

**Evaluation of a targeted intervention method
for
concept formation in chemical bonding
at
Grade 10 level**

Angela Roché

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ABSTRACT

Teaching of chemistry at secondary school level is not always carried out in the most effective way and this is often because teachers do not realise the difficulties experienced by pupils while studying a conceptually challenging topic. The development of a teaching strategy to assist teachers is thus of value.

The research questions:

- Do focussed intervention questions followed by rapid feedback to pupils foster sound concept formation in chemical bonding?
- Is this new teaching method more effective than traditional methods?

In this study I have examined the effect of a novel teaching method (referred to as the Targeted Intervention Questioning process) on concept formation during the study of chemical bonding. This study involves action research in secondary school classrooms. The findings from the study are being used to further inform current teaching practice. The teaching method is a set of focused intervention questions administered at relevant stages during the teaching of the topic. Pupils answer these questions with the help of their learning material and are given rapid feedback with an evaluation of their answers. This questioning process is designed to focus pupils' attention on the relevant concepts and the feedback is to inform pupils of their progress in mastering the topic. The effectiveness of the method was measured using a concept development test. The learning gain in a test group was compared to that of a control group in a quasi-experimental study.

This research involves action research as findings will inform practice and practice will change in line with the research findings. Data gathering to ascertain the effectiveness of the teaching method will be through quantitative methods in a quasi-experimental setup. The sample size was approximately 80 learners, divided into the four classes. All teachers use the methods and techniques that they normally use. The learning gain was determined through the use of a concept development test developed by the author (referred to as the Conceptual Test tool). This test tool contained a set of 25 conceptual questions, either requiring selection of a correct answer from a multiple choice selection or requiring a free response answer.

The testing tool was piloted using a group of Grade 11 pupils in 2010. The test was then refined and used to measure the effectiveness of the intervention questioning process in 2011. A second run of the intervention process was carried out in 2012 using a slightly modified testing tool.

The result of the test group was compared to that of the control group. A Correlation analysis and a Rasch analysis determined the validity of the testing tool.

Results from both runs of the intervention process show that the test group has a statistically significant greater learning gain (LG) over the control group. Analysis of answers given by pupils to the intervention questions provided insight into the learning process that was happening.

I, ANGELA ROCHE declare that the thesis,

which I hereby submit for the degree

MSc Science Education at the University of Pretoria,

**is my own work and has not previously been submitted by me for a degree at this or
any other tertiary institution.**

SIGNATURE:

DATE:

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CHAPTER 1

INTRODUCTION

1.1 Why did I start this study?

Chemistry is a vast subject and at secondary school level the basic concepts need to be cemented in pupils' understanding in order for them to progress in the study of the subject at tertiary level. Thousands of first year students in South Africa have to complete at least one semester of chemistry each year. Students of medicine, engineering, biological sciences all have to do some chemistry at tertiary level. This means that the grounding pupils receive at school in chemistry is of paramount importance.

Secondary school pupils begin their trip through chemistry with the atom - what is an atom, how it is put together? They then progress to looking at how and why molecules are formed. This involves the study of chemical bonding. Pupils also study the forces between molecules, those forces that determine melting and boiling points. Intermolecular forces are determined, amongst others, by the nature of the chemical bonds within molecules. The notion that chemical bonding is fundamental or central for other concepts in the chemistry curriculum cannot be overemphasised.

Secondary school pupils find it difficult to develop a sound understanding of chemical concepts – especially this fundamental concept of chemical bonding. After many years of teaching I have come to realise that the two sections of the high school Chemistry syllabus that pupils most often fail to “get” are chemical bonding and intermolecular forces. Changing the sequence of teaching, and, up until now, the way in which these topics are taught, seem to have little effect on the development of a sound understanding of the concepts.

These two sections of chemistry are highly theoretical and abstract. At the stage when these topics are taught (Grade 10 and 11) some pupils still function in the concrete operations phase which means that they are not able to visualise abstract concepts. They need to experience the concepts concretely before being able to form a mental picture of the concept and develop a sound understanding. It is desirable that all pupils form mental pictures of atoms and molecules in order to understand these abstract concepts. There are no photos, there is no microscope that can show pupils what atoms look like, how they combine and form molecules or ions.

