was taught in Grade 8, but this revealed that learners did not master it. Each outer shell was drawn with seven electrons instead of six. This led to them incorrectly showing the two outer shell electrons of calcium being transferred to two separate atoms of sulphur. However, the fact that this constrained knowledge of ionic bonding was only observed in these two learners warrants no generalisation of concluding that learners lack understanding of ionic bonding, or considering this knowledge as constrained by the intervention.

5.4.1.5 Evidence of ideas about nature of chemical bonding sense-making (ICB)

Sense-making of chemical knowledge that is idea-based involves learners engaging in discussions and debates by making reference to scientific theories and principles (Zimmerman et al., 2009). During Cycle 2, learners were also assessed for their ability to make sense of chemical bonding knowledge by basing their discussions and debates on scientific theories, laws, and principles. This is also hinted at by the Namibian Physical Science syllabus, which suggests that one of the best teaching and learning approaches to science knowledge should involve high degrees of learners' participation, contribution, and production of knowledge (Namibia. MoEAC, 2015). A remarkable shift in sense-making of chemical bonding knowledge by learners was observed, with learners' sense-making being much better during Cycle 2 than during Cycle 1.

One of the notable events where I identified this sense-making type was when learners were provided with an unidentified physical molecular model (Figure 14) (the model of a carbon dioxide molecule) to discuss and identify the compound it represents.

Figure 14. An unidentified physical molecular model (the model of a carbon dioxide molecule) (assembled for learners by the teacher during Cycle 2)

In order to assess the learners' critical thinking, it was not explained to them that the grey rubbery links joining the spherical balls together represent pairs of electrons shared between the bonded atoms. The discussions around this divided the class into two groups. The first group argued that this physical model is for a water molecule. They reasoned that the chemical formula for a water molecule is H_2O; which means there are two hydrogen atoms and one oxygen atom bonded. Learner E in this group said *"it is a bond in water molecule, because there are three atoms".* The second group said that the model is for a carbon dioxide molecule because it has the formula CO_2. Learner M in this group explained that the model is for a bond in a carbon dioxide molecule because *"there are three atoms with double bonds".* Even though the first group was incorrect, while the second group was correct, the learners in both groups referred to scientific theories and laws when explaining the science phenomenon represented by the physical model. However, the second group showed a higher order of sense-making of the knowledge than the first group, because they correctly explained multiple features in relation to theory. This revealed that learners' sense-making of the topic has been enhanced as a result of the coordinated use of the visual and verbal modes for teaching.

5.4.2 Findings from the teacher's and learners' reflective journals

In order to get first-hand data, as Mills and Airasian (2009) suggest, both the teacher's and learners' reflective journals were used in Cycle 2 as data collection instruments. In this sub-section, the results of the teacher's and learners' reflective journals are discussed separately, as was done for Cycle 1.

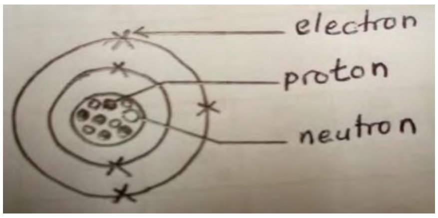
5.4.2.1 Teacher's reflective journals

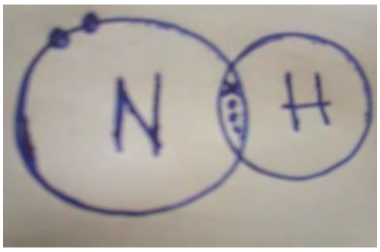
The guiding questions used in the teacher's reflective journals during Cycle 2 were the same as those used during Cycle 1. This was done to ensure the same foci were attended to in both cycles, as necessitated by the overall research question in general, and research questions 2 and 3 in particular. These guide questions were employed to elicit data on learners' sense-making of chemical bonding knowledge after a traditional approach and then a coordinated visual-verbal intersemiotic complementarity teaching approach.

The results of learners making sense of chemical bonding, accessed via the teacher's reflective journal during Cycle 2, are shown in Table 18. In this table, how learners made sense of knowledge of chemical bonding during the benchmark lessons was recorded according to the sense-making types. I realised that a shift in learners' sense-making of the topic shows an improvement, from being less aligned to science during Cycle 1, to being more aligned to science during Cycle 2.

Table 18. Cycles 1 and 2 sense-making evidence (identified from the teacher's reflective journals)

Sense-making evidence	**Description of chemical bonding knowledge learned (E) or not learned (C) Codes: Macroscopic (M), Sub-microscopic (SM), and Symbolic (S)**		**Improved (I), sustained (S), or worsened (W)**
	Cycle 1	**Cycle 2**	
Perceptual (descriptive) sense-making (P) – talk and/or visuals where learners identify, count, and describe concrete chemical bonding processes or objects observed	Few learners have correctly stated that metals are on the left and non-metals are on the right. (M)(E)	More than half of the learners in the class were able to distinguish between covalent and ionic bonding. (M)(E)	S
	Some learners stated that the vertical columns are called groups while the horizontal rows are called periods in the periodic table. (M)(E)	Most learners were able to identify the elements that made up certain compounds, such as carbon dioxide being made up of carbon and oxygen. (M)(E)	
	Most learners could distinguish between covalent and ionic bonding. (M)(E)	About the three quarters of the class was able to identify the names of the	

	Some learners explained that ionic compounds are soluble in water, giving an example of table salt, which dissolves in watery foods. (M)(E)	compounds represented by different models that were constructed. (M)(E)	
Chemical bonding facts sense-making (CBF) – talk and visuals about abstract chemical bonding processes and objects.	Some learners identified protons as positive (+), electrons as negative (–), and neutrons as neutral. (SM)(E)	Most learners have understood the concept of valency electrons being evenly shared in pairs. (SM)(E)	I
	Most learners could state that protons are in the nucleus, neutrons are in the nucleus, and electrons are in the shells, as shown in this diagram. (SM) (E) 	Many learners managed to work out the valency of some elements correctly. (SM)(E) Learners managed to classify many covalent bonds either as single, double, or triple by looking the number of shared electron pairs. (SM)(E)	
	One learner mentioned that protons are in the outer shell and they are equal to the period number, which is incorrect. (SM)(C)	All learners could define ionic bonding as involving electron transfer, adding that these electrons are transferred from metals to non-metals. (SM)(E)	
	Most learners have shown an understanding that the atom's first shell is full with two (2) electrons, the second shell with eight (8), and the third shell with eight (8). (SM)(E)	Many learners have successfully drawn ionic structures, and could label their ions and write their formulae. (SM)(E)	
	Some learners were noted stating that protons are equal to neutrons, which is incorrect. (SM)(C)		
	Some learners said that neutrons are determined by subtracting the mass number from the atomic number, which is incorrect. (S)(C)		
	Some learners stated that different atoms should be represented with a dot and a cross. (S)(E)		
	Some learners could not distinguish between cations and anions. (SM)(C)		
Connecting and analysing sense-making (CA) – talk and	Many learners could not correctly illustrate the bond between calcium and	Most learners were able to correct the Bohr structure of oxygen, which was	I

visuals where students make explicit and implicit comparisons and analogies to prior knowledge or experiences.	sulphur atoms. (SM)(C)	incorrectly drawn by the teacher. (SM)(E)	
		Many learners could link the symbolic level to the sub-microscopic level by deducing the formula for water from a model constructed. (S)(E)	
		More than half of learners managed to use balls and sticks provided to construct models of different covalent compounds. (SM)(E)	
	Some of the learners who understood valency were noted as using it to determine the formulae of ionic compounds. (S)(SM)(C)	Many learners could not apply their knowledge of valency to deduce the formula for aluminium oxide, though they were able to do this with other ionic compounds. (S)(C)	
	Some learners could not identify ions as either positive or negative. They kept debating that atoms that lost electrons are negative, while those that gained electrons are positive. (SM)(C)	Many learners could identify ions as either cations or anions for ionic compounds given. (S)(E)	
Clarification sense-making (Cl) – about how chemical bonding processes work and/or are applied in real life contexts.	Almost all learners failed to explain why atoms of elements form a bond. (SM)(C)	Some learners used helium and argon as examples of some of the elements that cannot bond, explaining that it is due to the full outer shells they have. (SM)(E)	I
	One learner drew the bond in ammonia incorrectly, as shown below. (SM)(C) 	More than half of the class were able to clarify that only atoms that have incomplete outer shells can bond, using the example of oxygen. (SM)(E)	
	About three quarters of the learners in the class could not explain the electron lost from a sodium atom as due to its instability from an incomplete outer shell. (SM)(C)	More than half of the class could correctly draw the bond in ammonia and methane. (SM)(E)	
Ideas about nature of chemical	Some learners debated that atoms do not	Most learners agreed that covalent	I

bonding sense-making (ICB) – how knowledge of chemical bonding is discovered by scientists.	really bond because no one could see the atoms bonding with his or her naked eye. (SM)(C)	substances are not soluble in water, asking whether butter is also a covalent substance, because it cannot dissolve in water. (M)(E)	
		Some learners tried to understand why ionic substances can dissolve in water though they have strong bonds between their ions, while covalent substances that have weak bonds cannot dissolve in water. (SM)(C)	

(a) Evidence of perceptual sense-making

I found that the learners' perceptual sense-making of chemical bonding knowledge from Cycle 1 to Cycle 2 was sustained. This means that in both cycles of this action research, learners could identify, count, and describe chemical objects and processes when accessing knowledge of chemical bonding. They were able to make sense of knowledge of chemical bonding represented macroscopically, which Johnstone (1982) describes as not problematic to many learners.

Many learners managed to distinguish between covalent and ionic bonding; some could identify elements that comprise the compounds, while others could identify the compounds that were represented by different physical models. Many learners were able to explain covalent bonding as involving only non-metals, and ionic bonding as involving metals and non-metals. This sense-making was perceptual, as many learners were unable to explain this knowledge at the particulate level, such as the number of atoms involved in the bond, the sharing of electrons in covalent bonds, and the transfer of electrons in ionic bonds. Many managed to identify carbon dioxide as made up of carbon and oxygen atoms reacted together, but they were unable to explain this bond by referring to valency and electron sharing. In Cycle 2, about three quarters of the class were able to identify carbon dioxide, ammonia, water, and oxygen molecules from the physical models that were constructed by the teacher. I therefore realised that the learners' perceptual sense-making had been sustained in this cycle (Cycle 2), though there were small improvements noted.

(b) Evidence of chemical bonding fact sense-making

There was a shift in the learners' sense-making from Cycle 1 to Cycle 2, evident in their visual or verbal communication about chemical bonding. I realised this shift in many learners referring to abstract chemical processes and objects when explaining knowledge of chemical bonding. This revealed that their sense-making of this chemical knowledge has shifted (improved) from being perceptual (P) to being fact-based (CBF). The fact-based sense-making is more aligned to scientific facts and rules than the perceptual sense-making, as it involves learners using more abstract chemical concepts than perceptible activities.

As indicated in Table 18, sense-making of chemical bonding knowledge shifted from being constrained to being enabled following the intervention. During Cycle 1, many learners incorrectly referred to protons and neutrons as equal. Other learners had difficulty differentiating between cations and anions formed during an ionic bond. These learning difficulties were not noted during Cycle 2, and this can be attributed to the integrated use of the visual and verbal modes during teaching chemical bonding. These learners used different elements for explaining that the number of protons is equal to the number of electrons, but did not refer to the number of protons being equal to the number of neutrons, as they did in Cycle 1. This revealed that their sense-making of this chemical knowledge improved drastically.

The learners' knowledge of valency and its application to bonding also improved during Cycle 2. The learners explained that the valency of an element determines the number of bonds it can form. This enabled them to correctly explain and distinguish between single, double, and triple covalent bonds. These refer to the number of electron pairs shared between two or more covalently bonded non-metal atoms. These learners were also able to apply their knowledge of valency to explain ionic bonding. Many of them explained that the number of electrons lost or gained by an atom is determined by the valency of the element. This enabled them to draw correct Bohr structures of ionic bonding, and to deduce correct chemical formulae of many ionic compounds.

(c) Evidence of connecting and analysing sense-making

Sense-making via connecting and analysing concerns learners making sense of science knowledge by referring to their prior knowledge or past experience. I evaluated the learners' ability to connect and analyse knowledge of chemical bonding. This enabled me to ascertain the influences the intervention had on the learners' sense-making of the topic. This evaluation targeted the learners' ability to make sense of knowledge of chemical bonding by referring to their prior knowledge and past experience. This included knowledge of the Bohr structures of atoms, the metallic nature of elements, and valency. This prior knowledge is essential for accessing knowledge of any chemical bonding type, as without it, learners will be beyond the Zone of Proximal Development, which is characterised by independent learning.

The learners' talk and visuals regarding connecting and analysing chemical bonding knowledge in Cycle 2 was different from that displayed in Cycle 1. I noted that the learners' ability to connect and analyse during Cycle 1 was constrained by the traditional teaching approach to the topic. However, a shift was discerned in the learners' ability to connect and analyse, from being constrained during Cycle 1, to being enabled during Cycle 2. This was a result of adapting the teaching approach in Cycle 2 to take the form of the visual and verbal semiotic modes integrated. During Cycle 1, many learners had difficulty drawing and deducing formulae of ionic compounds, and identifying ions as either positive or negative. I noted the difficulty with ionic bond diagrams, displayed by many learners drawing the bond diagram of calcium sulphide incorrectly. However, I noticed that few learners had this difficulty in Cycle 2. The only bond diagram I noted as challenging for the learners in Cycle 2 was that of aluminium oxide. This was because aluminium oxide consists of many ions (two aluminium ions and three oxygen ions), causing confusion in learners, as opposed to calcium sulphide, which consists of fewer ions (one calcium ion and one sulphur ion). Moreover, fewer learners had difficulty deducing formulae of ionic compounds during Cycle 2 than during Cycle 1. Though this was the case, this learning difficulty could have been avoided if learners had knowledge of how valency is applied in chemical bonding. However, the fact that they correctly deduced formulae of ionic compounds, with the exception of aluminium oxide, indicated that their ability to connect and analyse chemical knowledge was enhanced.

(d) Evidence of clarification sense-making

I gauged the learners' ability to clarify processes of chemical bonding, including their application in real life. This knowledge is more aligned to scientific facts and rules than perceptual, chemical bonding facts, and connecting and analysing sense-making, as was mentioned in Chapter 2. I noticed an improvement following the intervention, with more learners making sense of chemical knowledge at this sense-making level in Cycle 2 than in Cycle 1. Many learners had difficulty clarifying knowledge of chemical bonding in Cycle 1; however, this was reversed in Cycle 2.

During Cycle 1, I noticed learners' inability to clarify chemical bonding in both covalent and ionic compounds. First, many learners illustrated the bond in an ammonia molecule incorrectly – even though the formula for this compound was provided. Second, many learners failed to correctly explain that the electron lost from a sodium atom was due to its outer shell being unstable. This instability is caused by the weak electrostatic forces of attraction between the outer shell electron and the positive nucleus of the same atom; however, many learners did not mention this. Difficulties related to these were not identified during Cycle 2, revealing that there was a significant improvement following the intervention. I noticed this improvement in many learners explaining that helium and argon do not bond due to their full outer shells. Some of them correctly referred to these elements as noble gases due to their inertness (non-reactivity). They also explained that atoms with outer shells that are not full, such as oxygen, can bond because they are not stable. Consequently, more than half of the learners in the class managed to draw the bond diagram of an ammonia molecule correctly during Cycle 2.

The learners correctly clarifying chemistry concepts and processes is an indication that they are capable of using their mental models to perform high levels of mental processes, as suggested by Sunyono, Yuanita, and Ibrahim (2015). The findings from Cycle 2 showed this ability in the learners with regards to their sense-making of chemical bonding. The teaching approach used during Cycle 2 enabled learners to access and represent chemical knowledge at all levels of representation (macroscopic, sub-microscopic, and symbolic), realised in them using given chemical formulae to correctly explain and illustrate knowledge of chemical bonding. This implies that learners could draw links between chemical knowledge at three levels of representation. This ability to move between the levels of representation of chemical knowledge is described by Johnstone (1982) as essential for further learning of chemistry.

(e) Evidence of ideas about nature of chemical bonding sense-making

Cycle 2 showed more learners bringing their own ideas related to chemical bonding compared to Cycle 1. This showed that their understanding of chemical bonding improved in Cycle 2. Zimmerman et al. (2009) propose that learners making sense of science concepts through applying their own ideas in order to understand the topic taught is most aligned to scientific facts and rules. Considering this idea, when analysing the findings from Cycle 2, it was revealed that the learners' sense-making of chemical bonding indeed improved.

Though not all learners successfully reached this level of sense-making of chemical bonding, I found that during Cycle 2, many learners could use their ideas to access knowledge of this topic. This was discerned through them discussing that butter is a covalent substance because it is insoluble in water. They drew this from their prior knowledge of covalent substances being non-water soluble. However, several learners lacked understanding of why the bond in covalent substances is weak, while in ionic substances it is strong. They argued that the bonds in covalent substances are supposed to be strong because they are not soluble in water, while the bonds in ionic substances are supposed to be weak because they are soluble in water. Though their sense-making of this knowledge was constrained due to this misunderstanding, they could draw from their knowledge of electrostatic attractive force between particles in substances. Overall, the teacher's reflective journal undertaken in Cycle 2 revealed that learners' sense-making of chemical bonding improved as a result of the visual-verbal intersemiotic complementarity teaching approach that was employed.

5.4.2.2 Learners' reflective journals

I employed the learners' reflective journals in Cycle 2 as tools for collecting data on learners' sense-making of chemical bonding. These reflective journals were also employed as tools for collecting data on sense-making of chemical bonding by the learners. The journals contained guiding questions to focus learners' reflections after every benchmark lesson.

The detailed results obtained via this method are shown in Appendix R. These results are in the form of excerpts of learner talk and diagrams that are classified as either gained knowledge (GK) or challenging knowledge (CK), based on how the learners described them in their reflective journals. The knowledge themes of chemical bonding, as those identified in Cycle 1, have also emerged from analysing Cycle 2 data. The results were put in categories from which the coded themes were generated. This enabled me to realise an improvement in the learners' sense-making of chemical bonding that arose during the Cycle 2 lessons. Discussing the data about both covalent and ionic bonds in this section was done in two sections; the first section for gained knowledge (GK), and the second section for challenging knowledge (CK). Gained knowledge refers to the chemical bonding knowledge that learners learned successfully, while challenging knowledge refers to that which learners did not successfully learn during the lessons.

Gained and challenging knowledge of covalent bonding were also classified as being represented macroscopically, sub-microscopically, and symbolically in this section. This was done in order to ascertain which level of representation of covalent bond knowledge emerged as problematic to the learners, and whether the intersemiotic complementarity teaching approach had influences on sense-making of the topic by the learners.

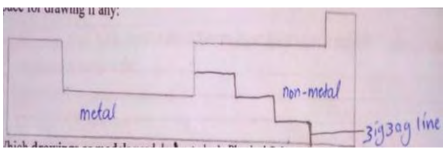
(a) Gained knowledge of chemical bonding (GK)

Gauging the learners' sense-making of chemical bonding in Cycle 2 was preceded by ascertaining their knowledge of the periodic table and the Bohr atomic model, the same way it was covered during Cycle 1. Knowledge of the periodic table and the atomic model are the basis for students' understanding of other chemistry topics (Ben-Zvi, Silberstein, & Mamlok, 1990). If there was lack of understanding of either the periodic table or the atomic model by students, there would be difficulty understanding further chemistry topics. I discussed the learners' GK in three data sets: knowledge of the periodic table and the atomic model; knowledge of covalent bonding; and knowledge of ionic bonding. Knowledge of the periodic table and atomic model contains two knowledge themes: classification (C), and electron arrangement (EA). Knowledge of covalent bonding consists of five knowledge themes: covalent bond (CB), electron sharing (ES), covalent bond types (CBT), valency (V), and physical properties of compounds (PPT). Knowledge of ionic bonding contains three themes: electron transfer (ET), ionic bond drawing (IBD), and physical properties of compounds (PPT). Each of these will now be discussed.

(1) The periodic table and the Bohr model knowledge

Due to the intersemiotic complementarity teaching approach to chemical bonding in Cycle 2, I noticed a remarkable improvement in how learners described and explained knowledge of the periodic table and the atomic model. Many of these learners revealed in their reflective journals that they understood these topics better after Cycle 2 than after Cycle 1.

Learner J wrote in her reflective journal that *"I remember that elements in the periodic table are classified as metals and non-metals that are separated by the line called zigzag line like this:*



".

This learner proved that she understood the overall structure of the periodic table. I ascertained this from the sketch she drew of the periodic table. It had a zigzag line that separated metals from non-metals, indicating that she successfully learned the classification of elements according to their grouping into metals, non-metals, and metalloids. The classification of elements as either metals or non-metals was also correctly mentioned by thirty-one other learners in their reflective journals. They stated that metals are located on the left and non-metals are located on the right side of the periodic table. Some stated that these two groups of elements in the periodic table are separated by a zigzag line. Learners accessing knowledge of the periodic table is essential, as it enables "efficient learning of chemistry" (Gilbert & Treagust, 2009, p. 313). Knowledge of the periodic table includes learning about elements and their classification in the periodic table. This knowledge is a scaffold for understanding the particulate nature of elements, and chemical reactions (such as chemical bonding) (Gilbert & Treagust, 2009).

Learner K wrote in his reflective journal that *"1st shell is full with 2 electrons, 2nd shell is full with 8 electrons and 3rd shell is full with 8 electrons".* This description is correct, and one cannot correctly draw the Bohr structure of the first 20 elements in the periodic table without knowledge of electron arrangement in an atom. Figure 15 shows the Bohr diagram of the structure of an oxygen atom he drew. The learner drew this diagram to show that he understood illustrating Bohr diagrams.

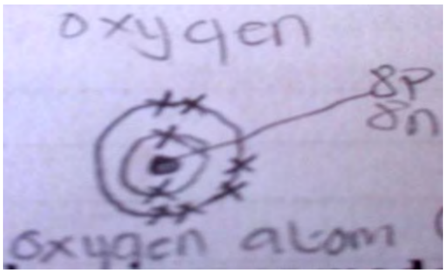


Figure 15. A Bohr model of an oxygen atom (drawn by Learner K after Cycle 2)

This diagram revealed that the learner could use knowledge of the periodic table and electron arrangement to draw the Bohr structure of an atom, because his Bohr diagram of an oxygen atom has the correct number of protons and neutrons in the nucleus, and correct distribution of electrons in the shells. This means that learners had the potential to learn other chemistry topics, as Ben-Zvi, Silberstein, and Mamlok (1990) explain. Therefore, gauging the learners' knowledge of the periodic table and the atomic model in this study was a pre-requisite to teaching and assessing their knowledge of covalent bonding, which is another sub-topic of chemical bonding in chemistry.

(2) Covalent bonding knowledge

Overall, the learners revealed, in their reflective journals, that their knowledge of covalent bonding improved in Cycle 2. This is one of various scientific models (the others being ionic and metallic bonding) that are required for a fundamental understanding of chemical bonding (Gilbert & Treagust, 2009). Therefore, understanding of molecular structures and processes of the bond models enables learners to know the structure-property relationship of substances – which is a link between the macroscopic and sub-microscopic levels of representation (Lijnse & Licht, 1990). This information was also accessed in this cycle by analysing learners' answers to the guiding questions in the reflective journals.

The learners indicated in their reflective journals that they understood chemical bonding. This understanding was enabled by their knowledge of chemical properties of elements, such as valency and attainment of noble gas structures of atoms. I found that more than half of the learners in the class made sense of covalent bond knowledge. Excerpts from their journals on covalent bonding revealed this. Two of these excerpts read: *"atoms bond to have full outer shells…"*, and *"Helium and argon do not form a bond because they have outer shells that are full"*. These excerpts correctly explain that only atoms that without full outer shells may share electrons during covalent bonding. Their mentioning of helium and argon as non-bonding elements confirmed that their sense-making of covalent bond improved.

Substantially, I expected learners to make sense of covalent bond knowledge effectively if they had knowledge of covalent bond types (CBT), electron sharing (ES), and valency (V). I noticed (from the learners' reflective journals) that many learners were able to describe covalent bonding as involving the sharing of electrons between atoms of non-metal elements that do not have full outer shells. Moreover, many learners were able to correctly explain valency, including how it can be determined using group numbers of elements in the periodic table. Learner V correctly wrote: *"the valency of elements in group 1, 2 and 3 is equal to the group number while the valency of elements in 4, 5, 6 and 7 is found by subtracting eight from the group number"*. Twenty-three other learners indicated in their reflective journals that the number of electrons shared between two atoms is determined by the valencies of their elements. Figure 16 shows Learner V's bond diagram of an oxygen molecule.

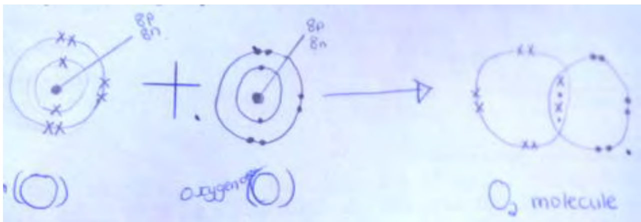


Figure 16. A correct bond diagram for the formation of an oxygen molecule (drawn by Learner V after Cycle 2)

It was evident in the learners' reflective journals that many learners sufficiently understood the physical properties of covalent compounds only after Cycle 2. I discerned this information based on excerpts from their reflective journals. These excerpts include:

- *"covalent substances are insoluble in water like fat"*
- *"covalent compounds are non-conductors of electricity like a switch is a plastic which does not conduct electricity"*
- *"covalent compounds have low melting and boiling points which means if you heat them they can easily melt and easily boil"*
- *"If you heat fat or butter, it can just melt fast and become water"*

The learners had no problem understanding the physical properties of covalent compounds, possibly because this chemical knowledge is macroscopic, which Johnstone (1982) describes as not usually being challenging. Though this knowledge was not difficult to students during Cycle 1, a big improvement was nevertheless noticed in the increased number of learners mentioning the physical properties of covalent compounds during Cycle 2.

Other possible reasons for the good understanding of physical properties of covalent compounds by learners include this knowledge being macroscopic, and thus easy to be rote-learnt. This chemical knowledge is macroscopic as the physical properties of covalent compounds are observable, and learners could thus easily recall the properties they learned or observed. Some learners could easily rote-learn the physical properties of covalent compounds if the teacher mentioned them frequently (Smith & Metz, 1996). These properties were first mentioned in Cycle 1, and then repeated in Cycle 2. It is possible that this repetition contributed to learners rote-learning physical properties, and thus understood them better. Even though rote-learning of chemical knowledge is effective, Smith and Metz (1996) argue that it can negatively impact on learners' ability to understand chemistry content deeply, as it makes no space for the person to think critically. However, avoiding this type of learning completely during the intervention was impossible, as it happens automatically. Moreover, the possibility for this to affect the results of study was lower, as physical properties of compounds represent a very small part of chemical bonding knowledge.

In summary, the learners revealed that their sense-making of covalent bonding improved more after Cycle 2 than after Cycle 1. Even though there were some knowledge aspects of covalent bonding that could not be directly represented via the coordinated visual and verbal semiotic modes, it was evident that the change in learners' sense-making of the topic had a direct link with the teaching approach used in Cycle 2. Moreover, despite the possibility of the physical properties being rote-learnt and observable, the use of physical models together with the verbal mode has greatly influenced sense-making of covalent bond knowledge by learners.

(3) Ionic bonding knowledge

Before discussing the learners' journal results on ionic bonding, I want to remind the reader about the difference in the pedagogy of covalent and ionic bonding in Namibia. In Namibia, covalent bonding is first taught in Grade 8 and repeated in Grade 9, while ionic bonding is taught for the first time in Grade 9, as earlier stated. The Physical Science syllabus does not provide any rationale for this arrangement. It is possible that the difference in making sense of these two types of chemical bonding is related to this particular sequential arrangement. Nonetheless, no specific effects that are linked to this arrangement were identified. The knowledge themes of ionic bonding that I identified as knowledge gained during teaching of ionic bonding in Cycle 2 are electron transfer (ET), ionic bond drawing (IBD), ions (IN), and physical properties of compounds (PPC). Through analysing learners' answers under each of these knowledge themes, I found that sense-making of ionic bonding occurred more during Cycle 2 than during Cycle 1.

The chemical knowledge classified as electron transfer (ET) and ionic bond drawing (IBD) in this study requires the sub-microscopic level of representation, which concerns non-observable aspects of ionic bonding (Johnstone, 1991). Even though this chemical knowledge is difficult to understand because it concerns microscopic entities (Johnstone, 1991), learners' understanding of it during the intervention was not a major challenge due to my use of physical models of these entities (atoms and ions) during the benchmark lessons. I deduced this from thirty-one learners reporting not having a problem with ET, and twenty-four learners indicating that they had a good understanding of IBD. Some of the excerpts that revealed how learners understood ET are: *"atoms of metals can transfer electrons to atoms of non-metals"* and *"If sodium and oxygen are bonded, sodium transfers electrons to the oxygen atom"*. An excerpt indicating that learners understood IBD reads *"If the electrons that are transferred are not enough to make a non-metal full you draw another metal atom so that it becomes enough"*.

The learners' understanding of ions (IN) and physical properties of compounds (PPC) was also noticed in the statements they made in their reflective journals. Two of their statements were *"I know that if atoms give away electrons they become positive ions which are called cations…if an atom is given electrons it become anion which is a negative ion"*, and *"In sodium chloride there are sodium ions which are cations and a chlorine ion which is an anion"*. First, these learners have understood that metal atoms transfer electrons to non-metal atoms, which results in both particles becoming ions; and second, these learners could use sodium chloride to illustrate their explanation. The learners' knowledge of PPC was discerned in Learner J saying *"I know that ionic compounds are soluble in water such as table salt but sugar maybe is also an ionic substance because it is also soluble by water"*. Even though the learner referred to sugar as an ionic compound, which is incorrect, he showed that he understood that ionic substances are soluble in water.

(b) Challenging knowledge of chemical bonding (CK)

Not all excerpts in the learners' reflective journals indicate gained knowledge of chemical bonding during Cycle 2. Some of the knowledge themes of chemical bonding that many learners successfully learned were challenging for a few learners. These are classification (Cl), valency (V), covalent bond drawing (CBD), bond strength (BS), ionic bond drawing (IBD), ions (IN), electrical conductivity (EC), and chemical formula (CF). Excerpts revealing how some learners described challenges of covalent and ionic bonding are discussed separately in this sub-section.

(1) Covalent bonding knowledge

The challenge of covalent bonding knowledge to learners was less evident during Cycle 2 than during Cycle 1. I accessed this information by both comparing the number of learners describing knowledge themes of covalent bonding during Cycle 1 and Cycle 2 as challenging, and analysing excerpts from the learners' reflective journals. While many learners indicated that they understood classification (Cl), valency (V), covalent bond drawing (CBD), and bond strength (BS), a few learners revealed that they had difficulty understanding these concepts. I therefore deduced that these few learners had difficulty with sense-making of covalent bond knowledge despite the teaching intervention undertaken, due to little attention paid to their learning.

The first two challenging themes of covalent bonding, classification (Cl) and valency (V), are necessary for understanding both covalent and ionic bonding, and for deducing formulae of the ionic compounds formed (Gilbert & Treagust, 2009). I identified the learners' difficulty making sense of this knowledge in three reflective journals. An excerpt from learner A's reflective journal reads: *"sometimes I confuse the periods and groups because I forget which one is vertical and which is horizontal".* This excerpt shows that the learner confused the meaning of two words: vertical and horizontal. Consequently, he had difficulty identifying groups and periods in the periodic table, which had the potential to hamper his learning of atomic structures, and thus any type of chemical bonding. Despite this learning challenge, I regarded this as a minor hindrance overall to learners' sense-making of covalent bonding, because it was only noted in a small number of learners. Learner W wrote in his reflective journal that *"I know the valency of many elements but I don't know the valency for argon because sir did not talk about it in the class".* This excerpt made me realise that the learner understands valency only partly. The part he failed to understand was that noble gases have the valency of 0 due to the complete outer shells they possess – they have the needed number of electrons.

I found that one learner had difficulty drawing bond diagrams of covalent compounds (CBD), while three other learners had difficulty understanding the bond strength (BS). Learner B said *"I only want to draw the bond in sulphur dioxide because the teacher did not show it to us… I was drawing it but it was not work".* The bond in sulphur dioxide is not recommended by the Namibian curriculum to be practised with learners, as it appears to contradict the basic rule taught at Grade 9 level for using valency in bonding. This learner attempted to draw the bond in sulphur dioxide out of curiosity, but failed as it violates the electron sharing rule. However, he had no difficulty drawing the bond diagrams of many other covalent compounds – indicating that his understanding of this bond has advanced. Learner D, one of the three learners who had difficulty understanding bond strength, wrote: *"I know that covalent compounds have weak bonds but I want to know why...but they dissolve in water".* This indicated that the learner knew that one of the physical properties of covalent compounds is the weak bond between atoms in their molecules. He showed lack of understanding knowledge related to the weak bond, but being inquisitive could indicate that he is smarter than other learners, and thus desired to know more about how this is possible at the particulate level.

(2) Ionic bonding knowledge

Even though knowledge of chemical bonding related to ionic bonding was noted as gained more during Cycle 2 than Cycle 1, there were learners who still had difficulty accessing this knowledge. This happened despite undertaking an intersemiotic complementarity teaching approach to this topic in this cycle of the action research study. Causes of the consistency of this learning difficulty may be hard to identify and control, as employing an intersemiotic complementarity teaching approach to knowledge of chemical bonding is susceptible to other factors that inhibit learning. Despite this being the case, this learning difficulty was noticed minimally during Cycle 2 when compared to Cycle 1. The learners' reflective journals revealed learners' specific challenges in learning ionic bonding. These challenges are ionic bonding drawing (IBD), ions (IN), electrical conductivity (EC), and chemical formulae of compounds (CF).

Thirty-three learners were identified as having the problem with ionic bonding drawing (IBD), which inhibited their accessing of knowledge of ionic bonding related to ions (IN). This was evident in their illustration of the bond in aluminium oxide. Learner M drew one aluminium atom transferring two electrons to one oxygen atom, without considering the valencies of these two elements – the number of bonding electrons of these elements. Transferring only two electrons from an aluminium atom to an oxygen atom resulted in one electron left in the outer shell of its atom, leaving an aluminium ion still unstable, as it would not yet have attained a noble gas electron structure. The correct way to do this is to draw two aluminium atoms, transferring a total of six electrons (three from each aluminium atom) to three atoms of oxygen (each gaining two electrons) to balance the overall charges formed during the bonding process. Another specific learning difficulty I identified regarding IBD involved learners incorrectly indicating the charges formed on ions. I noticed this in Learner Y complaining that he did not know where the positively and the negatively charged numbers came from if the symbols of elements in the periodic table had no charges. This revealed that the learner thought of charges as something already on atoms, not as something created as a result of an atom losing or gaining electrons. However, this problem was not evident in many learners.

Even though many learners could describe ionic substances as good conductors of electricity in a molten or aqueous state, few had difficulty explaining this knowledge at the particulate level – the sub-microscopic representation. This includes difficulty explaining electrical conductivity of ionic substances by referring to electrostatic forces of attraction between the ions (cations and anions) of dissolved or molten ionic compounds. Many learners were only able to explain this property by making reference to sodium chloride (table salt) dissolved in water. This was possible because I conducted an experiment with this compound during the lesson to confirm that dissolved ionic substances conduct electricity. This explanation is macroscopic, as it only concerns observable chemical knowledge, not knowledge of microscopic particles and processes of ionic substances. Johnstone (1982) argues against accessing chemical knowledge at this representational level only, describing it as insufficiently representing knowledge of chemistry.

Eleven learners indicated in their reflective journals that they had difficulty deducing formulae of ionic compounds. Some of them indicated that there were too many formulae to be known. This revealed the possibility that learners only wanted to memorise these formulae, without learning the skill for deducing them from the valencies (oxidation states) of the reactants. They should have applied their knowledge of valency to determine the chemical formulae of ionic compounds. Those who indicated not having a problem with writing formulae of ionic compounds actually memorised them. Despite this being the case, the impact of these learning difficulties on sense-making of ionic bonding during Cycle 2 was evidently less harmful than the impact noticed during Cycle 1.

In summary, both the teacher's and learners' reflective journals gathered convincing evidence that an intersemiotic complementarity teaching approach, undertaken as the intervention during Cycle 2, had influences on learners' sense-making of chemical bonding. These influences are beneficial to chemistry learners, particularly those learning chemical bonding for the first or the second time, because they are not sufficiently knowledgeable in the topic. However, since obtaining this information from structured lesson observation and reflective journals only may not be fully reliable I chose to administer a post-test as another data collection method. The findings and the results of the post-test will now be presented.

5.4.3 Findings and results of the post-test

I administered a post-test (Appendix T) during Cycle 2, following four benchmark lessons on chemical bonding. These lessons employed an intersemiotic complementarity teaching approach by coordinating the visual and verbal semiotic modes, as discussed in Chapter 3. The questions in the post-test were set to gauge learners' sense-making of the specific objectives of chemical bonding, as were the questions at the end of Cycle 1. The learners' responses and marks in both tests (pre-test and post-test) were compared to each other to ascertain the influence(s) of the intervention on learners' sense-making of the topic. In this sub-section, the data are presented in two sets: (a) learners' responses to the post-test questions, and (b) the learners' post-test and pre-test results.

5.4.3.1 Findings: learners' responses to the post-test questions

In this sub-section, I present the learners' responses to the post-test questions in terms of whether they indicate sense-making improved or not. I also present how a certain number of learners answered each question in this test. This made the analysis manageable, which successfully led to identification of the influences on learners' sense-making of the topic inculcated by the intervention. The change in the number of learners correctly answering each question in the post-test in comparison to the pre-test indicated the influences of an intersemiotic complementarity teaching approach on learners' sense-making of the topic.

(a) Question 1 (The relationship between the atomic structure and the periodic table)

I set this question to test the learners' ability to identify the group and period numbers of atoms of unidentified elements from their Bohr diagrams. This is knowledge of the periodic table in relation to an atomic structure, which is an introduction to basic chemistry concepts. I did this with the Bohr diagram of a nitrogen atom, shown in Figure 17. I allocated two marks to this question.

Figure 17. A Bohr diagram of an atom an unidentified element (provided by the teacher in the post-test)

Among thirty-eight learners who answered this question, only five could not correctly identify either the group or the period number of this element. Learner M, one of the five learners, did not score any mark due to interchangeably identifying groups and periods. Thirty-three learners scored full marks for this question. This was astonishing, because only twenty-two learners scored full marks for a similar question in the pre-test. This indicated that the learners' fundamental knowledge of the relationship between an atomic structure and the periodic table improved substantially during Cycle 2. Moreover, the sense-making type involved in accessing this knowledge was chemical bonding facts – learners making sense of abstract objects and processes of chemical knowledge – which is more aligned to science. This knowledge is sub-microscopic as it concerns microscopic entities of matter, and therefore learners being conversant with it after Cycle 2 were an indication of improved sense-making of the topic.

(b) Question 2 (The relationship between atoms, molecules, and the bonding process)

This question was set to test the learners' knowledge of the atom-molecule relationship and the bonding process. Answering this question was guided by the simplified Bohr diagram of the covalent bond in a carbon dioxide molecule, as shown in Figure 18.

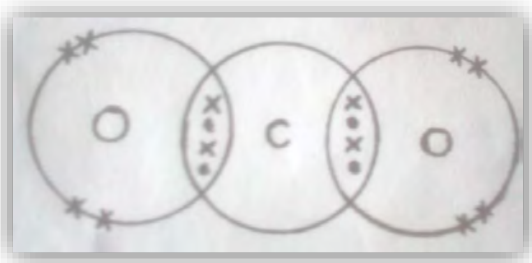


Figure 18. A Bohr diagram of a carbon dioxide molecule (Taken from the post-test)

I allocated three marks to this question. Among thirty-eight learners, three scored full marks for this question, thirty-one scored either two or one, and four did not score any marks. Comparing the learners' performance on this question to the similar question asked in the pre-test revealed a slight improvement, as the number of learners scoring full marks increased from zero to three.

I set Questions 2(a), (b), and (c) to test the learners' ability to distinguish between atoms and molecules. Even though only three learners scored full marks for this question, many learners managed to distinguish between atoms and molecules. They identified the circles labelled O and C as representing atoms of elements, and the combination of these circles as representing a molecule. This reveals a slight improvement in the learners' knowledge of the relationship between atoms and molecules, because many learners had difficulty doing the same in the pre-test. Knowledge of the relationship between atoms and molecules is also sub-microscopic, as it concerns microscopic particles that are non-observable and difficult to understand (Johnstone, 1982). The sense-making type involved in accessing this knowledge is chemical bonding facts, because atoms and molecules are abstract entities of chemical bonding. This reveals that the learners' sense-making of chemical bonding facts was better in Cycle 2 than in Cycle 1.

(c) Question 3 (Bond type identification)

This question was set to investigate learners' ability to identify bond types from bond diagrams. I did this with a fluorine molecule (two fluorine atoms bonded), shown in Figure 19. Learners were also asked to identify the side, whether left or right, of the periodic table where this element is located. Four marks were allocated to this question.

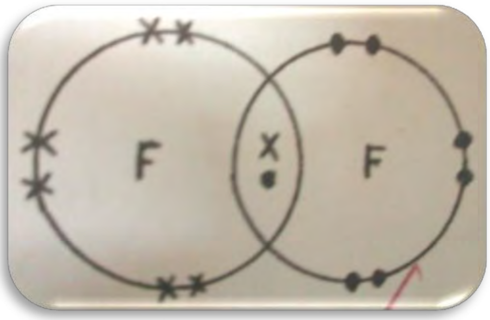


Figure 19. A bond diagram of a fluorine molecule (Taken from the post-test)

The visual-verbal intersemiotic complementarity was incorporated in the diagram in the form of visible overlapped shells, which collocated with 'covalent bond' as a lexical item. Moreover, the visible pair of electrons in the overlap is synonymous with the lexical item 'share' (a concept describing covalent bonding). This means that this knowledge was presented to learners in both visual and verbal modes coordinated for them to have a better chance of understanding the question than if it was presented in only one semiotic mode.

Remarkably, an improvement was noticed in how the learners answered this question in the post-test compared to how they attempted it in the pre-test. In the pre-test, only four learners scored full marks, while in the post-test, the number of learners who scored full marks rose to sixteen. They correctly stated that the type of chemical bond formed between the two fluorine atoms is covalent, and reasoned that it involved the sharing of electrons. They also identified these two atoms as belonging to an element on the right side of the periodic table, reasoning that all non-metal elements are located on the right side of the periodic table.

Moreover, the number of learners who scored three, or half, of the marks increased from fifteen in the pre-test to eighteen in the post-test. These learners lost either one or two marks for this question, indicating that they mostly understood the knowledge being tested. Incorrect answers that these learners provided involved 'protons shared' instead of 'electrons shared', and 'atoms giving away electrons' instead of 'atoms sharing electrons'. However, these errors were fewer in the post-test than in the pre-test. Few learners incorrectly mentioned that the two atoms in a molecule belong to an element found on the left side of the periodic table. The correct location of this element is the left, because it is where all non-metals are located in the periodic table. However, the average learners' performance on this question showed a substantial improvement in their understanding of covalent bonding. The sense-making of chemical bonding applied by the learners for this knowledge was clarification, where learners clarified the chemical process (Johnstone, 1993), such as the covalent bond in a fluorine molecule. These data reveal that their ability to clarify the sub-microscopic knowledge of covalent bonding was enhanced during Cycle 2.