The language of chemistry involves new terminology, chemical formulae and sub-microscopic diagrams. Pupils need to understand these new words and diagrams and then link the many terms and concepts together in order to end up with a unified picture or model in their mind of why and how atoms bond.

The nature of the content requires that teaching takes place over a length of time (about 3 weeks). There is a limit to the amount of new content that can be presented per lesson which means that teachers usually take an extended period of time to progress through the material. The extended teaching time coupled with the complicated concepts that are presented during that time results in pupils losing focus and not being able to see the connections between the concepts. In the end pupils only develop a limited or incomplete understanding of the concepts.

How do pupils (16 – 17 year old pupils) process the information presented in class so as to develop a conceptual understanding of complex material? Each day when a pupil comes to class does he/she remember what has gone before? Can the pupil link today's content to yesterday's content? Does the pupil actually know what he/she understands and has already grasped? Does the pupil actually know what the most important (core) aspects of what the teacher has talked about and explained are? Or is each lesson viewed by the pupil as a separate entity which results in minimal linking occurring between the different topics presented?

If we reason that pupils come to class day after day seeing each lesson as an entity and, despite homework and reinforcement, fail to see the material as a linked unit, then limited concept development will occur.

Pupils in South Africa generally end up exiting the school system with limited understanding of the concepts they have been taught. Current teaching methods in South Africa do not focus on teaching for concept formation. Potgieter, Rogan & Howie (2005) report this from their study:

“Upon exit from secondary education Grade 12 learners are poorly prepared for first-year chemistry in terms of conceptual understanding.”

Concepts are mental representations of knowledge that have to serve certain functions and that need to be connected in order to serve their function as representational structures (Carey, 2000). We begin developing concepts that make the world around us meaningful from the time we are born. Science teachers have to begin from the point of a naive conceptual understanding of the world around them as they guide pupils through the learning process

(Novak, 1990, Vosnaidou & Brewer 1987, Barke, Hazari & Yitbarek, 2009). Learning is therefore to be seen as conceptual change. Learning is described as implementing changes in already existing cognitive structures (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Research has been carried out that shows that pupils begin their study of scientific concepts with certain pre-concepts, misconcepts and naive concepts regarding the topic to be studied.

During the learning process pupils need to rework these pre-concepts and integrate the new material so as to arrive at a new understanding of concepts, a new mental model that fits all this together into a new coherent whole (Nakhleh, 1992).

According to Elyon & Linn (1988): “In general, students (a) use scientific terms imprecisely, (b) develop a reasonably sound descriptive world view based on observed events, (c) acquire limited or incorrect views of causal relationships, (d) view scientific phenomena in isolation, and (e) come to assume that science is memorized, not understood.”

Developing a mental model must involve learning the terminology associated with the concept. This knowledge forms the foundation on which the mental model is built. So when pupils progress through the teaching of a section of work with a hazy knowledge of the terms being used, then an incomplete mental model will be the result. Pupils observe science all around them. Teachers demonstrate and draw their attention to scientific phenomena. There is, however, little linking of terminology, understanding through observation and intuitive concept development. It is the linking of these three aspects of the learning of science that educators need to perfect in order to effectively promote concept formation.

Pupils should see that science is not just learning but involves learning basic terminology so that understanding can develop. There is a “big picture” in science and educators need to help pupils fill in all the “spaces” so that they can develop that picture.

There is a discrepancy – pupils assume that science is to be memorised and we the educators ask them to answer questions requiring application of knowledge and the use of higher thinking skills. We teach section by section and so pupils never see scientific phenomena linked, never realise that there are causal relationships between phenomena.

If the teacher were to pay attention to facilitating linking content and concepts during the teaching process it could be that better concept development would occur. The mental models

built up by pupils while learning about chemical bonding or intermolecular forces will be more complete and comprehensive.

1.2 The Focus of this Study

In order to improve teaching and to better facilitate the understanding of chemical bonding and intermolecular forces, I would like to explore a different approach to teaching these concepts and determine how effective this method is in developing concepts.

In this study I will develop and test a questioning strategy combined with feedback to pupils and I will investigate whether this strategy will foster sound concept development. I will also investigate whether this strategy is more effective than conventional teaching methods.

The method I will develop approaches the teaching of chemistry and in particular chemical bonding, in a way that leads to better concept formation than currently occurs with teaching methods that are largely “chalk and talk” followed by summative testing.

From my experience as a teacher there often seems to be a big gap between the teacher “teaching” and the learner “learning”. Even as an experienced teacher I am often startled to discover that the learning I have anticipated to be taking place is not occurring. Learning is defined as the acquisition of knowledge or skills through experience, practice, or study, or by being taught. The mental modelling and concept formation aspects of the learning process are seen as the key problematic areas and will be the focus of this study.

If I, as a teacher, want to improve mental modelling and concept formation I will pose the question asking whether a novel teaching method can be designed that improves concept formation during the study of chemical bonding.

This research is based on the theory that learners must construct knowledge and build up their own mental model in order for conceptual understanding to occur. Metacognitive processes and the effects of feedback on the learning process also form part of the theoretical framework that this research is based on.

The research takes the form of action research as test findings at each stage, as well as the informal observations obtained during the teaching process, will be used to inform teaching practice, which is the subject of the study. Any new knowledge and insight into pupil’s conceptual development that emerges from this research will be used to inform and improve

teaching methods. Teaching must benefit immediately from any positive results emanating from the research. The action research aspect of the project is of great importance.

Ultimately this research is aimed at development of a method that can be used by any teacher teaching these sections of the chemistry curriculum. This method could serve as an additional teaching aid irrespective of a particular teacher's teaching style. The teaching of chemistry at secondary level needs a "method" that will ensure good concept formation.

In this chapter I have outlined the reasons why I am undertaking this study and have alluded to the design and development of a teaching method that is to improve concept development.

In Chapter 2 I will discuss the literature sources underpinning this study and I will then describe the concepts that make up the topic of chemical bonding in Chapter 3. Chapter 4 and 5 describe the design and development of the method as well as the methodology used to ascertain the effectiveness of the method. In Chapter 6 I will discuss the results obtained from testing the method.

CHAPTER 2

LITERATURE REVIEW and THEORETICAL FRAMEWORK

2.1 INTRODUCTION

In developing a novel teaching method I started by considering learning to be concept development (or formation) and viewed learning from the constructivist perspective. This process of concept formation involves pupils in the development of mental models. The novel teaching method aims to improve this process of mental modelling by providing feedback timeously so as to limit the cognitive load and improve pupils' metacognitive processes.

This chapter discusses those aspects of the literature that relate to this study and discusses how the understanding gained by previous researchers in related fields supports this study.

This study is based on the following THEORETICAL FRAMEWORKS:

- The constructivist model of learning.
- Learning as concept formation or development.
- Mental modelling as part of the process of concept development.
- Metacognition.
- The feedback model of conceptual development.
- Cognitive Load Theory

2.2 CONCEPTUAL CHALLENGES:

Chemical bonding is a section of high school Chemistry that pupils find difficult to understand. Pupils will often comment on their lower Chemistry marks compared to what they score in a Physics exam. Pupils seem to be able to develop a "method" for studying Physics but are not always able to do this for Chemistry. The material covered in Chemistry involves abstract concepts that pupils do not seem to be able to assimilate. The sub-microscopic and the representational views of matter involve non-concrete representations. Most of chemistry is the study and understanding of the unseen. Pupils are often still in the Piagetian phase of concrete operations. In this phase pupils are able to do mental operations but only on real or concrete objects. They are unable to do abstract thinking (Wankat & Oreovicz, 1993). These pupils need to begin their reasoning and understanding from real, sensory experiences (Herron, 1975). Consequently abstract principles of chemistry are learned by many pupils at a superficial level and they do not develop proper mental models that result in effective concept formation. However, there are

some programs that lead pupils through self-regulation activities to operate in the formal operations phase that have proved successful (Smith, 1978).

There are misconceptions that pupils have when starting to study chemical bonding (Petersen & Treagust, 1989; Ozmen, 2004; Unal, Costu & Ayas 2010). Pupils begin their study with pre-conceptions that can arise from previous teaching or from life experiences. These are referred to as alternative conceptions (Horton, 2007). The distinction between atoms and molecules is not always clear, as is the distinction between electrons and atoms. Many years of teaching has shown me that pupils' distinction between the macroscopic (those things they can observe – the elements mercury or sulphur, compounds sodium chloride or water) and sub-microscopic (the atoms and molecules making up these tangible substances) is slow to develop. These fundamental concepts are still developing and are often not completely clear when pupils begin the next step of concept formation, such as how do the molecules form? Teachers do however assume that pupils begin their study of chemical bonding with certain clear foundation knowledge. Development of the new understanding is assumed to occur on a solid foundation but this is not the case (Taber, 2001).