(d) Question 4 (Determining the charge of ions)

This question assessed the learners' knowledge of charges formed when atoms lose or gain electrons. Learners were given the Bohr diagram of a sulphur atom. This diagram (Figure 20) shows the number of neutrons, protons, and electrons in a sulphur atom.

Figure 20. A Bohr diagram of a sulphur atom (Taken from the post-test)

This question was divided into two sub-questions assessing two knowledge aspects: (a) the charge this atom forms when it becomes an ion, and the reason for the answer given; and (b) the metallic nature of sulphur. The correct answer for the first questions is that the charge is -2 due to this element having a valency of two (it requires two electrons in order to attain a noble gas structure). The correct answer for the second question is that sulphur is a non-metal element.

I allocated three marks to this question, as I did with the corresponding question in the pre-test. This question was answered more correctly than its corresponding question in the pre-test. Unlike in the pre-test, where only seven learners scored full marks, the post-test had nineteen learners scoring full marks for this question. Seven learners managed to score two thirds of the available marks for this question, which shows that they understood much of the knowledge being tested. However, the number of learners who scored either one mark or no marks was still high – but lower than in the pre-test. Some of the common errors I identified involve some learners referring to a sulphur atom as becoming a cation, and others stating that it has a charge of +2. Other learners explained incorrectly that a sulphur atom loses two electrons to form a charge of +2. Some learners did not even attempt to answer this question. Despite some missing and incorrect answers, the overall learners' performance on this question was far better in the post-test than in the pre-test.

(e) Question 5 (Ionic bond and its bond strength)

This question assessed the same knowledge of chemical bonding as its corresponding question (Question 5) in the pre-test. I set this question to explore ionic bonding knowledge. In the pre-test, the learners were provided with the Bohr diagram of the bond between sodium and fluorine, while in the post-test, they were provided with the Bohr diagram of the bond between calcium and oxygen. The slight difference between these two questions was that the bond between sodium and fluorine only involves one electron being transferred, while the bond between calcium and oxygen involves two electrons being transferred. This question was presented via the coordinated visual and verbal semiotic modes, using the sense relations of similarity and collocation. Figure 21 shows this Bohr diagram of the bond between calcium and oxygen atoms.

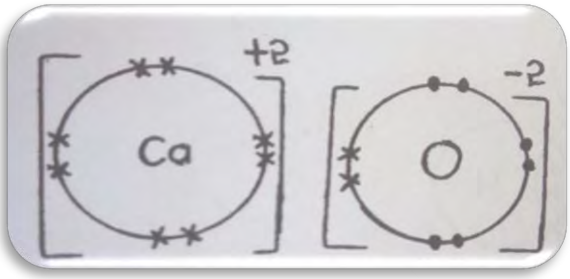


Figure 21. A Bohr diagram of the bond between calcium and oxygen atoms (Taken from the post-test)

This question was divided into two sub-questions [5(a) and 5(b)] that totalled two marks. Question 5(a) asked learners to identify a feature on the diagram that showed that the bond is ionic. The two electrons indicated by crosses in an oxygen ion collocates with the lexical items ‘calcium lost electrons’ and ‘oxygen gained electrons’, which is only applicable to ionic bonding. I expected these learners to mention electrons lost or gained, opposite charges formed, and the bond involving a metal and a non-metal. The visible structural diagrams of calcium and oxygen ions were similar to ‘metal and non-metal atoms bonded together’, to remind learners that the bond is ionic. The charges also indicated that the bond was ionic, as this is the only bond where both positive and negative ions are formed. Question 5(b) asked learners to identify the feature on the diagram that shows that the bond in calcium oxide is strong. The visible signs of the positive and negative charges collocated with the lexical item ‘strong forces of attraction’. Learners’ explanation of the bond strength in ionic substances revealed that their sense-making via clarifying was enhanced, since they were able to clarify sub-microscopic knowledge of ionic bonding, which is often a challenge to many learners, as Johnstone (1982) suggests.

The number of learners who did not score full marks for this question decreased from twenty-eight in the pre-test to twenty-one in the post-test, and the number of learners who did not score any marks, either because of giving an incorrect answer or not answering the question, decreased from seventeen to nine. This indicated that their sense-making of the knowledge tested improved. Despite this improvement, some learning difficulties on this knowledge persisted. I noticed this as several learners stated that the bond in calcium oxide is ionic because all shells are now full. This reasoning is incorrect, as a bond type is not determined by whether outer shells are full or not, but rather by the metallic nature of elements bonded. Other learners stated that the bond in calcium oxide is strong since calcium oxide does not dissolve in water easily. This answer is also incorrect because the bond strength is determined by opposite charges between ions of the bonded elements, not by the solubility of a substance.

Overall, I noticed from the findings above that there was a substantial improvement between Cycle 1 and Cycle 2 in terms of how learners make sense of ionic bonding and bond strength in ionic compounds. This indicated to me that many learners could make links between this macroscopic phenomenon (the bond between metals and non-metals), and its sub-microscopic model (the electron transfer process), as mentioned by Gilbert and Treagust (2009). The fact that many learners could explain ionic bonding by referring to electron transfer and the electrostatic attractive force between the oppositely charged ions testified that their ability to use sub-microscopic knowledge (rather than using only their macroscopic knowledge) to elaborate on chemical knowledge was improved.

(f) Question 6 (Ions, names, and formulae formed in ionic bonding)

Question 6 in the post-test differed slightly from its corresponding question in the pre-test. While both questions tested learners' ability to identify ions, write names, and deduce chemical formulae of ionic compounds, the pre-test used sodium chloride as an example, while question 6 in the post-test tested this knowledge with the bond in magnesium fluoride. The diagram in Figure 22 was drawn to guide learners in answering this question.

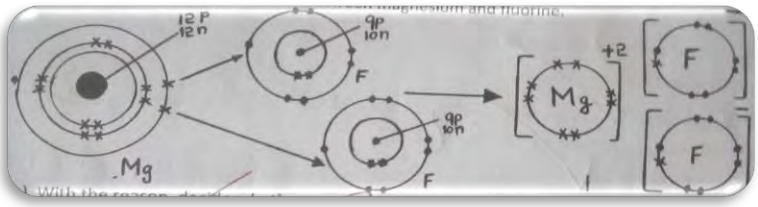


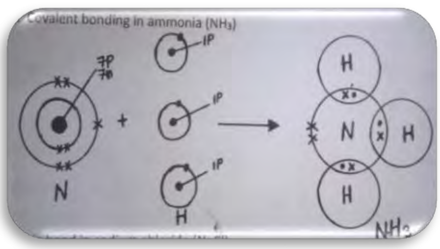
Figure 22. A Bohr diagram of the bond between magnesium and fluorine atoms (taken from the post-test)

This question consisted of three sub-questions: Question 6(a), which asked learners to classify a magnesium ion as either an anion or a cation; Question 6(b), which required learners to write down the chemical name of the compound formed; and Question 6(c), which asked the learners to write down the chemical formula of the compound formed. These sub-questions were worth four marks in total. I divided the learners' performance on this question into three groups: those who scored full marks, those who scored half or three quarters of the total marks, and those who scored one mark or no marks. There were sixteen learners who scored full marks, nineteen learners who scored either half or three quarters of the total marks, and three learners who either scored one mark or no marks. In total, the number of learners who scored marks for this question was thirty-five. This performance was better than in the pre-test, where only twenty-seven learners scored any marks.

The sixteen learners who managed to score all four marks stated that an ion formed by a magnesium atom is a cation. They reasoned that this atom loses two electrons, which are transferred to two fluorine atoms. They also managed to correctly write both the name and formula of the compound formed – the name is magnesium fluoride and the formula is MgF_2. This indicated that they had developed an ability to grasp both the sub-microscopic and the symbolic knowledge in the same way they had done with the macroscopic knowledge of chemical bonding. However, learners who did not score all marks for this question revealed that they were unable to access both the sub-microscopic and symbolic levels of representation of chemical knowledge. Several of them stated that a magnesium atom forms an anion. This is incorrect because magnesium is a metal, and atoms of metal elements form cations due to their tendency to lose electrons during a bond. Other learners incorrectly wrote the formula for the compound formed as Mg_2F or MgF. This revealed that they did not know how charges are used to deduce formulae of ionic compounds. Nevertheless, the overall learners' performance on this question demonstrated an improvement in learners' sense-making of the knowledge of ions, likely as a product of the teaching intervention.

(g) Question 7 (Distinguishing between covalent and ionic bonding)

As in the pre-test, this question was guided by the bond diagrams of two compounds: ammonia and sodium chloride. The bond in ammonia is covalent, while the bond in sodium chloride is ionic. The above-mentioned diagrams are shown in Figure 23.

(a)


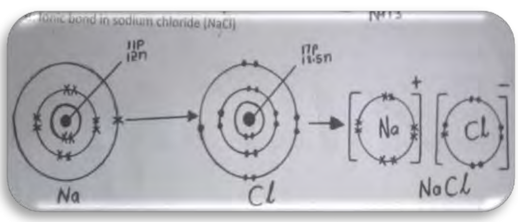
(b)


Figure 23. The Bohr diagrams of the bonds in ammonia and sodium chloride (Taken from the post-test)

I divided Question 7 into two sub-questions: Question 7(a), which tested the learners' knowledge of the sharing and transferring of electrons, and the strength of the bond formed; and Question 7(b), which tested the learners' knowledge of using the periodic table to draw the ionic bond in sodium chloride. I allocated seven marks to this question.

I found that twenty-one learners managed to score all possible marks for this question. They could therefore correctly explain what happens to the outer shell electrons of the atoms that make up ammonia and those that make up sodium chloride. They also managed to correctly classify the bond in both ammonia and sodium chloride as either strong or weak. This indicated that these learners had no difficulty with the sub-microscopic representation of chemical bonding related to bond strength. Interestingly, all these learners represented the ionic bond between magnesium and fluorine in Question 6 correctly.

Among learners who did not score all the marks were those who managed to get half of the marks and above. This was true of nine learners in total; however, these learners also demonstrated that their sense-making of the knowledge had improved. Many of them scored six marks – they were therefore close to scoring all marks available. Interestingly, these learners managed to explain correctly the bond in an ammonia molecule as involving electron sharing, and in sodium chloride as involving electron transfer. Even though a few misconceptions were identified, such as ammonia gaining three electrons and seven protons in outer shells, the learners' performance on this question in the post-test was remarkably better than their performance in the pre-test.

5.4.3.2 The comparison between the learners' pre-test and post-test marks

In addition to analysing the learners' responses to the post-test questions, I recorded the learners' scores in the pre-test and post-test in Table 19 for comparison. This table consists of three columns; the first column contains the pre-test marks, the second column contains the post-test marks, and the third column shows the difference between the marks scored in these tests.

The difference between the post-test and pre-test marks was found by subtracting each learner's pre-test marks from his/her post-test marks. I listed learners in the table starting with those who improved most and continuing to those who did not improve. The last four rows were added to compare the overall learners' performance by determining the highest, lowest, and mean scores.

Table 19. Learners' pre-test and post-test marks

Learner	Pre-test (Marks: 25)	Post-test (Marks: 25)	Difference (post-test score minus pre-test score)
L33	5	22	+17
L31	7	22	+15
L34	5	17	+15
L19	12	22	+10
L16	13	23	+10
L20	12	21	+9
L23	11	19	+8
L17	13	21	+8
L10	15	23	+8
L36	2	10	+8
L18	13	20	+7
L37	2	9	+7
L21	12	18	+6
L22	12	18	+6
L27	9	15	+6
L35	2	8	+6
L7	17	23	+6
L38	2	8	+6
L30	8	13	+5
L15	14	19	+5
L11	15	20	+5
L12	15	19	+4
L1	20	24	+4
L26	10	14	+4
L8	16	20	+4
L6	17	21	+4
L28	9	13	+4
L4	18	22	+4

L2	19	22	+3
L9	16	19	+3
L3	19	22	+3
L24	11	14	+3
L13	15	17	+2
L29	9	11	+2
L32	7	8	+1
L14	15	16	+1
L25	11	11	0
L5	18	15	-3
Highest score	**20**	**24**	
Lowest score	**2**	**8**	
Mean score	**12**	**17**	
Total score	**466**	**659**	

As shown in Table 19, thirty-five learners who wrote the post-test showed a significant improvement in performance. The most improved learner had a difference in marks of +17, while the least improved learner had a mark difference of +1. Both the highest and the lowest scores were higher in the post-test than in the pre-test. The mean score increased from twelve marks (48%) in the pre-test to seventeen marks (68%) in the post-test. These collectively show that the intervention had positive influences on the learners' sense-making of chemical bonding.

5.5 Conclusion

This chapter presents the findings in three data sets, as discussed in Section 5.1. The first data set concerns the visual-verbal demands that the curricular documents make on the topic of chemical bonding. This information was necessary for preparing visual-verbal notes and lesson presentation. The analysis of these documents revealed a need, and identified specific requirements and the means for preparing the hypothetical pedagogy of this topic that was explored in this study. The second data set concerns the knowledge of chemical bonding constructed by learners after their exposure to a traditional teaching approach. The compelling evidence revealed that sense-making of this topic was a challenge, and this led to further identification of knowledge aspects that needed serious attention, and the means to address them during Cycle 2 of this action research study. The visual-verbal sense relations of intersemiotic complementarity were the means explored during Cycle 2, using data collection tools, and they revealed a shift in sense-making of the topic from being less aligned to being more aligned to science. Chapter 6 summarises these findings, their implications, and the recommendations thereof.

CHAPTER 6: SUMMARY OF FINDINGS, RECOMMENDATIONS, AND CONCLUSION

6.1 Introduction

As mentioned earlier, various data sets in this study were collected to explore the influences of visual-verbal intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding. I explored the influences of this pedagogic approach to ascertain whether they have potential for realising the JS Physical Science syllabus' expectation of learners exiting the phase with an understanding of, and ability to illustrate, both covalent and ionic bonding (Namibia. MoEAC, 2015). This study was informed by scholarly perspectives on multimodal discourse analysis of Systemic Functional Linguistics (Lemke, 2000; Chittleborough & Treagust, 2008; O'Halloran, 2008, 2011), intersemiotic complementarity (Royce, 1998; Talanquer, 2011; Gilbert & Treagust, 2009), social constructivism (Vygotsky, 1978; Gredler, 1997; Kim, 2006), and sense-making (Solomon, 1997; Zimmerman et. al., 2009).

This study took the form of education action research consisting of two cycles: Cycle 1, which was taught in the traditional way, and Cycle 2, which involved the intersemiotic complementarity teaching intervention. The results obtained during Cycle 1 were used to inform the intervention undertaken during Cycle 2. Improving reliability of this study was achieved by piloting the research tools, such as the document analysis sheet, structured lesson observation sheets, teacher's and learners' reflective journals, and learners' pre- and post-tests. Reliability of this study was also improved by triangulation, as collecting the same sets of data with these different research tools enhances validity of the findings. Piloting of these tools was undertaken with the Grade 8 learners at the same school. The discussion in Chapter 5 presented detailed findings indicating the positive influences of an intersemiotic complementarity teaching approach on Grade 9 learners' sense-making of chemical bonding. This chapter comprises the summarised findings of this study, the recommendations that arose from these findings, and the conclusion drawn.

6.2 Summary of findings

Exploring the influences of an intersemiotic complementarity teaching approach on learners' sense-making of chemical bonding was led by one main research question, from which three research sub-questions were formulated. These are outlined in Chapter 1, and explained in detail in Chapter 4, Section 4.2.

Answering these sub-questions required three related data sets: the visual-verbal demands of the curriculum; the learners' knowledge of chemical bonding after a traditional teaching approach; and the influences of the coordinated visual-verbal intersemiotic complementarity teaching approach on learners' sense-making of chemical bonding. These data sets are related in that the first data set informed the collection of both the second and third data sets, and the second data set informed the collection of the third data set.

The first data set related to the visual-verbal demands of the curriculum, collected during Cycle 1. I determined this set of data by analysing the Grade 9 Physical Science syllabus' learning expectations on chemical bonding, including how these expectations are addressed by the prescribed Grade 9 Physical Science textbook. I also collected the second data set during Cycle 1. It concerned the knowledge of chemical bonding that the Grade 9 Namibian learners had following a traditional teaching approach. The third data set was collected during Cycle 2 of this action research, and comprised forms into which learners' sense-making of chemical bonding was shaped by the coordinated visual-verbal intersemiotic complementarity teaching approach. Cycle 2 was the intervention where a hypothetical teaching approach was employed, and then explored in terms of the influences it had on learners' sense-making of chemical bonding.

6.2.1 The visual-verbal demands of the curriculum (Cycle 1)

Knowledge of the visual-verbal demands of the curriculum was obtained by analysing three curricular documents: the broad National Curriculum for Basic Education (Namibia. MoEAC, 2015), the Grade 9 Physical Science syllabus (Namibia. MoEAC, 2015), and the Physical Science textbook (Haimbangu, Poulton & Rehder, 2016). These documents are interrelated, as the broad National Curriculum informs syllabi documentation, which guides textbook publication (Namibia. MoEAC, 2015). The analysis of these documents provided answers to the first research sub-question: The findings highlighted the need to use the visual and verbal semiotic modes in teaching (with no specifications of how).

The data regarding the curriculum's visual-verbal demands were collected prior to the traditional teaching of chemical bonding in order to inform planning of the prototype lessons in Cycle 1 and the benchmark lessons in Cycle 2, as outlined in Chapter 4. The curriculum document broadly suggests that visuals are needed for learners to use learning skills such as investigation, interpretation, analysis, and evaluation (Namibia. MoEAC, 2015). In addition, it suggests teaching and learning should be done via mixed modes, such as written and visual or oral and visual works (Namibia. MoEAC, 2015). This revealed that the potential possessed by the visuals and other semiotic modes in making meaning is recognised by the curriculum developers. This confirmed that a dire need to use the coordinated visual and verbal modes in teaching exists and is recognised in Namibia; however, no details appear in the curriculum as to how this may be undertaken.

The documentation of the Grade 9 Namibian Physical Science syllabus did not directly consider the coordinated use of the visual and verbal semiotic modes – though this document is more specific on how teaching of chemical bonding should be undertaken. I realised this deficiency in that no specifications were made by the syllabus as to how chemical bonding may be taught via the coordinated visual and verbal modes, even though it suggests that combining visual and verbal modes is necessary. This coordinated use of visual and verbal modes, according to Gilbert and Treagust (2009), is necessary for helping learners to depict chemical models, which are central to accessing chemical knowledge. Moreover, Pozzer and Roth (2003) suggest that it enhances understanding of the sub-microscopic knowledge of chemical bonding, which is considered as challenging. This provided a rationale for undertaking a teaching intervention during Cycle 2 of this action research study that employed the coordinated visual-verbal semiotic modes in order to explore the influences they would have on learners' sense-making of chemical bonding. In short, analysing the syllabus revealed that there was a need to explore and employ the combined visual and verbal semiotic modes in teaching chemical bonding. These visual-verbal demands of the syllabus include the need to effectively use Bohr diagrams, and physical models of atoms, molecules, and ions, together with spoken or written words. This is achievable by coordinating the sense relations of visual-verbal intersemiotic complementarity for use as a teaching approach, as explained in Chapter 3.

Other data on the visual-verbal demands of the curriculum were collected from analysing the Physical Science textbook for Grade 9, as stated in Chapter 4. The word 'verbal' grammatically refers to spoken words. However, I adopted the use of this word from Royce (1998), where it is used to refer to either written or spoken words, implying that spoken words are presented in written forms in textbooks. I analysed each of the verbal and visual semiotic modes used in this textbook separately – drawing from ideas of various scholars on multimodality. This simplified identification of the teaching and learning needs that arise, even though some scholars critique the individual use of these semiotic modes (visual and verbal), while others critique their complementary use in the teaching and learning process.

I realised that difficult lexical items (difficult content/technical words in a clause or sentence) of chemical bonding knowledge are used excessively in this textbook, at the expense of the visual items that have potential to enhance learners' sense-making of the topic. Unsworth (2006) critiques this solitary and excessive use of the verbal (either spoken or written) semiotic mode in teaching and learning, arguing that it is compounded by lexical difficulty. He further argues that this is worst with learners who are not proficient in the Language of Learning and Teaching (LoLT). These learners have problems with the LoLT, and their teachers, struggle with the same problem (as per the Teachers' Language Proficiency Test), compounding the issue.

I found that grammar use in the textbook did not consider the learners' low proficiency level in the LoLT. I noticed this in a teacher needing to compile learners' notes in simpler language to help them better understand knowledge of chemical bonding. This shows grammatical complexity (complexity of the language used) (Unsworth, 2006), which has the potential to negatively affect both teaching and learning of chemical knowledge.

I found that the visual mode, in the form of Bohr diagrams of atomic and bonding structures, is used implicitly in this textbook, creating a high possibility of confusion in learners. This includes Bohr diagrams of chemical bonding not being clear enough to help learners make a distinction between metal and non-metal elements. This hinders the inherent potential of the visual mode to make explicit the explanation of mental models of microscopic particles and their behaviour (Gilbert, et al., 2000), and to develop engagement of, and motivation in, learners (Gilbert & Treagust, 2009).

The analysis of the use of the visual and verbal modes in the textbook revealed that there is a need to employ these modes in their coordinated form. This is achievable by using both physical models and diagrams of atoms of elements, and ions and molecules of compounds, together with words describing them. This information was used in preparing learners' notes that coordinate the visual and verbal modes, as the textbook was not explicit enough to make learners understand knowledge of chemical bonding.

6.2.2 Grade 9 learners' knowledge of chemical bonding after the traditional teaching approach (Cycle 1)

I accessed learners' knowledge of chemical bonding after the traditional teaching approach in this study by analysing their sense-making of it. Sense-making was assessed on how learners linked theories to evidence as Zangori et al. (2013) suggest. This was accomplished by analysing five sense-making types (discussed in Chapter 2). The findings showed that learners possessed insufficient knowledge of chemical bonding, and hence there a need for an intervention aimed at addressing this problem.

The perceptual (descriptive) sense-making type is least aligned to scientific facts and theories, and refers to when learners describe, identify, and count concrete objects and processes of chemical bonding that they perceive. This sense-making theme is followed by the chemical bonding facts theme, which is more aligned to scientific facts and rules than is the perceptual sense-making. This is realisable in learners talking or visualising abstract concepts, objects, and processes of chemical bonding knowledge. The third sense-making theme, which is scientific than the first two, is the connecting and analysing theme, realisable in learners making links between the knowledge aspects they learn. During this sense-making type, learners analyse their prior knowledge and compare it to the knowledge they have newly gained (Zimmerman et al., 2009). The fourth sense-making theme, and that second most aligned to science, is clarification, which is realisable in learners using talk and visuals in clarifying processes of chemical bonding, including their application in real life. The fifth and most scientific sense-making theme is the ideas about chemical bonding theme, which is realisable in learners involving themselves in discourse (discussing or debating) by drawing from or relating to ideas of chemical bonding knowledge. During this sense-making type, scientific reasoning, as a means of explaining chemical knowledge, is most important. These sense-making types were used to analyse sense-making of chemical bonding across the data gathered via structured lesson observation, teacher's and learners' reflective journals, and pre-testing. The analysis revealed that the learners' knowledge of chemical bonding after the traditional teaching approach was insufficient and non-scientific.

Structured lesson observation during Cycle 1 revealed that the knowledge of chemical bonding that learners possessed was insufficient. This means their sense-making of the knowledge was mainly perceptual, as it concerned knowledge of what learners observed, and was not based on scientific facts and reasoning. Moreover, much of this knowledge is represented macroscopically, as it usually concerns observable objects and processes of chemical bonding. I accessed this information by assessing the sense-making types involved, as well as classifying the knowledge possessed by learners as macroscopic, sub-microscopic, or symbolic. I found that sense-making during this cycle was enabled for a few knowledge aspects, and constrained for many knowledge aspects of chemical bonding.

The structured lesson observation revealed that the sense-making types enabled in Cycle 1 were the perceptual, and the chemical bonding facts. The perceptual sense-making of chemical bonding knowledge was realised in learners describing, counting, and identifying knowledge aspects of the topic. Moreover, knowledge of chemical bonding that learners accessed by performing perceptual activities was dominantly macroscopic, as it concerned observable aspects of chemical bonding. However, this does not indicate sufficient scientific sense-making, as the perceptual activities performed and the macroscopic knowledge accessed by the learners would not equip them with knowledge of chemical bonding at the particulate level. The fact-based sense-making of chemical bonding also occurred during this cycle. I realised this in many learners using slightly more abstract concepts and processes of chemical bonding. This showed that their sense-making of the topic was becoming more aligned to science, as learners could consider, and use, scientific facts and theories when describing this knowledge. In sum, the perceptual and chemical bonding facts sense-making were enabled by the traditional teaching approach, and while important, they are weaker forms of sense-making in science compared to the other types.

The connecting and analysing sense-making type was among the remaining three types that were constrained by the traditional teaching approach used. Even though this sense-making type is more aligned to scientific rules and theories than the first two types, structured lesson observation revealed it to be unsuccessfully achieved. This negatively impacted on learners' sense-making of chemical bonding, as they could not use their prior knowledge or past experience to access this chemical knowledge. I found that learners were unable to link their knowledge of valency to determining electron structures of ions and deducing formulae of ionic compounds. Moreover, learners who were able to access this knowledge via connecting and analysing were fewer than those who were unable to access it, indicating that this sense-making was generally unsuccessful following the traditional teaching approach employed in Cycle 1.

I found that the last two sense-making types, the clarification and the ideas about chemical bonding facts, were most constrained by the traditional teaching approach used in Cycle 1, despite them being more aligned to scientific sense-making. I noticed difficulty making sense via clarification in learners struggling to elucidate the processes of chemical bonding, as much of the knowledge they portrayed was rote-learned. Explaining the properties of both covalent and ionic compounds was one example of chemical bonding knowledge rote-learnt by the learners. In addition, this knowledge was dominantly macroscopic, as properties of compounds are observable – learners had no difficulty mentioning them. However, this does not sufficiently cover knowledge of chemical bonding, as knowledge of particles in substances in relation to their physical properties is not accessed. The ideas about the nature of chemical bonding overlaps strongly with scientific sense-making; however, I found that only a few learners managed to make sense of chemical bonding knowledge at this level. Many of them were unable to participate in classroom discourse (discuss or debate) by drawing from or relating to the theories and principles of chemical bonding that had been taught. Failure to constructively debate about the bond between lithium and oxygen was one example of this.

In summary, structured lesson observation revealed the need to employ the visual-verbal intersemiotic complementarity teaching approach. This was deduced from the fact that only the perceptual and fact-based sense-making types were successful, and these are the least aligned to scientific facts and rules. The other three types of sense-making, which are more aligned to science than the first two types, were poorly engaged in by the learners. This helped with understanding the reason for many Namibian Science learners' poor performance in the topic of chemical bonding when they reach Grade 10 – the traditional approach (which does not consider intersemiotic complementarity) only activates lower order sense-making types that are associated more with the macroscopic level.

Considering the fact that reflective journals provide first-hand data (Gay et al., 2009), evidence from both the teacher's and learners' reflective journals played a significant role in ascertaining whether or not chemical bonding knowledge was successfully gained during Cycle 1. This was achieved by gauging and analysing the sense-making types identified in the learner talk and visuals, as it was done with structured lesson observation.

The teacher's reflective journals revealed that only two sense-making types occurred successfully during Cycle 1: the perceptual and the chemical bonding facts sense-making types. Perceptual sense-making was recognised as successfully occurring, as many learners were able to perform perceptual activities (identifying, counting, and describing) on chemical bonding sub-topics. The success in chemical bonding sense-making was realised in many learners using more abstract chemical bonding concepts when explaining the relationship between the periodic table and the atomic structure. However, this sense-making only occurred to a limited degree. This was noticed in some learners rarely using abstract chemical bonding concepts in explaining the relationship between the periodic table and the atomic structure. Notwithstanding this impeded knowledge of chemical bonding, both the perceptual and the fact-based sense-making were regarded as having successfully occurred.

The sense-making types I found to be unsuccessful during Cycle 1 were the connecting and analysing, clarification, and ideas about chemical bonding sense-making types. I discerned lack of connecting and analysing in learners failing to illustrate bonding, deduce formulae, and identify ions comprising an ionic compound. This showed that they had difficulty connecting the knowledge they already had to the knowledge being taught. I noticed lack of clarification in learners failing to explain processes of covalent bonding, and an electron transfer or sharing concept. This may be due to the fact that their knowledge was limited, and thus they could not provide details related to valency and attainment of noble gas structures of some non-metal atoms. This revealed their lack of sense-making of covalent bonding via clarifying behaviours and processes of non-metal atoms, which are microscopic. The lack of ideas about the nature of chemical bonding was discerned in learners engaging in classroom debates and discussions without supporting their claims and arguments with facts and rules of chemical bonding.

The learners' reflective journals generally unveiled knowledge of chemical bonding as challenging to learners during Cycle 1. This was realised in the two data sets: learners' knowledge of covalent bonding, and learners' knowledge of ionic bonding. It should be noted that learners were identified as having varied abilities and difficulties – some understood this chemical knowledge, while others had difficulty accessing it.

The knowledge of chemical bonding that some learners revealed as not challenging included knowledge of the periodic table, atomic structure, electron arrangement, and types of chemical bonding. These learners stated clearly that they had no difficulty using the periodic table, and this enabled them to access knowledge of the atomic structures of the first 20 elements in the periodic table, as expected by the Physical Science syllabus. Many of them further stated that they had no problem with the electron arrangement of atoms of these elements. This aided their understanding of covalent bonding, as this chemical knowledge is relevant for understanding noble gas structures, valency and electron sharing, which are the key concepts for explaining covalent bonding. Though several learners stated their understanding of these topics, it was concluded that this knowledge was generally inadequately possessed.

As mentioned previously, the majority of learners revealed that the challenging knowledge of covalent bonding was dominant over the gained knowledge of covalent bonding. They indicated confusion with using the periodic table and understanding the Bohr structures of atoms of the first 20 elements – which are pre-requisites to learning covalent bonding. They mostly could not distinguish between groups and periods, and the relation of these to atomic structures. Moreover, many of them revealed that they had difficulty with the atomic structure. I suspected that this learning difficulty reduced their ability to understand an atomic model, valency, and electron sharing. Overall, there was a large disparity between the knowledge gained and the challenging knowledge of covalent bonding, as evident from so many learners describing this knowledge as a challenge. These findings guided the plan to consider knowledge of covalent bonding for the intervention, to teach the topic via verbal and visual modes integrated.

During Cycle 1 (where a traditional teaching approach was used), it was explicit from the learners' reflective journals that accessing knowledge of ionic bonding was hugely constrained, though there were some traces of it being successfully learned. This was recognised from the excerpts taken from these reflective journals. Moreover, it was recognised that this knowledge was not uniformly acquired or uniformly constrained, because what was understood by different learners varied. Most of these excerpts either revealed learners arguing that certain knowledge aspects of ionic bonding were difficult, or learners requesting that the teacher explain this bond type more clearly. However, some excerpts of learner talk revealed that several learners had no difficulty accessing this chemical knowledge. These learners were few compared to those who had difficulty with this knowledge, revealing that sense-making of this knowledge was generally hampered.

The learners' challenge in learning ionic bonding was due to a lack of the fundamental knowledge that concerns the periodic table and the atomic structure. Many learners could not apply knowledge of valency and noble gas structure. Accessing this knowledge was hindered by their lack of knowledge of the periodic table and atomic structure. This knowledge is essential for accessing knowledge of ionic bonding. Knowledge of valency and noble gas structure would help learners to know the number of electrons lost or gained by an atom during ionic bonding for it to attain a stable (full) outer shell. Lack of this fundamental knowledge negatively impacted on the learners' ability to illustrate and explain ionic bonding knowledge, which includes ion formation, electrical conductivity, and bond strength. Therefore, I considered employing the visual-verbal intersemiotic complementarity teaching approach on knowledge of noble gas structure and valency, in order to explore its influences on learners' sense-making of these two knowledge aspects of ionic bonding.

The few learners who had no learning difficulty with knowledge of ionic bonding during this cycle (as per their reflective journals) understood the concepts of electron transfer, drawing of ionic bonding, and ion formation. This happened despite them learning this topic (ionic bonding) for the first time in Grade 9, unlike covalent bonding, which was first taught in Grade 8. These learners showed awareness of the electron transfer concept, which is critical for understanding ionic bonding. However, few learners having these knowledge aspects of chemical bonding was a sign that knowledge of ionic bonding was constrained – revealing that a teaching intervention considering these knowledge aspects was necessary.

In summary, both covalent, and ionic bonding, were found to have been constrained, based on more learners describing these knowledge aspects as challenging, in their reflective journals, than those claiming to understand them – the same way it was revealed by the teacher's reflective journal. This consolidated the decision that the intervention should not exclude knowledge of both covalent and ionic bonding.

I also employed the learners' pre-test towards the end of Cycle 1 as a data collection tool to assess the learners' knowledge of chemical bonding after employing the traditional teaching approach to this topic, as explained in Chapter 4. The assessment of learners' performance in the pre-test was two-fold: assessing learners' answers and assessing learners' marks. The outcome of these assessments confirmed the findings from the structured lesson observations and reflective journals.

I still found that many learners had difficulty using the periodic table, and subsequently understanding an atomic structure. One of the challenges I noticed in this test involved difficulty distinguishing between the groups and the periods of the periodic table. Gilbert and Treagust (2009) describe knowledge of the periodic table as central to learning other chemistry topics. Drawing from this idea, learners' lack of understanding of knowledge of the periodic table negatively affected their ability to access chemical knowledge related to atoms, molecules, and the bonding process. Other concepts of chemical bonding that were also affected by this difficulty involve identifying bond types, determining the charges of ions, and explaining bond strength in compounds. I noted that only a few learners did not have problems with knowledge of the periodic table.

The marks scored by the learners in this test also showed that knowledge of chemical bonding after the first cycle of teaching was insufficient. I discerned this information from three statistics from the test: highest score, lowest score, and mean score. This test had a total of 25 marks. I found that the learners' performance, as per these averages, was low towards the end of Cycle 1. Specifically, the learner with the highest performance scored 20 marks (80%), while the learner with the lowest performance scored 2 marks (8%). The mean score (average class performance) was 12 marks (48%), which is below 50%, and indicated that learners' general performance was low.

The learners' answers to the pre-test questions, and the marks they scored, collectively revealed that learners lacked thorough understanding of chemical bonding – their sense-making of the topic was of the type least aligned to science rules and facts. These findings concur with those of the structured lesson observations and the reflective journals. This concurrence strengthened the need to simultaneously employ and explore the influences of a visual-verbal intersemiotic complementarity teaching approach on learners' sense-making of chemical bonding.

6.2.3 The influences of visual-verbal intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding (Cycle 2)

During Cycle 1, the research undertaken accessed two data sets as summarised earlier in this section, and the findings informed planning and employing the visual-verbal intersemiotic complementarity teaching approach to chemical bonding undertaken in Cycle 2. The data collected during Cycle 2, showed positive influences of this teaching approach on learners' sense-making of this topic, as will now be summarised.

Analysing excerpts of learner talk, observed during the lessons, revealed the results of using the coordinated visual and verbal semiotic modes as a teaching approach to chemical bonding. This was enabled by evaluating and rating these excerpts according to the sense-making types that were regarded, in this study, as the determiners of sense-making of chemical knowledge. It was found that this teaching approach had positive influences on the learners' sense-making of chemical bonding knowledge, realised in an increased number of learners making statements and drawing diagrams that were more relevant to the topic.

Specifically, the positive influence of this teaching approach was noticed in a shift in the learners' sense-making of chemical bonding from being perceptual (least aligned to scientific facts and rules), through other sense-making indicators, to being idea-based (most aligned to scientific facts and rules). This shift was visible through a decrease in learners' talk and visuals that involved perceptual activities, and an increase in those that were based on facts and rules of science. Furthermore, learners used more abstract chemical bonding concepts, engaged in connecting and analysing skills, and were found to be clarifying chemical bonding process and using science ideas to defend or critique scientific claims. For example, learners changed from using general to specific science concepts and phrases, such as changing from 'particles' to 'atoms and molecules', 'atoms combining' to 'atoms bonding', and 'ionic solutions passing electricity' to 'ionic solutions conducting electricity'. These are some of the observations that confirmed the positive influences of this intervention on learner's sense-making of the topic. Therefore, the overall lesson observations concluded that the visual-verbal intersemiotic complementarity teaching approach did enhance understanding of chemical bonding by learners. Hence it was considered a suitable pedagogic approach to chemical bonding, and other chemistry topics.

The result of the analysis of the teacher's and learners' reflective journals revealed an improvement in the learners' sense-making of chemical bonding during Cycle 2, compared to Cycle 1. This improvement is evidence that the intervention had positive influences on learners' sense-making of chemical bonding.

Analysis of the results collected via the teacher's reflective journals revealed that Grade 9 learners' sense-making of chemical bonding shifted from being least aligned to most aligned to scientific facts and rules. This shift was noticed in a decrease in the number of learners performing perceptual activities (identifying, counting, and describing), and an increase in the number using facts and rules of chemical bonding. Knowledge of facts of chemical bonding, which was constrained during Cycle 1 due to using a traditional teaching approach, became enabled during Cycle 2 due to using the visual-verbal intersemiotic complementarity teaching approach. This was discerned in the decrease of learners' problems with abstract concepts of chemical bonding in Cycle 2. The learners being able to link their existing knowledge to their prior knowledge was recognised in many cases, including deducing formulae of ionic compounds by linking them to valency and noble gas structure. The idea-based sense-making of chemical bonding was noticed in learners explaining some of the chemical phenomena by referring to chemical bonding ideas. Therefore, the teacher's reflective journals also found that an intersemiotic complementarity teaching approach positively influenced learners' sense-making of chemical bonding.

Learners revealed in their reflective journals that their sense-making of chemical bonding was enhanced after a coordinated visual-verbal intersemiotic complementarity teaching approach was employed. The knowledge of chemical bonding that these learners described as challenging during Cycle 1 was in turn described as gained during Cycle 2.

It was evident from the learners' reflective journals in Cycle 2 that learners' sense-making of covalent bonding was enhanced following the intervention. This was noticed in learners not having problems with valency and the classification of elements in the periodic table, which was identified during Cycle 1. During Cycle 2, many learners described knowledge of classification of elements in the periodic table as easy. They further stated that drawing covalent bonds was not a problem to them, and some of them illustrated covalent compounds correctly in their reflective journals. Their enhanced sense-making of this knowledge was also recognised in their desire to understand bond strength to a greater degree. This desire was noted in some learners asking the teacher to explain, at the particulate level, why covalent compounds have weak bonds. Since the learners' remarks during Cycle 2 generally indicated that covalent bonding was easy, it was concluded that the intervention had enhanced sense-making in this topic.

The knowledge of ionic bonding that was found to be difficult during Cycle 1 was described as easy during Cycle 2. The learners testified that their knowledge of ionic bonding advanced during Cycle 2. This was seen in many of them being able to draw bond diagrams of simple ionic compounds, such as sodium chloride and magnesium chloride. However, many learners still did not illustrate the ionic bond in aluminium oxide correctly, while others had difficulty deducing its chemical formula. Despite these challenges, considering the fact that the bond in aluminium oxide is complex as it involves many atoms, and that only a few learners struggled with deducing formulae of other ionic compounds, I concluded that the teaching intervention had addressed the learners' problems with making sense of ionic bonding.

The analysis of the learners' answers to the post-test questions, and the marks they scored, confirmed the findings of the structured lesson observations and reflective journals that learners' sense-making of chemical bonding was enhanced – revealing that the intervention was effective. This was evident through comparing the findings of the post-test with those of the pre-test.

I noticed this improvement in the way the learners answered post-test questions during Cycle 2, compared to how they had answered pre-test questions during Cycle 1. Most answers to the post-test questions regarding the relationship between the periodic table and the atomic structure were correct – indicating that the learners possessed this knowledge. This test also revealed that the learners correctly made sense of how atoms and molecules are related. This was seen in them correctly identifying drawings of particles as either atoms or molecules. Moreover, these learners showed deeper understanding of both covalent and ionic bonds, by being able to draw bond diagrams and deduce formulae of ionic compounds. This indicated that the learners gained both sub-microscopic and symbolic knowledge of chemical bonding. In contrast, there were cases where these learners showed misunderstanding of some knowledge aspects of chemical bonding. However, this was less frequent in the post-test than in the pre-test.

The learners' marks in the post-test were higher than their marks in the pre-test. This was visible in the three marks averages (highest score, lowest score, and mean score). These made it evident that the intervention caused an improvement in the learners' performance, revealing that the visual-verbal intersemiotic complementarity teaching approach did improve learners' understanding of chemical bonding. Hence the recommendations related to the pedagogy of this topic arose from this study, and will now be presented.

6.3 Recommendations

I found from this action research study that the visual-verbal intersemiotic complementarity teaching approach had positive influences on learners' sense-making of chemical bonding. This suggests that it can be a suitable pedagogic approach to chemical bonding. I also realised that considering visual-verbal intersemiotic complementarity as a pedagogic approach to chemical bonding requires understanding of its (chemical bonding) complexity and representational levels, and the point where the visual and verbal semiotic modes complement each other to form a unified and comprehensible message. For these reasons, and other reasons that are also related to this study, the following recommendations are presented:

- The Ministry of Education, Arts, and Culture (MoEAC); the line ministries; agencies; and teacher-training institutions (University of Namibia, Namibia University of Science and Technology, International University of Management, etc.) should consider visual-verbal intersemiotic complementarity as a contributor to effective pedagogy for chemical bonding, and possibly other chemistry topics in Namibian schools. Therefore, it should be integrated in both pre-service and in-service training of all Physical Science teachers during training and continuing professional development activities.

- The curriculum review and development process for Namibian schools should recognise and consider the inherent potential possessed by coordinating the visual and verbal semiotic modes. I recommend that the curriculum should highlight the use of the coordinated visual-verbal semiotic modes in teaching.
- Science textbook publishing and other science-teaching material production should consider how visual and verbal semiotic modes contained within them could better complement each other.
- I, as a Grades 8 and 9 Physical Science teacher, should continually employ the visual-verbal intersemiotic complementarity teaching approach in chemical bonding, and consider its possible use in other chemistry topics and, if possible, on other science topics. These would form the next cycles for the action research to be expanded on.
- Other Physical Science teachers (after reading this thesis, attending my presentation on intersemiotic complementarity as a pedagogic approach, or consulting me) should use the visual-verbal intersemiotic complementarity as a teaching approach for chemical bonding by first understanding the nature and representational levels of chemical bonding, and how the visual and verbal modes complement each other to make a unified and comprehensible message.
- Planning visual-verbal lessons in this action research study was time consuming. Therefore, preparing for a visual-verbal lesson should be time conscious, proactive, and involve testing of materials prior to using them during the lesson.

6.4 Conclusion

This action research study explored the influences of the coordinated visual-verbal intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding. Undertaking it was informed by Systemic Functional Linguistics multimodal discourse analysis, where meanings are known to arise from the use of multiple semiotic resources other than language alone (O'Halloran, 2008). This study also considered Vygotsky's (1978) social constructivism, which recognises learning as being a product of social interaction, with more knowledgeable others being agents of this active process. The role of more knowledgeable others in this action research study was played by a Physical Science teacher (myself), who aided learners in reaching the zone of proximal development (ZPD), which is characterised by independent learning. The visual-verbal intersemiotic complementarity teaching approach in this study was achieved by using the various sense relations of ideational metafunction features of the two semiotic modes combined. Accessing the influences of this pedagogic approach on learners' sense-making of chemical bonding was enabled by coding the sense-making indicators of science discourse that are proposed by Zimmerman et al. (2009).