Literature studies report that there is a fundamental misconception amongst pupils in that they have an inability to differentiate between atoms and molecules. How and why atoms bond, electronegativity, the polar nature of some bonds and energy changes during bonding are also all reported misconceptions amongst high school pupils (Nicoll, 2001).

When pupils begin the study of chemical bonding with an incomplete picture of what matter is made up of on the sub-microscopic level they will experience difficulties understanding the complexity of chemical bonding. The simple definition of molecules as two or more atoms joined chemically can be reconciled with covalent bonding but the more complex bonding in lattices requires a different level of understanding. This has been reported by Boo and Watson (2001) "They were confused as to the nature of chemical bonds. Bonds are viewed as entities linking atoms and so a giant lattice of ions, in which no ions are specifically linked to other ions, are difficult to understand in terms of bonding." (p578).

In the short space of time during which pupils receive instruction on this topic, how do they cope with the many and often conflicting ideas? According to De Posada (1981) pupils can misinterpret what the teacher teaches in order to strengthen the ideas they already have. They even go so far

as to keep their ideas and the teacher's model in parallel, disbelieving the correct taught model but learning it for examination purposes.

Many years of experience of teaching high school pupils chemical bonding have made me aware that this is the case. Pupils very easily learn by rote what they have to know to pass a test or examination but probing shows little conceptual understanding. As an example, pupils will be able state that metals always conduct electricity and that ionically bonded compounds only conduct when molten or in solution. They might even be able to write down dissociation equations for ionically bonded compounds. However, when asked to draw a diagram to help with the explanation very few can. This shows that the fundamental mental model of the nature of the chemical bonds in each of these substances is lacking. Relating the macroscopic properties to sub-microscopic properties is difficult and poorly understood and Talanteur (2011) discusses problems students encounter dealing with the chemistry "triplet", namely the macroscopic, sub-microscopic and symbolic aspects, see Figure 2.1 (Talanteur, 2011; Johnstone, 2010; Zhang, 2011; Hilton and Nicholls, 2011; Luxford & Bretz, 2013). Teachers are quick to refer to the three levels but pupils have difficulty understanding the concept.

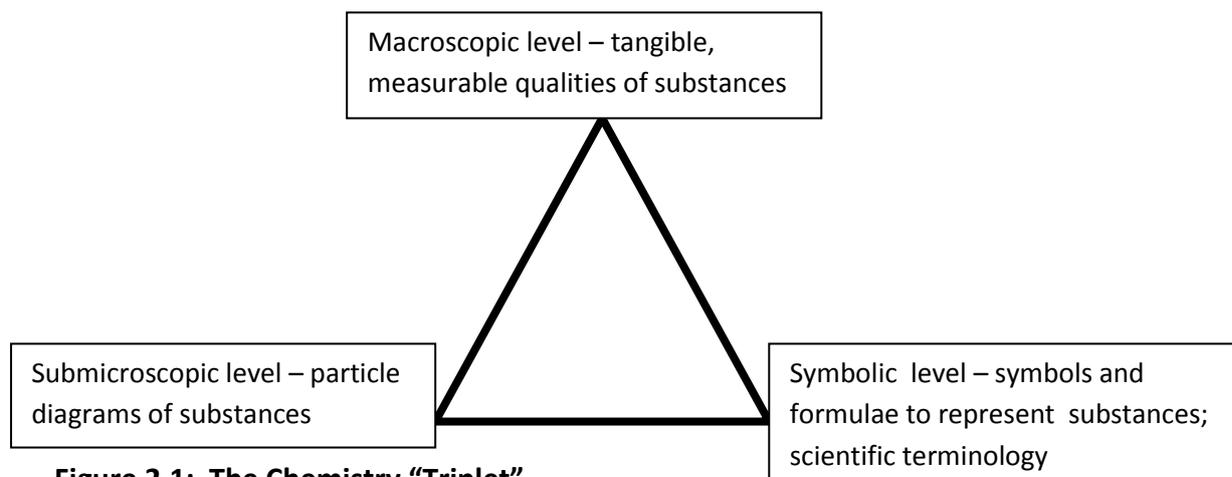


Figure 2.1: The Chemistry "Triplet"