The results of this study reveal that the coordinated visual-verbal intersemiotic complementarity teaching approach had positive influences on learners' sense-making of chemical bonding. This was realised in the improvement of the learners' understanding of chemical bonding after employing the intersemiotic complementarity teaching approach in Cycle 2. First, this improvement was discerned in learners showing understanding of chemical bonding knowledge at all three levels of representations, and making connections between knowledge at any of these three levels – a point highlighted by Johnstone (1982) as central to success in chemistry education. Second, this improvement was realised in the shift in learners' talk and visuals from being perceptual (the least aligned to scientific facts and rules), through a series of intermediate types, to being idea-based (the most aligned to scientific facts and rules). Other aspects that were considered as indicators of sense-making involved increased self-motivation, and a strong desire to gain complex knowledge of chemical bonding. In conclusion, this action research study declares that visual-verbal intersemiotic complementarity can be considered to be a suitable pedagogic approach to chemical bonding in my practice, and for consideration in Junior Secondary Schools in Namibia.

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APPENDICES

Appendix A

Ethical clearance approval letter

RHODES UNIVERSITY

Grahamstown • 6140 • South Africa

EDUCATION FACULTY • PO Box 94, Grahamstown, 6140
Tel: (046) 603 8385 / (046) 603 8393 • Fax: (046) 622 8028 • e-mail: d.wilmot@ru.ac.za

PROPOSAL AND ETHICAL CLEARANCE APPROVAL

Ethical clearance number 2017.12.08.12

The minute of the EHDC meeting of 05 December 2017 reflect the following:

2017.12.8 ***CLASS B RESTRICTED MATTERS***
MASTER OF EDUCATION RESEARCH PROPOSALS

To consider the following research proposal for the degree of Master of Education in the Faculty of Education:

Mr Frans Aikanga (15A8709)

Topic: Exploring the influences of an intersemiotic complementarity teaching approach on grade 9 Namibian learners' sense making of chemical bonding.

Supervisor: Mr K Jawahar

Decision: *Approved*

This letter confirms the approval of the above proposal at a meeting of the Faculty of Education Higher Degrees' Committee on the 5 December 2017.

The proposal demonstrates an awareness of ethical responsibilities and a commitment to ethical research processes. The approval of the proposal by the committee thus constitutes ethical clearance.

Sincerely

Ms Zisanda Sanda
Secretariat of the EHDC, Rhodes University
8th December 2017

Appendix B

Consent-seeking letter to a critical friend

P. O. Box 217

Outapi

10 October 2017

Ms [redacted]

[redacted] Combined School

P. O. Box [redacted]

Outapi

Dear Ms [redacted]

Re: Invitation to participate in action research study

You are invited to participate in a research study entitled: **Exploring the influences of coordinated intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of Chemical bonding**. The aim of this research is to explore the possibilities of using the coordinated visual and verbal modes for enhancing the learners' sense making of Chemical bonding. Your participation is important and it may enhance the learners' level of making sense of chemical bonding by providing any relevant information. I request you to be a critical friend in this study. Your duty in this study is to observe the lesson, advise me and engage in a critical discussion with me on the aspects of the study that I conduct. The research will be undertaken through observing. I would also request your help in video-recording the lesson since I cannot do it while I am teaching. Your participation in the research is anonymous and your identity will not be revealed. Data collection will take place during Physical Science lessons as from January to February 2018.

If you agree to participate, we will explain in more detail what would be expected of you, and provide you with the information you need to understand about the research during a one-on-one meeting with you which is scheduled to be held in January 2018. The guidelines would include your rights as a participant. The ethical approval is received from Ethics Committee of the Faculty of Education and the proof is available on request. Participation in this research is voluntary and a positive response to this letter of invitation does not oblige you to take part in this research. To participate, you will be asked to sign a consent form to confirm that you understand and agree to the conditions, prior to the discussion we are going to have. Please note that you have the right to withdraw at any time during the study.

Thank you for your time and I hope that you will respond favourably to my request.

Yours sincerely,

Frans P. S. Aikanga FPSaikanga

Student name Signature

Appendix C

Consent letter from a critical friend

[redacted] Combined School
P. O. Box [redacted]
Outapi
06 February 2018

Dear Mr Aikanga

Re: Permission to participate in your action research study

I am [redacted], a Life Science Teacher at [redacted] **Combined School**, hereby giving my consent to participate in your action research study by performing the role of a critical friend, as per your request. I know and understand that the title of your action research study is: **Exploring the influences of an intersemiotic complementarity teaching approach to Grade 9 Namibian learners' sense-making of chemical bonding**.

I am aware of the role I need to play in your study. I am also prepared to keep the results of your study confidential because ignoring this may affect the ethical principles in your study. I am also ready to make time for availing myself wherever I will be needed. I hope your study will collect relevant information and improve science education.

Thanks in anticipation

Yours in education

[redacted]

Ms [redacted] ([redacted] Teacher)

Appendix D
Consent-seeking letter to participating learners

P. O. Box 217
Outapi
10 October 2017

Ms/Mr [redacted]
[redacted] combined school
P. O. Box [redacted]
Outapi

Dear Ms/Mr [redacted]

Re: Learner invitation to participate in research study

You are invited to participate in a research study entitled: **Exploring the influences of coordinated intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding**. The aim of this research is to explore the possibilities of using the coordinated visual and verbal modes in teaching chemical bonding. Your participation is important because it may improve your understanding of chemical bonding by providing any relevant information.

I have chosen your class, including you, to be the participants in the research that I plan to conduct. Your duty in this study is to take part in writing tests, writing guided reflective journals and you will be video-recorded in order to correct real information that will improve the teaching and understanding of Chemical bonding more in detail than before. You have right to become a participant and the right to reject this participation; however, you remain part of the class that I will teach. Your participation in the research is anonymous and your identity will not be revealed. Data collection will take place during Physical Science lessons as from January to beginning of March 2018.

If you agree to participate, we will explain in more detail what would be expected of you, and provide you with the information you need to understand the research during the meeting with you that is scheduled to be held in January 2018. The guidelines would include your rights as a participant. Participation in this research is voluntary and a positive response to this letter of invitation does not make it your responsibility to take part in this research. To participate, you will be asked to sign a consent form to confirm that you understand and agree to the conditions. Please note that you have the right to withdraw at any time during the study and without any bad consequences. Thank you for your time and I hope that you will respond favourably to my request.

Yours sincerely,

Frans P. S. Aikanga	*FPSaikanga*
Student name	Signature

Appendix E

Consent-seeking letter to parents of participating learners – English version

P. O. Box 217

Outapi

30 January 2018

Mr/Ms [redacted]

P. O. Box [redacted]

Outapi

Dear parent

Re: Request for permission for your child's participation in my research

I have chosen your child, **name** [redacted] who belongs to the class chosen for participation in an education research entitled: **Exploring the influences of coordinated intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of Chemical bonding**. The aim of this research is to explore the possibilities of using the visual and verbal communication modes for enhancing the learners' sense making of Chemical bonding. Chemical bonding is a challenging topic to both Grade 9 and 10 learners and it impedes their ability to do well in chemistry. The participation of your child in this research may indeed be helpful towards improving learners understanding in science.

Neither allowing nor rejecting the participation of the child in the study will result in the exclusion of him/her from the teaching involved. Permitted learners will participate in the research through answering both the pre-test and post-test and will also write reflective journals. Video-recording will be part of the study and it will only target those learners that are permitted to be research participants. Your child's participation in the research is anonymous and so his/her identity will not be revealed. The collection of this data will take place during Physical Science lessons as from February to March 2018. If you allow your child to participate, we will explain in more detail what would be expected of your child, and provide him/her with the information he/she needs to understand about the research, during the meeting I will hold with him/her. These guidelines would include your child's rights as a participant. The ethical approval is received from Ethics Committee of the Faculty of Education and the proof is available on request. The child's participation in this research is voluntary and a positive response to this letter does not oblige him/her to take part in this research. To participate, you as a parent are required to sign the attached consent form to confirm that you understand and agree to the conditions, prior to your child participating in this study. Please note that the child has the right to withdraw at any time during the study.

Thank you for your time and I hope that you will respond favourably to our request.
Yours sincerely,

Frans P. S. Aikanga	FPSaikanga
MEd Student name	Signature

Appendix F

Consent-seeking letter to parents of participating learners – Oshiwambo version

P. O. Box 217
Outapi
30 January 2018

Tate/Meme [redacted]
P. O. Box [redacted]
Outapi

Omuvali omusimanekwa

Oshinima: Eindilo lyekuthombinga lyomunona (omulongwa) momapekapeko gelongo lyoshilongwa shuunongononi

Ngame, Frans Aikanga, ondili omuilongi-longi moshiputudhilo sha Rhodes Univesity sha South Africa, ndili tandi ilongo notandi pekapeka omikalo omipe notadhi opalele elongo lyaanona muunongononi. Omumwoye gwedhina [redacted] okuli mongundu ndjoka ngame nda tothamo opo yi kuthe ombinga momapekapeko gelongo tandi kega ninga kohi yoshipalanyolo tashi landula: **Omapekapeko gelongitho lyiikwamathano melongo lyuunongononi wondondo ontimugoyi (9) maalongwa aaNamibia**. Elalakano lyomapekapeko ngaka oku tutsa nkene iikwamathano tayi vulu/ ihayi vulu oku kwathela iitya yomokana moku fatulula oshilongwa shuunongononi kaanona, shoka ndi inekela tashi kwathele aanona opo ya uveko nawa yo ya kwatwe kohokwe yelongo. Ekuthombinga lyomunona moshinyangadhalwa shika otali humitha omunona komeho pamadhiladhila.

Epitiko lyomunona halyo tali indike nenge tali utha elongo lyomunona. Oto indilwa nee u gandje epitiko opo omulongwa nguka a ninge omukuthimbinga momapekapeko ngaka moka taka nyola uututsa nomishangwahokololo dhashono euvite nenge a mona. Otapu ka kala wo uukwatamawi nomizizimbe kaanona mboka ya pitikilwa ekuthombinga ndika. Ndhindhilika, ekuthombinga ndika lyomunona nomauyelele agehe taka holola ogeli oshiholekwa noitashi ka hololwa omolwa uuthemba nuuntu womulongwa. Omapekapeko ngaka otaga ka tameka nuumvo mu February sigo o Maalitsa. Omauyelele gi ihwapo otaga ka gandjwa komunona uuna a pewa epitiko komuvali nenge komutekuli gwe. Ombapila tayi kwashilipaleke omapekapeko ngaka yaza koshiputudhilo shelongo sha Rhodes University opo yili notayi gandjwa uuna pena ngono weyi pumbwa.

Ekuthombinga lyomunona olyeiyambo na ishewe kalishi oshinakugwanithwa. Onkene, omunona okuna uuthemba wa udhilila oku ikuthamo mwene moshinyangadhalwa shika noka pena oshilanduli oshiwinayi nenge itashi hokitha. Opo omunona a wape oku kutha ombinga mushika, shaina ombapila ya kwatelwa kumwe na ndjika. Tangi sho to pitike omunona a kuthe ombinga momapekapeko ngaka.

Gwoye

Frans Aikanga FPAikanga

Omuilongi-longi Eshainokaha

Appendix G
Consent-seeking letter to the school principal

P.O. Box 217
Outapi
20 October 2017

The principal
[redacted] Combined School
P. O. Box [redacted]
Outapi

RE: Request for permission to conduct research at [redacted] Combined School

Dear Mr [redacted]

My name is **Frans P. S. Aikanga**, and I am a MEd student at Rhodes University (RU) in Okahandja, Namibia. The research I wish to conduct for my Master's full thesis requires me to explore the influences of coordinated intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of Chemical bonding in Physical Science. The research will involve observations, document analysis, teacher's reflective journal, learners' reflective journal, pre-test and post-test as methods of collecting data. The video-recording of the lesson will be done in the class. This research will be conducted under the supervision of Mr Kavish Jawahar, a Science Education lecturer at Rhodes University.

This letter serves to seek formal consent from your office to approach the science teacher, Ms [redacted] and 38 Grade 9 learners as participants in this study. Parents of the participating learners in this research will be conducted for the permission of their learners' participation in the research. I request your permission to begin with my research at the school in February 2018 as outlined in my research proposal. I attach a copy of the Rhodes University ethics approval form. As part of this, I undertake to ensure that the name of the school and all participants will be replaced with pseudonyms and that all the materials I collect as part of the research will be accessible only to myself and my supervisor.

Upon completion of the study, I undertake to provide you and Ms [redacted] with access to the research findings. If you require any further information, please do not hesitate to contact me on 0812237729 or at paulusfrans268@gmail.com.

Thank you for your time and consideration in this matter.

Yours sincerely

FPSaikanga
Student number: **15A8709**
Rhodes University

Appendix H
Permission letter from the Principal

Ministry of Education, Arts & Culture
Omusati Region, Directorate Education,
[redacted] School
P.O. Bo[redacted]
Telefax: [redacted]
Email: [redacted]

Enquiries: [redacted]
Cell.

[redacted] Cluster
e Circuit

07 February 2018

Mr. Frans P.S. Aikanga
P.O. Box 217
Outapi
Omusati Region

Re: Permission to conduct research at [redacted] Combined School

This note aims to inform you, **Mr. Frans P.S. Aikanga** that permission has been approved to carry out your research under the topic: **"to explore the influence of coordinated intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of chemical bonding in Physical Science"** at [redacted] Combined School in Anamulenge Circuit. However, you are advised, the research to be carried out should by no means interfere with the normal teaching and learning process of the learners.

As Management, we hope this research will benefit and elevate the body of knowledge in our school particularly in Physical Science.

Yours sincerely

[redacted]

Mr [redacted]

[redacted]

Appendix I
Consent-seeking letter to the Regional Education Director

P.O. Box 217

Outapi

26 January 2018

The Regional Education Director

Omusati Regional Council

Directorate of Education

Private Bag 529

Outapi

Request for permission to conduct research at [redacted] Combined School in your Education Region

Dear Mr [redacted]

My name is **Frans P. S. Aikanga**, and I am a MEd student at Rhodes University (RU) in Okahandja, Namibia. The research I wish to conduct for my Master's full thesis requires me to explore the influences of coordinated intersemiotic complementarity teaching approach on Grade 9 Namibian learners' sense-making of Chemical bonding in Physical Science. The study will benefit learners, I as a teacher-researcher and possibly other science teachers who may have access to effective pedagogies that will appear in publications that arise from it. The research will involve observations, document analysis, teacher's reflective journal, learners' journal, learners' pre-test and learners' post-test as methods of collecting data. The video-recording of the lesson will be done in the class. This research will be conducted under the supervision of Mr Kavish Jawahar, a Science Education lecturer at Rhodes University.

This letter serves to seek formal consent from your office to conduct the research with learners at [redacted] Combined School in Anamulenge Circuit which falls under your directorate. The school principal is informed about this study and a letter for seeking the consent from him is sent. Participating learners, learners' parents and teachers will receive letters for seeking informed consents from them. I request your permission to begin with my research at the school in February 2018 as outlined in my research proposal. I attach a copy of the Rhodes University ethics approval form. As part of this, I undertake to ensure that the name of the school and all participants will be replaced with pseudonyms and that all the materials I collect as part of the research will be accessible only to myself and my supervisor. Upon completion of the study, I undertake to provide you and the assistant teacher with access to the research findings. If you require any further information, please do not hesitate to contact me on 0812237729 or at paulusfrans268@gmail.com.

Thank you for your time and consideration in this matter.
Yours sincerely

FPSaikanga

Student number: **15A8709**
Rhodes University

Appendix J

Permission letter from the Regional Director of Education

REPUBLIC OF NAMIBIA

OMUSATI REGIONAL COUNCIL

DIRECTORATE OF EDUCATION, ARTS AND CULTURE

Team Work and Dedication for Quality Education

Tel: [redacted]

Fax:

Private Bag [redacted]

OUTAPI

Enq: [redacted]

05 February 2018

Mr. Frans P.S. Aikanga
P.O. Box 217
Outapi

Subject: **Permission to conduct research at [illegible] Combined School**

This letter serves to notify you (**Mr. Frans P.S. Aikanga**) that permission has been granted to conduct a research "**to explore the influence of coordinated intersemiotic complementarity teaching approach on grade 9 Namibian learners'sense-making of chemical bondingin physical science**" specifically at [illegible] CS in [redacted] Circuit. Please be informed that the research to be conducted at school should by no means whatsoever disrupt teaching and learning.

We hope and trust this exercise will enhance quality education in the Region.

Yours faithfully

OMUSATI REGIONAL COUNCIL
DIRECTORATE OF EDUCATION
2018 -02- 05
THE DIRECTOR
PRIVATE BAG 529, OUTAPI
REPUBLIC OF NAMIBIA

[redacted]

Mr.

Director of Education Arts and Culture

Teamwork and dedication for quality education

Cc: Principal, [illegible] Combined School
Inspector of Education for [redacted] Circuit

Appendix K
Prototype Lesson Plans for Cycle 1

PROTOTYPE LESSON PREPARATION – LESSON WITHOUT INTERSEMIOTIC COMPLEMENTARITY

LESSON 1
CYCLE 1

Subject: Physical Science	**Date: 15 / 03 / 2018**
Grade: 9	**Duration: 40 minutes**
Topic: Matter Sub-topic: Chemical bonding	**Lesson topic: Types of Chemical bonding**

1. **General objective: Learners will:**
    - understand the different types of bonding (page 31 of Grade 9 syllabus, bullet number 2.4).
    - know how to illustrate covalent bonding as the sharing of electrons when atoms combine (page 31 of Grade 9 syllabus, bullet number 2.4.1).

2. **Specific objectives: Learners should be able to:**
    - describe and distinguish between covalent and ionic bonding as different types of bonding and relate bonding to position (group) of elements in the Periodic Table.
    - describe how non-metal atoms combine with other non-metal atoms by sharing electrons in their outer shells with the result that both atoms achieve full outer shells.

3. **Teaching Materials:**

- Platinum Physical Science Textbook, Periodic table, blank papers for drawing and chalkboard.
    - ✓ The two textbooks are in use at the school and learners will use them as additional source for Chemical bonding knowledge.
    - ✓ Periodic tables will be used for drawing Bohr structures and answering questions related to Chemical bonding.
    - ✓ Blank papers will be used by learners for drawing Bohr structures and bonding structures.

4. **Lesson presentation**

Introduction (5 minutes)	The teacher introduces the lesson to learners by revising Grade 8's content with learners that elements in the periodic table are classified as metals (on the left) and non-metals (on the right). He also revises with them that elements in the periodic table are arranged into groups (vertical columns) and periods (horizontal rows) that determine number of outer shell electrons and number of periods of their atoms respectively and how these determine bonding of an element with other elements. The teacher also draws the Bohr structure of oxygen to remind learners on how Bohr structures of elements are drawn using a periodic table.		
Content	**Teacher's activities**	**Learners' activities**	**Time frame**
Presentation	Teacher defines chemical bonding as when atoms of elements with incomplete outer shells chemically combine to obtain a full outer shell.	Learners analyse how chemical bonding relates to electrons in outer shells of atoms of elements.	25 minutes
	Teacher explains that chemical bonding does not happen with atoms of group 8 elements because their outer shells are full.	Learners analyse why atoms of group 8 elements do not chemically bond.	
	Teacher describes and differentiates between two types of chemical bonding: covalent and ionic. He defines covalent as involving sharing electrons and happens between non-metal	Learners distinguish between ionic and covalent bonding with reference to electrons sharing or transferring between atoms of elements.	

	elements. He defines ionic bonding as involving the transfer of electrons from one atom to another atom which usually happens between metal and non-metal atoms.		
	Teacher use the periodic table to demonstrate to learners how covalent bonding diagrams are drawn by using a periodic table to draw **H_2O** and **N_2** molecules.	Learners observe and apply the skills to draw bonding structures in **NH_3** and O_2 molecules.	
Learning support	Teacher attends to learners who struggle to draw Chemical bonding structures correctly.	Learners compare their drawn diagrams to those drawn by the teacher to rectify their mistakes.	5 minutes
Conclusion	Teacher emphasizes that Chemical bonding happens for atoms to obtain a full outer shell.	Learners deduce that atoms that do not have a full outer shell have to bond with other atoms to have outer shells that are full.	2 minutes
Assessment	Teacher gives guided reflective journals for the lesson taught to learners to hand them in at 8 o'clock the next day.	Learners receive guided reflective journals for the lesson taught for submission in the next day.	3 minutes
Evaluation/ evaluation	What went well/wrong:		
	What needs to be changed:		
Teacher's signature: ____________________ Date: ____________________			

PROTOTYPE LESSON PREPARATION – LESSON WITHOUT INTERSEMIOTIC COMPLEMENTARITY

LESSON 2
CYCLE 1

Subject: Physical Science **Date: 16 / 03 / 2018**
Grade: 9 **Duration: 40 minutes**
Topic: Matter Sub-topic: Chemical bonding **Lesson topic: Properties of covalent compounds**

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1. **General objective: Learners will:**
    - know how to illustrate covalent bonding as the sharing of electrons when atoms combine (page 31 of Grade 9 syllabus, bullet number 2.4.1).

2. **Specific objectives: Learners should be able to:**
    - describe how non-metal atoms combine with other non-metal atoms by sharing electrons in their outer shells with the result that both atoms achieve full outer shells.

3. **Teaching Materials:**

- Platinum Physical Science Textbook, Periodic table, blank papers for drawing and chalkboard.

4. **Lesson presentation**

Introduction (5 minutes)	The teacher test learners' knowledge about Chemical bonding as provided to them in lesson 1 by asking them to define Chemical bonding in their own words.		
Content	**Teacher's activities**	**Learners' activities**	**Time frame**
Presentation	Teacher first checks how learners have drawn bonding structures of NH_3 and O_2. He then uses the periodic table to demonstrate to them how covalent bonding structures in NH_3 and O_2 are drawn.	Learners rectify the errors they did in the structures they have drawn.	25 minutes
	Teacher explains that covalent compounds are those substances formed when a non-metal bonds with another non-metal. He then list for them other examples of covalent compounds such as **sulphur dioxide (SO_2)**, **methane (CH_4)**, **carbon dioxide (CO_2)** and **hydrogen chloride (HCl)**.	Learners analyse that covalent compounds are only composed of non-metals only.	
	Teacher lists and explains to learners the properties of covalent compounds such as: • Low melting and boiling points • Insoluble in water • Soluble in organic solvents • Poor conductors of heat • Non-conductors of electricity • Has weak bonds	Learners relate the properties of covalent compounds to how the bond in them happens.	

Learning support	Teacher attends to learners who struggle to draw Chemical bonding structures correctly.	Learners compare their drawn diagrams to those drawn by the teacher to correct their errors.	
Conclusion	Teacher emphasizes that properties of chemical compounds are results of electrons sharing between the atoms.	Learners properties of compounds	5 minutes
Assessment	Teacher gives guided reflective journals for the lesson taught to learners to hand them in at 8 o'clock the next day.	Learners receive guided reflective journals for the lesson taught for submission in the next day.	5 minutes
Evaluation/ evaluation	What went well/wrong: ______________________________ ______________________________ ______________________________		
	What needs to be changed: ______________________________ ______________________________		
Teacher's signature: ______________________ Date: ______________________			

PROTOTYPE LESSON PREPARATION – LESSON WITHOUT INTERSEMIOTIC COMPLEMENTARITY

LESSON 3
CYCLE 1

Subject: Physical Science **Date: 19 / 03/ 2018**
Grade: 9 **Duration: 40 minutes**
Topic: Matter **Sub-topic: Chemical bonding** **Lesson topic: Ionic bonding**

1. **General objective: Learners will:**

- know how to illustrate ionic bonding as the transfer of electrons to form oppositely charged ions which attract electrostatically (page 32 of the syllabus, bullet number 2.4.2).

2. **Specific objectives: Learners should be able to:**

- describe how the reaction between a metal and a non-metal result in the transfer of electrons from metal atoms to non-metal atoms so that both achieve full outer shells and form positive ions (cations) and negative ions (anions) respectively.
- predict the positive and negative charges of ions (in terms of attained noble gas electronic structures.
- define ions as atoms with a net electric charge due to the loss or gain of one or more electrons (e.g. cations have lost electrons and anions have gained electrons in order to attain noble gas structure).
- draw Bohr structures of ionic compounds

3. **Teaching Materials:**
- Platinum Physical Science Textbook, Periodic table, blank papers for drawing and chalkboard.

4. **Lesson presentation**

Introduction (5 minutes)	The teacher asks learners to tell what happens when objects with unlike charges (positive and negative) are brought closer to each other. By recalling what they learnt in Grade 8, learners may say tell that the two objects will attract each other because opposite charges always attract. The teacher then briefly links this idea to ionic bonding.		
Content	**Teacher's activities**	**Learners' activities**	**Time frame**
Presentation	Teacher defines ionic bonding as the bond where electrons are transferred usually from a metal to a non-metal.	Learners analyse how ionic bonding differs from covalent bond.	25 minutes
	Teacher explains that an atom that loses electrons is a cation while that gains electrons is called an anion and that cations are positively charged while anions are negatively charged.	Learners deduce that ionic bonding is a result of attraction between positive and negative ions since unlike charges attract each others.	
	Teacher draws the bonding structure of ionic bonding while explaining skills involved in the ionic bonding process. He uses Lithium Fluoride as an example.	Learners observe and relate to the teacher's explanation that atoms in ionic bonding lose or gain electrons to attain a stable outer shell.	
Learning support	Teacher attends to learners who struggle to draw ionic bonding structures correctly.	Learners compare their drawn diagrams to those drawn by the teacher to rectify their mistakes.	5 minutes

Conclusion	Teacher emphasizes that ionic bonding involves the transfer of electrons usually from metal atoms to non-metal atoms.	Learners recognise that ionic bond involves the transfer of outer shell electrons from metals to non-metals.	3 minutes
Assessment	Teacher gives guided reflective journals for the lesson taught to learners to hand them in at 8 o'clock the next day.	Learners receive guided reflective journals for the lesson taught for submission in the next day.	2 minutes
Evaluation/ evaluation	What went well/wrong: __________ __________ __________		
	What needs to be changed: __________ __________		

Teacher's signature: ____________________

Date: ____________________

PROTOTYPE LESSON PREPARATION – LESSON WITHOUT INTERSEMIOTIC COMPLEMENTARITY

LESSON 4
CYCLE 1

Subject: Physical Science **Date: 20 /03 / 2018**
Grade: 9 **Duration: 40 minutes**
Topic: Matter Sub-topic: Chemical bonding Lesson topic: Properties and formulae of ionic compounds

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1. **General objective: Learners will:**

 - know how to illustrate ionic bonding as the transfer of electrons to form oppositely charged ions which attract electrostatically (page 32 of the syllabus, bullet number 2.4.2).

2. **Specific objectives: Learners should be able to:**

 - explain ionic (electrovalent) bonding as the electrostatic attraction between oppositely charged ions (cations and anions).
 - describe the lattice of an ionic compound as a regular arrangement of alternating positive and negative ions.
 - write the formulas of ionic compounds including polyatomic ions (i.e. $\mathbf{SO_4^{2-}}$, $\mathbf{NO_3^-}$, $\mathbf{CO_3^{2-}}$, $\mathbf{HCO_3^-}$, $\mathbf{OH^-}$).

3. **Teaching Materials:**
 - Platinum Physical Science Textbook, Periodic table, blank papers for drawing and chalkboard.

4. **Lesson presentation**

Introduction (5 minutes)	The teacher tells learners that the unlike charges between ions causes an attraction between them which results in the strong bond formed. He then explains that the charges of ions determine the formula of the compound formed.		
Content	**Teacher's activities**	**Learners' activities**	**Time frame**
Presentation	Teacher explains that cations and anions attracting each other cause ionic bond to be very strong unlike the covalent bond.	Learners analyse deduce that a stronger attraction between cations and anions results in a strong bond.	25 minutes
	Teacher explains that the attraction between ions cause lattices to be formed which results in ionic substance being found as crystalline.	Learners relate the explanation to crystals in which table salt is found.	
	Teacher explains and demonstrates to learners how formulas of ionic compounds are deduced from the valencies of reacting elements and polyatomic ions. He does it with: • Sodium chloride • Lithium oxide • Magnesium oxide • Calcium chloride	Learners observe and use the same skills to determine the formula of: ✓ Beryllium fluoride ✓ Sodium oxide ✓ Magnesium chloride	

Learning support	Teacher attends to learners who struggle to write chemical formulas of compounds correctly.	Learners correct the errors they made.	5 minutes
Conclusion	Teacher emphasizes that writing formulas of ionic compounds requires balancing between the charges.	Learners recognise that formulas of ionic compounds are determined by balancing the negative and positive charges.	3 minutes
Assessment	Teacher gives guided reflective journals for the lesson taught to learners to hand them in at 8 o'clock the next day.	Learners receive guided reflective journals for the lesson taught for submission in the next day.	2 minutes
Evaluation/ evaluation	What went well/wrong: ______		
	What needs to be changed: ______		
Teacher's signature: ______ Date: ______			

Appendix L
Benchmark Lessons Plans for Cycle 2

BENCHMARK LESSON PREPARATION – LESSON WITH VISUAL-VERBAL INTERSEMIOTIC COMPLEMENTARITY

LESSON 1
CYCLE 2

Subject: Physical Science	**Date: 27 /03 / 2018**
Grade: 9	**Duration: 40 minutes**
Topic: Matter	**Sub-topic: Chemical bonding**

1. **General objective: Learners will:**
   - understand the different types of bonding (page 31 of Grade 9 syllabus, bullet number 2.4).
   - know how to illustrate covalent bonding as the sharing of electrons when atoms combine (page 31 of Grade 9 syllabus, bullet number 2.4.1).

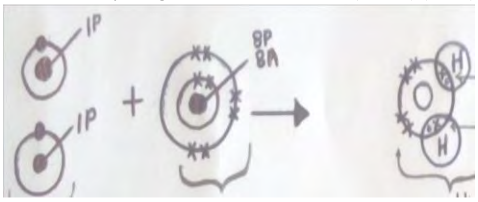
2. **Specific objectives: Learners should be able to:**
   - describe and distinguish between covalent and ionic bonding as different types of bonding and relate bonding to position (group) of elements in the Periodic Table.
   - describe how non-metal atoms combine with other non-metal atoms by sharing electrons in their outer shells with the result that both atoms achieve full outer shells.

3. **Teaching Materials:**
   - Platinum Physical Science text book, models of covalent bonding and posters diagrams of covalent bonding.

4. **Lesson presentation**

<table>
<tr><td>Introduction
(5 minutes)</td><td colspan="4">The teacher introduces the lesson to learners by revising Grade 8's content with learners that elements in the periodic table are classified as metals (on the left) and non-metals (on the right). He also revises with them that elements in the periodic table are arranged into groups (vertical columns) and periods (horizontal rows) that determine number of outer shell electrons and number of periods of their atoms respectively and how these determine bonding of an element with other elements. The teacher also draws the Bohr structure of oxygen to remind learners on how Bohr structures of elements are drawn using a periodic table.</td></tr>
<tr><td>Content</td><td colspan="4">Lesson presentation (25 minutes)</td></tr>
<tr><td>Teacher's activities</td><td>Visual semiotic mode used</td><td>Verbal semiotic mode used (Spoken words)</td><td>Sense relation of intersemiotic complementarity</td><td>Learners' activities</td></tr>
<tr><td rowspan="2">• Teacher explains that Chemical bonding happens with atoms that do not have full outer shells, except for the elements in group 8 that have 8 electrons in outer shells.

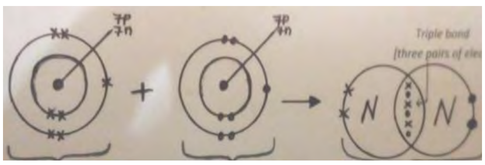
• Teacher introduces two types of Chemical bonding to learners: covalent and ionic.

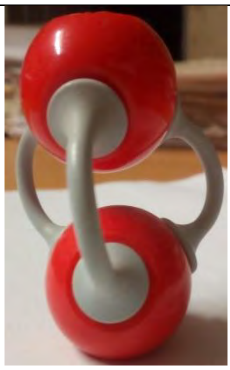
• He defines covalent bond as involving sharing electrons which happens between non-metal</td><td rowspan="2">1. Hydrogen oxide molecule (water)(H_2O)


(a) Bond diagram</td><td>Each hydrogen atom has only "one (1) electron in the outer shell" while oxygen has only "six (6) electrons in the outer shell".</td><td>Similarity (Sm) - Visible electrons in atoms are repeated with the lexical item "one (1) electron" and "six (6) electrons" in outer shells.</td><td rowspan="2">• Learners observe and analyse the diagram and model shown to make sense of why atoms of group 8 elements do not chemically bond.

• Learners distinguish between ionic and covalent bonding with reference to electrons sharing or transferring between atoms of elements.

• Learners observe the diagrams and models shown and apply the</td></tr>
<tr><td>Each atom "shares one (1) electron".</td><td>Similarity (Sm) - Outer shells overlapping point with 1 dot and 1 cross between any two atoms have similar meaning as the lexical item "shares one (1)</td></tr>
</table>

elements. He defines ionic bonding as involving the transfer of electrons from one atom to another atom which usually happens between metal and non-metal atoms. • Teacher uses the periodic table and clearly labeled diagrams to demonstrate to learners how covalent bonding diagrams are drawn by using a periodic table to draw **H_2O** and **N_2** molecules. • The teacher shows the model of a hydrogen oxide and nitrogen molecule to explain how the molecules ideally look like. • Teacher instructs learners to draw the covalent bonding in the **NH_3** and **H_2**.	 (b) bond model		electron”.	skills to draw bonding structures in **NH_3** and **H_2** molecules.
		The bond formed is “covalent”.	Collocation (C) - The diagram of shells overlapping collocates with the lexical item “covalent” because it is defined as the sharing of electrons.	
		Atoms in this molecule form a “single bond”.	Similarity (Sm) - The visible one pair of a dot and a cross between the overlapped outer shells is repeated by the lexical item “single bond”.	
		Atoms in the hydrogen oxide molecule have “full outer shell” after bonding.	Meronymy (M) - The visible drawing of atoms in a molecule shows the part-whole relationship between the words ‘atoms’ and ‘molecule’.	
		Hydrogen and oxygen are “atoms before bonding” but “after bonding their bond is called a molecule”.	Meronymy (M) - The visible drawing of atoms in a molecule shows the part-whole relationship between the word ‘atoms’ and ‘molecule’.	
		Hydrogen and oxygen form a “weak bond”.	Collocation (C) - The drawings of hydrogen and oxygen atoms with no charge (+ and -) in the hydrogen oxide molecule collocates with the lexical item “weak bond” due to no (opposite) charges to attract each other.	
	2. Nitrogen molecule (N_2)  (a) bond diagram	Each atom of nitrogen has only “five (5) electrons in the outer shell”.	Similarity (Sm) - Circles of atoms drawn with five (5) dots mean the same as the lexical item ‘five electrons in the outer shell’.	
		Each atom of “nitrogen shares	Similarity (Sm) - Overlapping shells	

	 (b) bond model	three (3) electrons".	drawn is a similar to the lexical item "share".	
		The two atoms of nitrogen "form a covalent bond".	Collocation (C) - The diagram of shells overlapping collocates with the lexical item "covalent" because it is defined as the sharing of electrons.	
		They form a "triple bond".	Similarity (Sm) - Three pairs of dots and crosses are repeated by the lexical item 'triple bond'.	
		Each atom in the bond has "eight (8) electrons in the outer shell".	Similarity (Sm) - The visible eight (8) dots and crosses on each nitrogen atom drawn in a molecule is repeated by the lexical item 'eight (8) electrons in the outer shell".	
		"The bond in the nitrogen molecule is weak".	Collocation (C) - Atoms of nitrogen drawn with no charges (+ and -) in the nitrogen molecule collocates with the lexical item "weak bond".	
Learning support (5 minutes)	Teacher attends to learners who struggle to draw chemical bonding structures correctly.			Learners compare their drawn diagrams to those drawn by the teacher to rectify their mistakes.
Conclusion (3 minutes)	Teacher emphasizes that chemical bonding happens for atoms to obtain a full outer shell and that it only happens with atoms whose outer shells are incomplete (not full).			Learners deduce that atoms that do not have a full outer shell have to bond with other atoms to have outer shells that are full.
Assessment/task (2 minutes)	Teacher gives guided reflective journals for the lesson taught to learners to hand them in at 8 o'clock the next day.			Learners receive guided reflective journals for the lesson taught for submission in the next day.
Evaluation/ reflection	What went well/wrong: __________ __________ __________ __________ __________ __________ __________ What needs to be changed: __________			

	____ ____ ____ ____ ____ ____

Teacher's signature:

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Date:

______ / ______ / 2018

BENCHMARK LESSON PREPARATION – LESSON WITH VISUAL-VERBAL INTERSEMIOTIC COMPLEMENTARITY

LESSON 2
CYCLE 2

Subject: Physical Science	**Date: 28 /03 / 2018**
Grade: 9	**Duration: 40 minutes**
Topic: Matter	**Sub-topic: Chemical bonding**

1. **General objective: Learners will:**
   - know how to illustrate covalent bonding as the sharing of electrons when atoms combine (page 31 of Grade 9 syllabus, bullet number 2.4.1).

2. **Specific objectives: Learners should be able to:**
   - describe how non-metal atoms combine with other non-metal atoms by sharing electrons in their outer shells with the result that both atoms achieve full outer shells.

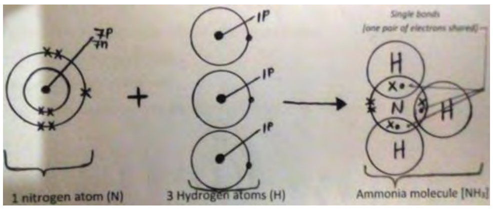
3. **Teaching Materials:**
   - Platinum Physical Science text book, models of covalent bonding and posters with labeled diagrams of covalent bonding.

4. **Lesson presentation**

<table>
<tr><td>Introduction
(5 minutes)</td><td colspan="4">The teacher tests learners' knowledge about Chemical bonding as provided to them in lesson 1 by asking them to define Chemical bonding in their own words. He also asks them to differentiate between covalent and ionic bond.</td></tr>
<tr><td>Content</td><td colspan="4">Lesson presentation (25 minutes)</td></tr>
<tr><td>Teacher's activity</td><td>Visual semiotic mode used</td><td>Verbal semiotic mode used (spoken)</td><td>Sense relations of intersemiotic complementarity used</td><td>Learners' activities</td></tr>
<tr><td rowspan="4">• He then uses the periodic table and sketches to demonstrate to them how covalent bonding structures in NH_3 and O_2 look like.

• Teacher explains that covalent compounds are those substances formed when a non-metal bonds with another non-metal. He shows them diagrams of covalent bonds in methane (CH_4).

• Teacher explains to learners the properties of covalent compounds such as:
✓ Low melting and boiling points
✓ Insoluble in water
✓ Soluble in organic solvents</td><td rowspan="4">1. Ammonia molecule (NH_3)

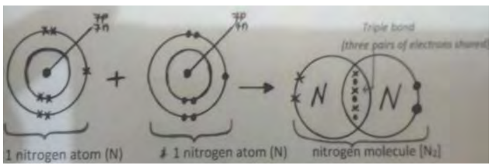


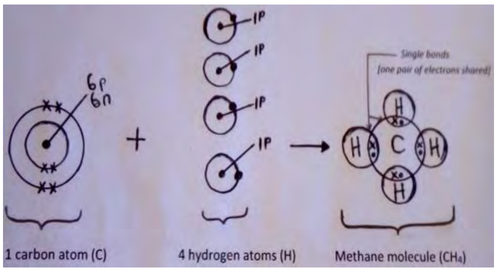
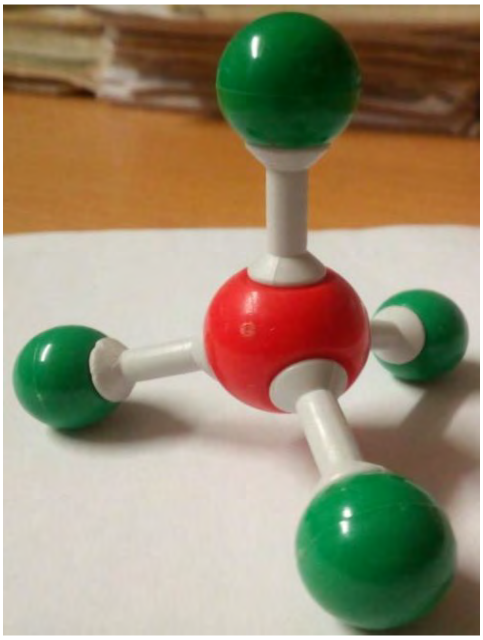
(a) bond diagram


(b) bond model</td><td>The "nitrogen atom has five (5) electrons in outer shell" while the "hydrogen atom has one (1) electron in the outer shell".</td><td>Similarity (Sm) - five electrons indicated on the nitrogen atom and one electron indicated on each hydrogen atom are repeated with lexical items 'five (5) electrons' and 'one (1) electron'.</td><td rowspan="4">• Learners observe and identify how the covalent bond happens.

• Learners observe and analyse that covalent compounds are only composed of non-metals only and that outer shells overlap during covalent bonding.

• Learners relate the properties of covalent compounds to how the bond in them happens.</td></tr>
<tr><td>Nitrogen atom "shares three (3) electrons" while each hydrogen atom "shares one (1) electron".</td><td>Similarity (Sm) - Visible three crosses of a nitrogen atom and one dot of each hydrogen atom between the overlap are the same as the lexical item "share".</td></tr>
<tr><td>Nitrogen and hydrogen "form a covalent bond".</td><td>Collocation (C) - The diagram of shells overlapping collocates with the lexical item "covalent" because it is defined as the sharing of electrons.</td></tr>
<tr><td>Hydrogen has</td><td>Hyponymy (H) - the</td></tr>
</table>

✓ Poor conductors of heat ✓ Non-conductors of electricity ✓ Has weak bonds		"valency of one (1)" while nitrogen has "the valency of three (3)".	three needed in the outer shell of nitrogen and one electron needed in the outer shell of hydrogen belong to the class of the lexical item 'valency".	
		Nitrogen and hydrogen in ammonia molecule "form a single bond".	Similarity (Sm) - the lexical item 'single bond' is similar to the visible two electrons drawn in the overlap.	
		Atoms in a molecule have "full outer shells".	Similarity (Sm) - visible full outer shells (hydrogen with 2 and nitrogen with 8) of hydrogen and nitrogen are the same as the lexical item 'full outer shell'.	
		The "bond in the ammonia molecule is weak".	Collocation (C) - diagrams of hydrogen and nitrogen atoms with no charges (+ and -) in ammonia molecule collocates with the lexical item 'weak bond'.	
	2. Oxygen molecule (O_2)	Each oxygen atom has "a valency of two (2)".	Collocation (C) - Visible six (6) electrons in the outer shells of each oxygen atom collocates with the lexical item "valency of two (2)".	
		"Each atom shares two electrons in during bonding".	Similarity (Sm) – two electrons in the overlap have the same meaning as the lexical item "each atom shares electrons".	
	(a) bond diagram	The two (2) oxygen atoms form a "double bond".	Similarity (Sm) - The visible two (2) pairs of electrons between the overlapping shells have the same meaning as the lexical item "double bond".	
	 (b) bond model	All atoms in the oxygen molecule "gained a noble gas structure".	Hyponymy (H) - Visible eight (8) electrons in the outer shell of each oxygen atom in the oxygen molecule makes it	

			belonging to a class of noble gases. Similarity (Sm) – the visible diagrams with full outer shells is repeated with the lexical item 'noble gases'.	
		The "bond in oxygen molecule is weak".	Collocation- The atoms of oxygen drawn with no charges (+ and -) collocates with the lexical item "weak bond".	
	3. Methane molecule (CH_4)  (a) bond diagram	A carbon atom has four (4) electrons in the outer shell while a hydrogen atom has one (1) electron in the outer shell.	Similarity (Sm) - Visible four electrons in the outer shell of carbon atom and one electron in the outer shell of each hydrogen atom are repeated with the lexical items 'four (4) electrons' and 'one (1) electron'.	
		Carbon has the valency of four (4) electrons while hydrogen has the valency of one (1) electron.	Collocation (C) - Visible four electrons in the carbon atom and one electron in the carbon atom collates with lexical item 'valency'.	
		A carbon atom shares four (4) electrons while each of the four hydrogen atoms shares one (1) electron during bonding.	Similarity (Sm) - The four electrons drawn in the bond is similar to the lexical item 'share'.	
	(b) Bond model	The bond formed between any two atoms in this molecule is single (only one (1) pair of electrons being shared).	Similarity (Sm) - the lexical item 'single pair' is similar to two electrons drawn in the bond.	
		All atoms in this	Hyponymy (H) -	

		molecule have gained a full noble gas structure (they all have full outer shells).	Visible two electrons in the hydrogen atom and eight electrons in the carbon atom are a class of a lexical item ‘noble gases’.	
		The “bond in methane is weak” because there is “no electrostatic attraction” between the atoms in the molecule.	Collocation (C) - Visible drawn atoms of carbon and hydrogen with no charges indicated collocates with the lexical item ‘weak bond’.	
Learner support (5 minutes)	Teacher attends to learners who struggle to draw Chemical bonding structures correctly			Learners compare their drawn diagrams to the models shown by the teacher.
Conclusion (3 minutes)	Teacher emphasizes that properties of chemical compounds are results of electrons sharing between the atoms.			Learners deduce the properties of covalent compounds from bonding process involved
Assessment (2 minutes)	Teacher gives guided reflective journals for the lesson taught to learners to hand them in at 8 o’clock the next day.			Learners receive guided reflective journals for the lesson taught for submission in the next day.
Evaluation/ reflection	What went well/wrong: ______________________________ ______________________________ ______________________________			
	What needs to be changed: ______________________________ ______________________________ ______________________________			
Teacher’s signature: ____________________ Date: _____ / ________ / 2018				

LESSON 3
CYCLE 2

Subject: Physical Science	**Date: 29 /03 / 2018**
Grade: 9	**Duration: 40 minutes**
Topic: Matter	**Sub-topic: Ionic Bonding**

1. **General objective: Learners will:**

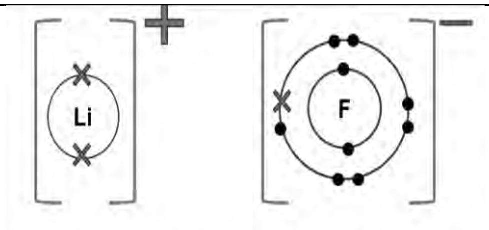
- know how to illustrate ionic bonding as the transfer of electrons to form oppositely charged ions which attract electrostatically (page 32 of the syllabus, bullet number 2.4.2).

2. **Specific objectives: Learners should be able to:**

   - describe how the reaction between a metal and a non-metal result in the transfer of electrons from metal atoms to non-metal atoms so that both achieve full outer shells and form positive ions (cations) and negative ions (anions) respectively.
   - predict the positive and negative charges of ions (in terms of attained noble gas electronic structures.
   - define ions as atoms with a net electric charge due to the loss or gain of one or more electrons (e.g. cations have lost electrons and anions have gained electrons in order to attain noble gas structure).
   - draw Bohr structures of ionic compounds

3. **Teaching Materials:**
   - Platinum Physical Science Textbook, Periodic table, blank papers for drawing and chalkboard.

4. **Lesson presentation**

Introduction (5 minutes)	The teacher asks learners to tell what happens when objects with unlike charges (positive and negative) are brought closer to each other. By recalling what they learnt in Grade 8, learners may say tell that the two objects will attract each other because opposite charges always attract. The teacher then briefly links this idea to ionic bonding.			
Content	**Lesson presentation (25 minutes)**			
Teacher's activities	**Visual semiotic mode used**	**Verbal semiotic mode used (Spoken words)**	**Sense relation of intersemiotic complementarity**	**Learners' activities**
• Teacher defines ionic bonding as the bond where electrons are transferred usually from a metal to a non-metal. • Teacher explains that an atom that loses electrons is a cation while that gains electrons is called an anion, and that cations are positively charged while anions are negatively charged. • Teacher draws the bonding structure of ionic bonding while explaining skills involved in the ionic bonding process. He uses Lithium Fluoride as an example.	 Lithium atom loses an electron to form lithium ion Li^+ **Fluorine atom gains an electron to form fluoride ion F^-**	Lithium atom lost one electron	Collocation (C) – the lexical item 'lost' collocates with the *visible two crosses* (indicating electrons) left in the outer shell of a lithium atom	• Learners analyse how ionic bonding differs from covalent bond. • Learners deduce that ionic bonding is a result of attraction between positive and negative ions since unlike charges attract each others. • Learners observe and relate to the teacher's explanation that atoms in ionic bonding lose or gain electrons to attain a stable outer shell.
		Lithium atoms forms a cation	Similarity (Sm) – a visible positively charged ion has a similar meaning as the lexical item *cation*	
		Fluorine atom gains one electron	Collocation (C) – the lexical item 'gained' has an expectancy relationship with the *visible one cross* (indicating an electron) in the	

<table>
<tr><td rowspan="2"></td><td rowspan="2"></td><td></td><td>outer shell of fluorine</td><td rowspan="2"></td></tr>
<tr><td>Fluorine atom forms an anion</td><td>Similarity (Sm) – a visible negatively charged ion has similar relationship with a lexical item anion</td></tr>
<tr><td>Learning support
(5 minutes)</td><td colspan="3">The teacher identifies learners struggling to illustrate ionic bonding and provides additional learning support to these learners.</td><td>Learners who understand assists those who do not understand</td></tr>
<tr><td>Conclusion
(3 minutes)</td><td colspan="3">The teacher emphasises that ionic bonding involves electrons being transferred from metal to non-metal atoms.</td><td>Learners realise that ionic bond involves metals and non-metals</td></tr>
<tr><td>Assessment/task
(2 minutes)</td><td colspan="3">Teacher gives guided reflective journals for the lesson taught to learners to hand them in at 8 o'clock the next day.</td><td>Learners receive guided reflective journals for the lesson taught for submission in the next day.</td></tr>
<tr><td>Evaluation/ reflection</td><td colspan="4">What went well/wrong:
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What needs to be changed:
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<tr><td colspan="5">Teacher's signature:

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Date:

______ / ______ / 2018</td></tr>
</table>

BENCHMARK LESSON PREPARATION – LESSON WITH VISUAL-VERBAL INTERSEMIOTIC COMPLEMENTARITY

LESSON 4
CYCLE 2

Subject: Physical Science	**Date: 30 /03 / 2018**
Grade: 9	**Duration: 40 minutes**
Topic: Matter	**Sub-topic: Ionic bonding**

5. **General objective: Learners will:**
   - know how to illustrate ionic bonding as the transfer of electrons to form oppositely charged ions which attract electrostatically (page 32 of the syllabus, bullet number 2.4.2).

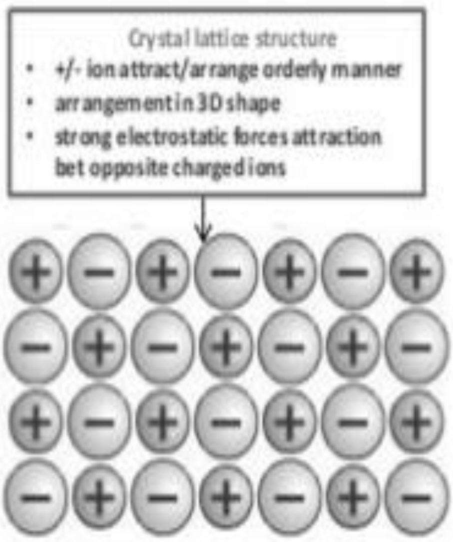
6. **Specific objectives: Learners should be able to:**
   - explain ionic (electrovalent) bonding as the electrostatic attraction between oppositely charged ions (cations and anions).
   - describe the lattice of an ionic compound as a regular arrangement of alternating positive and negative ions.
   - write the formulas of ionic compounds including polyatomic ions.

7. **Teaching Materials:**
- Platinum Physical Science text book, models of covalent bonding and posters with labeled diagrams of covalent bonding.

8. **Lesson presentation**

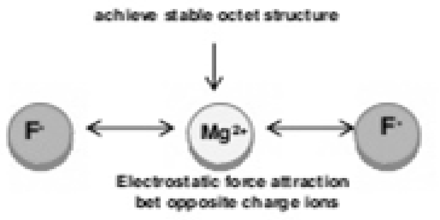
<table>
<tr><td>Introduction
(5 minutes)</td><td colspan="4">The teacher asks learners to differentiate between covalent and ionic bond. He then explains that the ionic bond has ions which attract each other to make the bond strong. He then tells them that the charges formed by ions are useful for deducing formulae of ionic compounds.</td></tr>
<tr><td>Content</td><td colspan="4">Lesson presentation (25 minutes)</td></tr>
<tr><td>Teacher's activity</td><td>Visual semiotic mode used</td><td>Verbal semiotic mode used (spoken)</td><td>Sense relations of intersemiotic complementarity used</td><td>Learners' activities</td></tr>
<tr><td rowspan="2">• Teacher explains that cations and anions attracting each other cause ionic bond to be very strong unlike the covalent bond.

• Teacher explains that the attraction between ions cause lattices to be formed which results in ionic substance being found as crystalline.

• Teacher explains and demonstrates, using magnesium fluoride as an example, to learners how formulas of ionic compounds are deduced from the valencies of reacting</td><td rowspan="2">(a) the diagram of cations and anions in a lattice

Crystal lattice structure</td><td>Positive and negative ions attracting and resulting in a strong electrostatic force</td><td>Similarity (Sm) - the visible ions with different charges have the similar meaning with the lexical item 'attract'.</td><td rowspan="2">• Learners analyse and deduce that a stronger attraction between cations and anions results in a strong bond.

• Learners relate the explanation to crystals in which table salt is found.

• Learners observe and use the same skills to determine the formula of:
✓ Beryllium fluoride</td></tr>
<tr><td>Ions arranged in order and form a 3D shape</td><td>Similarity (Sm) – the rows of positive and negative ions are similar to lexical items 'orderly packed' and 'a 3D structure'</td></tr>
</table>

elements and polyatomic ions. He does it with: ✓ sodium chloride ✓ lithium oxide ✓ magnesium fluoride	(b) cations and anions in a magnesium fluoride lattice  	Electrostatic force of attraction magnesium and fluorine ions	Similarity (Sm) - the *visible two-way* arrows have the same meaning as *ions attracting*	✓ Sodium oxide ✓ Magnesium chloride
		One magnesium and two fluorine ions	Similarity (Sm) – the *visible one magnesium ion and two fluorine ions* are repeated by the formulae MgF_2	
Learner support (5 minutes)	Teacher attends to learners who struggle to draw chemical bonding structures correctly			Learners who do not understand seek help from the teacher
Conclusion (3 minutes)	The teacher consolidates that opposite charges of ions determines ionic compounds to be very strong and they are also used to deduce formulae of ionic compounds			Learners take note of the importance of charge
Assessment (2 minutes)	Teacher gives guided reflective journals for the lesson taught to learners to hand them in at 8 o'clock the next day.			Learners receive guided reflective journals for the lesson taught for submission in the next day.
Evaluation/ reflection	What went well/wrong: ______________________________ ______________________________ ______________________________			
	What needs to be changed: ______________________________ ______________________________ ______________________________			
Teacher's signature: ______________________ Date: _____ / ________ / 2018				

Appendix M

Document analysis instrument for Physical Science Syllabus and Textbook

ANALYSIS OF 2015 GRADE 9 PHYCICAL SCIENCE SYLLABUS	
1. Introduction	
Items to be analysed/ searched	**Answer**
1.1 What type of document?	
1.2 When was it written?	
1.3 Who is the author?	
2. General and specific objectives of chemical bonding	
Aspects to be analysed/searched	
(a) What is/are the general objective(s) of:	**Answer**
2.1 Chemical bonding	______________________________________ ______________________________________ ______________________________________
2.2 Covalent bonding	______________________________________ ______________________________________ ______________________________________
2.3 Ionic/electrovalent bonding	______________________________________ ______________________________________ ______________________________________
(b) What is/are the specific objectives of:	**Answer**
2.1 Chemical bonding	______________________________________ _______________________________________ ______________________________________
2.2 Covalent bonding	______________________________________ ______________________________________ ______________________________________
2.3 Ionic bonding	______________________________________ _______________________________________
3. Syllabus' suggested approaches to chemical bonding teaching	
3.1 What are the suggested approaches to teaching chemical bonding?	______________________________________ ______________________________________
3.2 What is the syllabus' emphasis on the use of illustrated diagrams to clarify chemical bonding?	______________________________________ _______________________________________ _______________________________________
3.3 What does the syllabus suggest on the use of models, flipcharts or sketches in illustrating processes of chemical bonding?	Yes/No________________________________ _______________________________________ _______________________________________ _______________________________________
ANALYSIS OF PLUTINUM PHYSICAL SCIENCE TEXTBOOK	
1. Does the textbook contain pictures illustrating chemical bonding Yes/No: If yes, explain: ____ ____ ____	

2. Do the diagrams in the textbook have words explaining how chemical bonding takes place? Yes/No: If Yes, give examples: ____ ____ ____ ____ ____
3. Are the intersemiotic relations of ideational meaning evident in the combined use of visual and verbal (written) semiotic modes? Yes/No: If yes, Provide examples: ________ ____ ____ ____ ____ ____ ____ ____

Appendix N

Lesson observation instrument

Sense-making classroom observation instruments (Adapted from Zimmerman, 2009, p. 486)

[redacted]

Lesson number: 1 **Grade: 9**

Topic: Chemical bonding **Sub-topic: Types of chemical bonding** **lesson length: 40 minutes**

Sense-making indicator	**Sample quotations from the data**	**Number of sense-making items**
Perceptual (descriptive) talks and visuals [P]		
Talks and visuals about types of chemical bonding [CBF-1]		

Talks and visuals about covalent bonding and how it forms [CBF-2]		
Talks and visuals about connecting and analysing covalent bonding facts [CA]		

Talks and visuals about clarification of covalent bonding [CI]		
Talked and visualized ideas about nature of covalent bonding [ICB]		

Appendix O

Teacher's reflective journal guide

Lesson number: ___ **Grade: 9** **Date: __ /____ /2018**

Topic:_____________________________________ **Lesson length: 40**

1. Which visual-verbal ideational relations have improved the learners' sense-making of Chemical bonding during the lesson? Indicate the signs of sense-making observed.

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2. Which visual-verbal ideational relations have constrained the learners' sense-making in the topic? Indicate how.

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3. Which knowledge of covalent/ionic bonding did learners successfully make sense of during the lesson related to intersemiotic complementarity? Provide details.

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4. Did learners make perceptual (non-scientific) talk or drawings that show sense-making of covalent/ionic bonding? If yes, explain.

Space for drawings observed indicating learners' perceptual sense-making of the topic:

5. What connections between **macroscopic**, **sub-microscopic** and **symbolic** levels of Chemical bonding representation were learners able to make during the lesson? Provide details.

6. What are the evidences of learners' ability to make explicit and implicit comparisons to prior knowledge or experiences? Provide details.

Space for drawing indicating evidence of implicit and explicit comparisons to prior knowledge or experience:

7. What knowledge of applying chemical bonding in real life did learners demonstrate? Provide details.

8. What discussions, questions or diagrams showing that learners have the knowledge of how chemical bonding has developed? Provide evidence.

9. General remarks on the overall lesson or the approach

Appendix P

Learners' reflective journal guide

Lesson number: **Grade: 9** **Date: ___ /____ /2018**

Topic: _________________ **Lesson length: 40**

1. What can you remember about today's science topic? Explain in detail.

Space for drawing if any:

2. Which **drawings** or **models** used during today's Physical Science lesson helped you understand the topic taught? Explain how.

Space for drawing if any:

3. Which **drawings** or **models** used during today's Physical Science lesson confused you? Explain how.

Space for drawings if any:

4. Which teacher's **words** or **explanations** used during today's Physical Science lesson helped you understand the topic taught? Explain how.

5. What teacher's **words** or **explanations** used during today's Physical Science lesson confused you? Explain how.

6. What connections did today’s Physical Science lesson helped you make between **substances**, **their particles** and their **formulas** or **symbols**? Provide details or examples.

7. What else would you like to discuss or ask about chemical bonding?

Appendix Q

Learners' knowledge of chemical bonding after the traditional teaching approach (Accessed via learners' reflective journals during Cycle 1)

Lesson	**Learners' excerpts (including those related to them) indicating:**				
	Gained knowledge (GK)	**Total (including all related excerpts)**		**Challenging knowledge (CK)**	**Total (including all related excerpts)**
1 & 2 (covalent bonding)	*"elements in the periodic table are classified as metals (left) and non-metals (right) that are separated by the line called zigzag line"* (**Code: Classification)(M)**	27		*"do not know the difference between periods and groups"* **(Code: Classification)(M)**	2
				"do not know how to draw atoms well" **(Code: Bohr diagrams)(SM)(S)**	2
	"1st shell is full with 2 electrons, 2nd shell is full with 8 electrons and 3rd shell is full with 8 electrons" **(Code: electronic arrangement)(SM)**	20		*"don't understanding chemical properties of elements"* **(Code: chemical properties)(SM)**	1
	"atoms bonding to have full outer shells…" ; "Helium does not form a bond because its outer shell is full" **(Code: Chemical bonding)(SM)**	9		*" I am confused by the valency"* **(Code: valency)(SM)(S)**	8
	"during covalent bonding electrons are shared in pairs between non-metal atoms" **(Code: electron sharing)(SM)**	16		*"I cannot know the difference between types of bonds"* **(Code: bond differentiation)(SM)**	1

	"covalent bond can be single, double or triple" **(Code: covalent bond types)(SM)**	10		*"I am confuse by drawing covalent bonding"* **(Code: covalent bond drawing)(SM)**	7
				"I do not know why the triple bond and double bond formed"; "why single bond but two atoms?" **(Code: covalent bond types)(SM)**	5
	"valency electrons are used in bonding" **(Code: valency)(SM)**	4		*"I don't know which elements share protons"; "what happen if electrons are shared?"; "Why only non-metals share electrons?"* **(Code: electron sharing)(SM)**	8
	"covalent substances do not soluble in water like fat"; "covalent compounds are not conduct electricity"; "covalent have low melting and boiling points" **(Code: Physical properties of compounds)(M)**	15		*"I don't understand why covalent compounds have weak bond?"* **(Code: bond strength)(SM)**	4
3 & 4 (ionic bonding)	*"You need to know the rule of outer shell and the atoms that lose or gain electrons to understand ionic bond"; metals are transfer electrons to non-*	3		*"I don't know the groups and periods needed to draw ionic bond"* **(Code:**	1

	metals" **(Code: electron transfer)(SM)**			**classification)(M)**	
	"I understanding drawing ionic bond by transferring electrons in outer shell"; "I know that electrons are transfer from metals to non-metals"; "we used arrows which show electrons travelling from a metal to a non-metal" **(Code: Ionic bond drawing)(SM)**	3		*"I confuse by drawing ionic bonding"* **(Code: ionic bond drawing)(SM)(S)**	3
				"valency electrons confuse me when teacher explains" **(Code: valency)(SM)**	8
	"sodium is giving electron to fluorine and become positive"; "lithium is a cation while fluorine is anion" **(Code: ions)(SM)(S)**	3		*"why non-metals are not give away electrons?"; "I don't know which atoms should give away electrons"; I think electrons must be shared between metals and non-metals"* **(Code: electron transfer)(SM)**	5
	"ionic compounds can dissolve in water such as table salt"; ionic substances have strong bonds" **(Code: Physical properties of compounds)(M)**	6		"*I confuse by cations and anions"; "why cations lost but positive while anion gain but negative?"* **(Code: ions)(SM)(S)**	5
				"why ionic substances pass electricity while covalent substances pass electricity?" **(Code: electrical conductivity)(SM)**	1

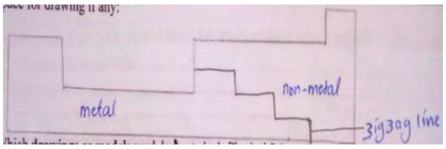
				"why do ions attract?"; "why do ionic compounds are strong?" **(Code: bond strength)(SM)(S)**	2
				"I do not understand how to use formulas of compounds" ; "I don't know how to find charges to writing formula of a compound" **(Code: chemical formulae)(S)**	8

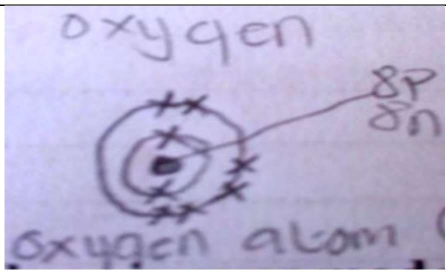
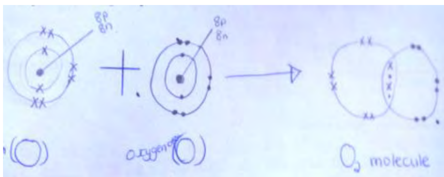
1. **Representational levels of chemical bonding knowledge:**
   - Macroscopic level (M)
   - Sub-microscopic level (SM)
   - Symbolic level (S)
2. **Sense-making types and codes**
   - Perceptual talk and visuals (P)
   - chemical bonding facts talk and visuals (CBF)
   - Connecting and analysing talk and visuals (CA)
   - Clarification talk and visuals (Cl)
   - Ideas of chemical bonding (ICB)

Appendix R

Learners' knowledge of chemical bonding after the intersemiotic complementarity teaching approach

(Accessed via learners' reflective journals during Cycle 2)

Lesson	Learners' excerpts and drawings indicating:				
	Gained knowledge (GK)	**Total (including all related excerpts)**		**Challenging knowledge (CK)**	**Total (including all related excerpts)**
1 & 2 (covalent bonding)	• *"I remember that elements in the periodic table are classified as metals (left) and non-metals (right) that are separated by the line called zigzag line like this:*  • *"these elements are also put in groups and periods"* **(Code: Classification)(M)**	32		• *"sometimes I confuse the periods and groups because I forget which one is vertical and which is horizontal"* **(Code: Classification)(M)**	3
	• *"1st shell is full with 2 electrons, 2nd shell is full with 8 electrons and 3rd shell is full with 8 electrons"* • *"we are able to draw structures of elements such as oxygen:*	29		• *" I know the valency of many elements but I don't know the valency for argon because sir did not talk about it in the class"* **(Code: valency)(SM)**	1

	 ” **(Code: electronic arrangement)(SM)**				
	• *“atoms bonding to have full outer shells…”* • *“Helium and argon do not form a bond because they have outer shells that are full”* **(Code: chemical bonding)(SM)**	33			
	• *“during covalent bonding electrons are shared in pairs between non-metal atoms”* **(Code: electron sharing)(SM)**	16		• *“I only want to draw the bond in sulphur dioxide because the teacher did not show it to us.”* **(Code: covalent bond drawing)(SM)**	
	• *“during covalent bonding, electrons are shared in pairs between non-metals only”* • *“I can draw the double bond in the oxygen molecule like this:*  ” **(Code: covalent bond types)(SM)**	10			

	• *"valency electrons are used in bonding"* • *"the valency of elements in group 1, 2 and 3 is equal to the group number while the valency of elements in 4, 5, 6 and 7 is find by subtracting eight from the group number"* **(Code: valency)(SM)**	23		• *"I know that covalent compounds have weak bonds but I want to know why "* • *"how can we make this bond strong because the teacher said that the bond is weak?"* **(Code: bond strength)(SM)**	3
	• *"covalent substances are insoluble in water like fat"* • *"covalent compounds are non-conductors of electricity like a switch is a plastic which is not conduct electricity"* • *"covalent compounds have low melting and boiling points which means if you heat them they can easily melt and easily boil"* • *If you heat fat or butter, it can just melt fast and become water"* **(Code: Physical properties of compounds)(M)**	34			
3 & 4 (ionic bonding)	• *"atoms of metals can transfer electrons to atoms of non-metals"* • *"If sodium and oxygen are bond, sodium transfer electrons to oxygen atom"*	31		• *"I don't know how to draw the ionic bond of aluminium oxide because I was not given a mark when I draw my diagram"*	1

	(Code: electron transfer)(SM)			**(Code: ionic bond drawing)(SM)(S)**	
	• *"if you want to draw ionic bond you should transfer outer shell electrons from a metal to a non-metal"* • *"I know that electrons are transfer from metals to non-metals"* • *The electrons that are transferred should be shown with arrows and can also write transfer on the arrow"* • *If the electrons that are transferred are not enough to make a non-metal full you draw another metal atom so that become enough"* • *"if the metal has two electrons in the outer shell and the non-metal needs only one electron, you draw two atoms of this non-metal"* **(Code: Ionic bond drawing)(SM)**	24		• *"I don't know the valency of copper and zinc because they are not found in the groups that we are taught because they may be they can also bond with oxygen like just like sodium"* **(Code: valency)(SM)**	1
	• *"I know that if atoms give away electrons they become positive ions which are called cations…if an atom is given electrons it become anion which is a negative ion"* • *"I know that all metals losing electrons are becoming cations and all non-metals*	17		• *"I want to know why our teacher said that cations are positive while anions are negative"* • *"why is the cation having + while anion having – on top? … I want to know because*	2

	gaining electrons become anions" • *"In sodium chloride there is sodium ions which is cation and chlorine ion which is anion"* **(Code: ions)(SM)(S)**			*+ means you add but now where you subtract you write + and where you add you write-"* **(Code: ions)(SM)(S)**	
	• *"I know that ionic compounds are soluble in water such as table salt but sugar may be is also ionic substances because it is also soluble by water"* • *"Ionic substances they have a high meting point and also high boiling points…just all of them do not melt"* • *"we know that ionic compounds do not conduct electricity if they are the solid…but just if I put it water it will make electricity move in it like in wires…"* • *"I also ionic can break if they are hammered…salt can break if you hammer it with a hammer"* **(Code: Physical properties of compounds)(M)**	12		• *"I want the teacher to explain why ionic substances pass electricity while covalent substances do not pass electricity?"* **(Code: electrical conductivity)(SM)**	1
				• *"sometimes I write the formula correct but sometimes I fail and I don't know why"* **(Code: chemical formulae)(S)**	4

1. **Representational levels of Chemical bonding knowledge:**

- Macroscopic level (M)
- Sub-microscopic level (SM)
- Symbolic level (S)

2. **Sense-making types and codes**
    - Perceptual talk and visuals (P)
    - Chemical bonding facts talk and visuals (CBF)
    - Connecting and analysing talk and visuals (CA)
    - Clarification talk and visuals (Cl)
    - Ideas of chemical bonding (ICB)

Appendix S

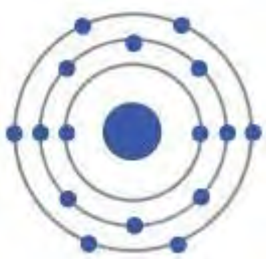
Learners' pre-test

[redacted] Combined School

Physical Science test **Date: 09/04/2018**
Grade 9 **Marks: 25**

Topic: Matter

1. Study the diagram below to answer the questions that follow.



Examine the atomic structure of an element above to determine:

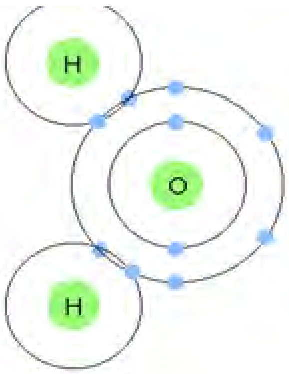
(a) Its group number in the periodic table.

____ [1]

(b) Its period number in the periodic table.

____ [1]

2. The diagram below is the illustration of a covalent bond formed between hydrogen and oxygen.



List of possible answers: ***atom, molecule, share, transfer***

Choose from the list, the word that describes:

(a) A circle labelled with letter **H**.

____ [1]

(b) A circle labelled with letter **O**.

____ [1]

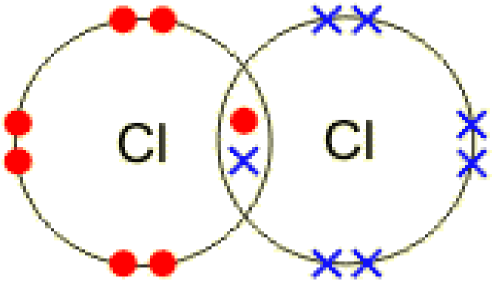
(c) The whole diagram (all three circles, labelled **O** and **H**).

____ [1]

(d) Overlapping shells with electrons between them.

____ [1]

3. The diagram shows atoms sharing electrons.



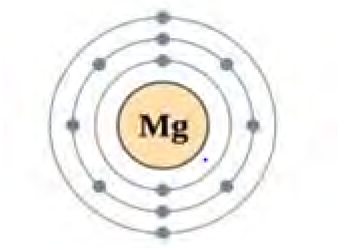
(a) Identify the type of chemical bond illustrated by the diagram. Explain your answer.

____ [2]

(b) On what side ***(left or right)*** of the zigzag line in the periodic table do elements of these atoms belong? Explain your answer.

____ [2]

4. The diagram shows the Bohr structure of a magnesium atom.



(a) The imbalance (unequal number) of protons **(+)** and electrons **(-)** in an atom creates charges. During bonding, the magnesium atom above loses two (2) electrons **(-)** to form an ion. Determine the charge of a magnesium ion. Explain your answer.

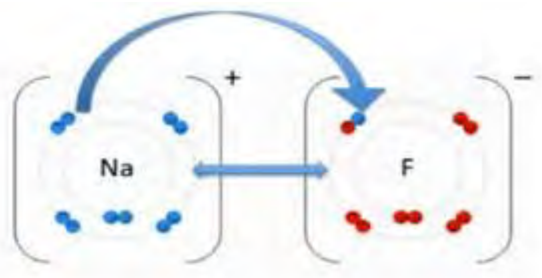
____

____ [2]

(b) Determine the metallic nature of magnesium (metal, metalloid or non-metal).

____ [1]

5. The diagram represents an ionic bond between sodium and fluorine.



Identify the feature on the diagram above that:

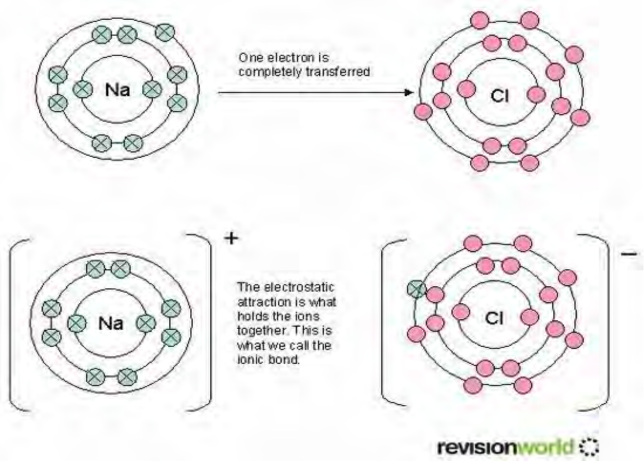
(a) classifies the bond as ionic bond.

____ [1]

(b) describes this chemical bond as very strong.

____ [1]

6. The diagram illustrates an ionic bond formed between sodium and chlorine.



A cation is an atom that lost electrons while an anion is an atom that gained electrons. The chlorine atom becomes an anion after it gained one electron.

(a) With a reason, decide whether a sodium atom becomes an **anion** or a **cation** after it lost one electron.

____ [2]

(b) Write down the name of the compound formed from the reaction above.

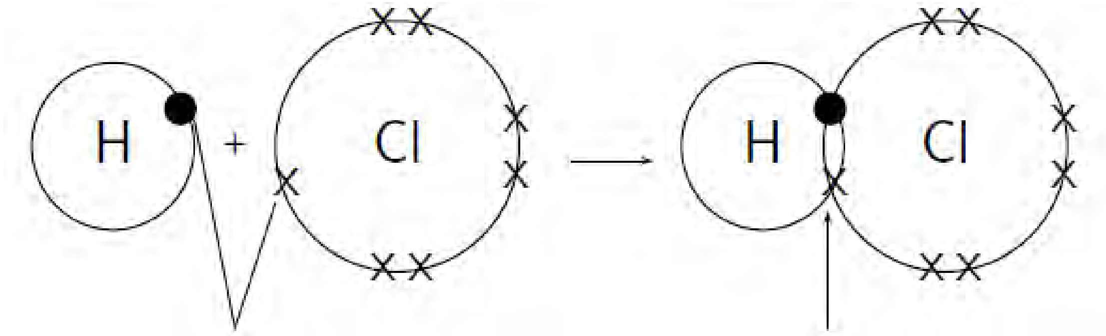
____ [1]

(c) Write down the formula of the compound formed from the reaction above.

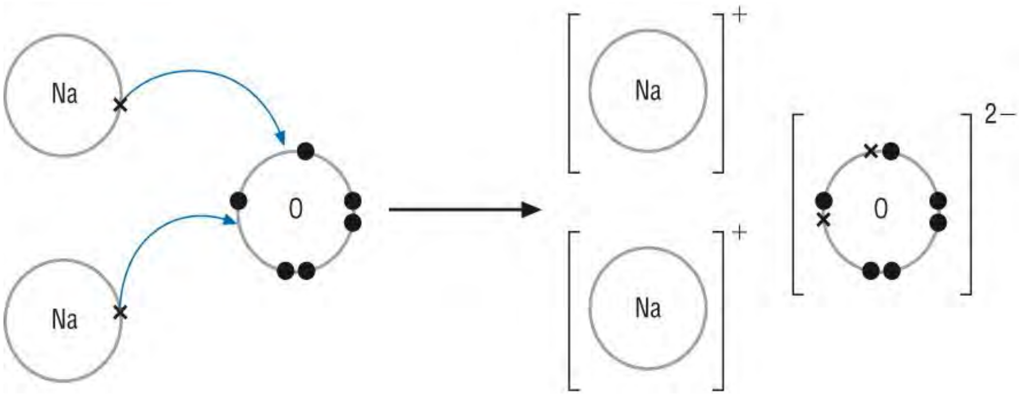
____ [1]

7. The diagram illustrates the difference between covalent and ionic bond.

A: covalent bonding



B: Ionic bonding



(a) Complete the table to identify differences between covalent and ionic bond that are shown by the diagram. [4]

	Covalent bond	Ionic bond
What happens to electrons	(i)	(ii)
Bond strength	(iii)	(iv)

(b) Diagram **B** (ionic bonding) is incomplete. Copy diagram B above and add missing information to make it complete.

[2]

Appendix T
The learners' post-test

[redacted] Combined School

Physical Science Post-test
Grade 9
Name: ____________________

20/04/2018
Marks: 25

1. Study the diagram below to answer the questions that follow:

Examine the atomic structure of the element above to determine:

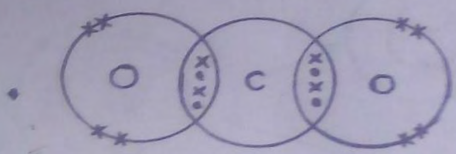
(a) Its group number [1]

5

(b) Its period number [1]

2

2. The diagram below is the illustration of a covalent bond formed when carbon and oxygen atoms bond.



List: atom, molecule, share, transfer.

Choose from the list, the word that describes:

(a) a circle labeled O [1]

atom

(b) a circle labeled C [1]

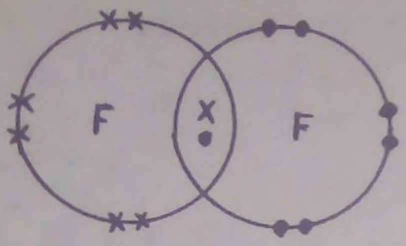
atom

(c) all three circles combined [1]

Molecule

1

3. The diagram shows similar atoms sharing electrons.



(a) Identify the type of chemical bond illustrated by the diagram. Explain your answer. [2]

covalent, because electrons are shared / it happens btween non-metals.

(b) On what side (**left or right**) of the zigzag line in the periodic table does the element of these atoms belong?

Explain your answer.

Side: right

Reason: it is a non-metal [2]

4. The diagram shows the Bohr structure of a sulfur atom.

(a) During its bonding with another element, sulfur gains two (2) electrons to form an ion.

Determine the charge of a sulfur ion. Explain your reason

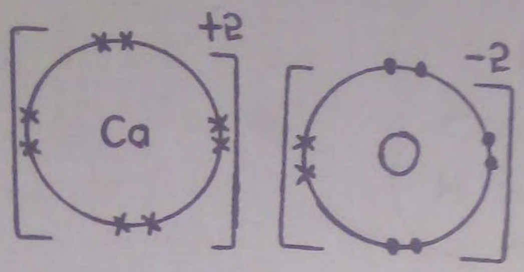
Charge: −2

Reason: because it loses two electrons [2]

(b) Determine the metallic nature (**metal, metalloid or non-metal**) of sulfur. [1]

It is a non-metal

5. The diagram represents an ionic bond between calcium and oxygen



Identify the feature on the diagram that:

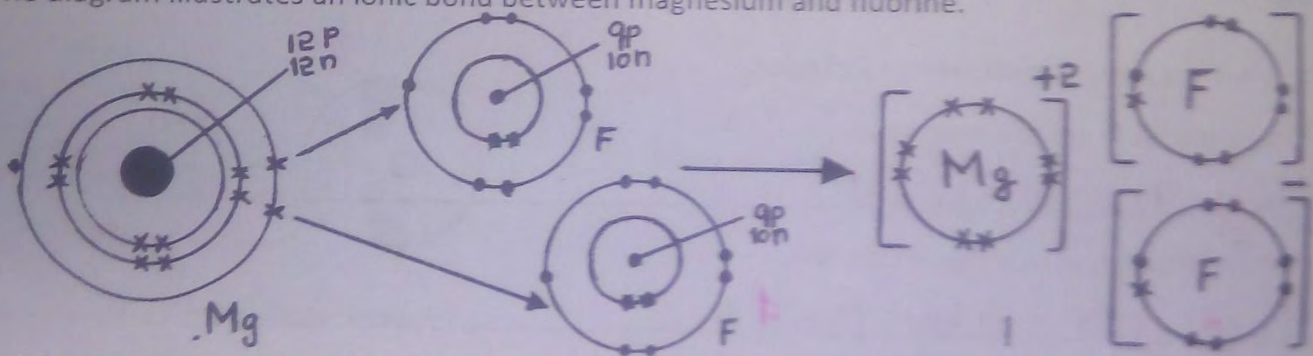
(a) Classify the bond as ionic. [1]

opposite charge/a metal and non-metal

(b) Describes this bond as very strong. [1]

opposite charges

6. The diagram illustrates an ionic bond between magnesium and fluorine.



(a) With the reason, decide whether magnesium is an anion or a cation.

Answer: cation

Reason: because it loses electrons [2]

(b) Write down the name of the compound formed from the reaction above. [1]

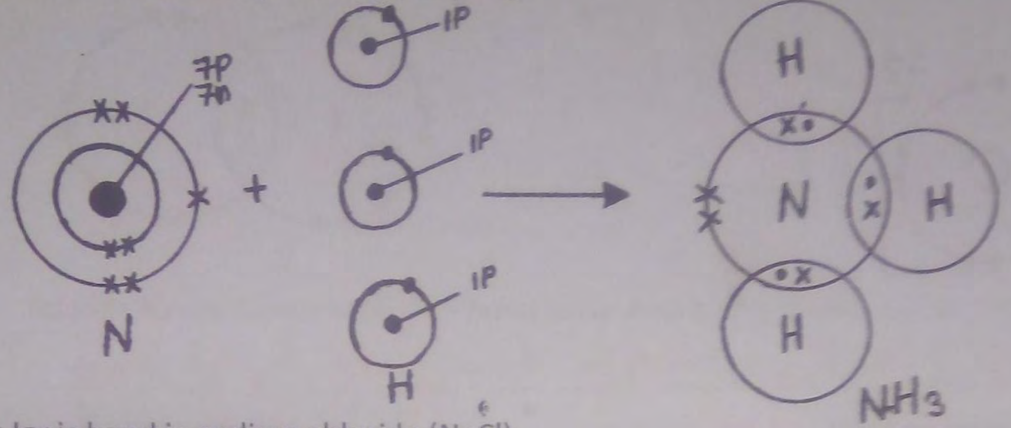
magnesium fluoride

(c) Write down the formula of the compound formed from the reaction above. [1]

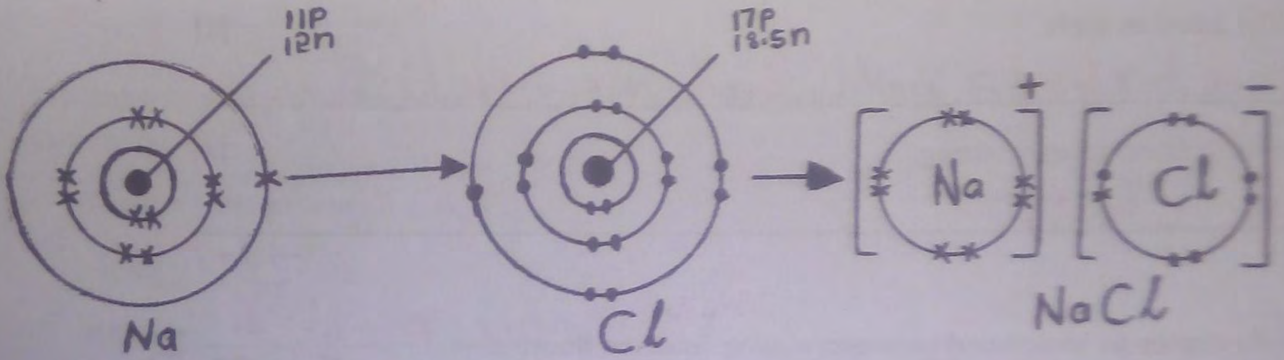
MgF_2

7. The diagram illustrates the difference between covalent and ionic bonding.

A: Covalent bonding in ammonia (NH_3)



B: Ionic bond in sodium chloride (NaCl)



(a) State what happens to outershell electrons:

(i) in the covalent bond in ammonia. [1]

• they are shared

(ii) in the covalent bond in sodium chloride. [1]

They are transfered

State bond strength (weak or strong bond):

(i) in ammonia [1]

weak

(ii) in sodium chloride [1]

strong

(b) Use the periodic table to draw the bond between magnesium and fluorine. [3]

Appendix U

The Turnitin Similarity Report

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