While approaching the study of this chosen topic there are certain aspects of previous research that are relevant and should be considered to add credence to my study. The phenomenon of learning will be considered from a constructivist point of view. I will look at what is concept formation, as it is this aspect of the learning process that I am trying to enhance. The development of mental models is part of the process of concept development. The two go hand in hand. The learning process also requires that pupils begin to know and understand what their body of knowledge should encompass, the depth to which their knowledge should extend and at each step how close are they to the target. This involves their metacognitive functioning.

2.3 LEARNING, CONSTRUCTIVISM and CONCEPTUAL CHANGE

Research in Chemistry Education has largely approached the study of learning Chemistry from one of four different viewpoints: a concept-learning focus, a developmental focus, a differential focus, or a focus on problem solving (Eylon & Linn, 1988). Studies of chemistry learning viewed from the developmental perspective consider optimal phases in a pupil's life for learning chemistry. The differential perspective looks at the effects of individual differences in aptitude on learning. The effect of the approach pupils employ when problem solving has also been considered in chemistry learning research. In this study I will focus on concept learning and consider the structure and content of the knowledge that pupils acquire.

Chemical bonding is a difficult concept for students of chemistry to grasp. The results can reflect good marks but bad concept formation. Pupils often study their Chemistry by means of rote learning. The result of rote learning and the problem with rote learning is that pupils have knowledge of facts but a limited understanding of the basics of chemistry. They also develop and perpetuate many mis-concepts and alternative concepts. This is true in general, but is particularly so when considering pupil learning of chemical bonding. According to Nahum, T R, Mamlok-Naaman, R, Hofstein, A, Krajcik, J, (2007) "The traditional pedagogical approach for teaching chemical bonding is often overly simplistic and not aligned with the most up-to-date scientific models. As a result, high-school students around the world lack fundamental understanding of chemical bonding". In a literature review of misconceptions and teaching of chemical bonding, Ozmen (2004) refers to the abstract nature of the concept and the use of known terminology in a new context as being prime causes of lack of proper conceptual development.

In order to improve pupil learning of chemical bonding the focus must be directed at improving pupil understanding of the individual concepts embodied in the larger topic of chemical bonding. In so doing pupils must construct their new knowledge if the process is to be effective (Spencer, 1999). Currently, learning science is seen from the perspective of constructivism. "The constructivist epistemology asserts that the only tools available to a knower are the senses. It is only through seeing, hearing, touching, smelling, and tasting that an individual interacts with the environment. With these messages from the senses the individual builds a picture of the world. Therefore, constructivism asserts that knowledge resides in individuals; that knowledge cannot be transferred intact from the head of a teacher to the heads of students. The student tries to make sense of what is taught by trying to fit it with his/her experience." (Lorsbach & Tobin, 1997). This

means that pupils need to actively engage in the learning process. The days of “chalk and talk” in the classroom should be over.

Constructivism looks at learning as a process of fitting new knowledge and concepts into already existing mental constructs. The fit of the two must be seen to be “right” or to have order for the one developing the new knowledge (von Glasersfeld, 1983). Extending on this idea, radical constructivism sees knowledge as being constructed by the learner solely based on his experiences in order to make sense of those experiences (Hardy & Taylor, 1997). In the world of science, scientists constantly struggle to order their experiences of the world around them by developing models, testing models through controlled experimentation. According to von Glasersfeld (2001) even scientific “truths” are constructed from human experience interpreted in terms of human concepts and are therefore experiential. De Berg (2006) describes science teaching as proceeding from the viewpoint of Piagetian constructivism where individual construction of knowledge accounts for learning or from a perspective of social constructivism where meaning and knowledge construction are negotiated. Piagetian theory describes learning as organisation and adaptation which takes place in a hierarchical fashion with skills and operations becoming more and more complex (Nurrenbern, 2001). Therefore Piagetian theory indicates that pupils progress through different phases of development which has implications for teaching science especially when considering learning from a constructivist point of view.

What is “learning”? “Learning is thus a kind of inquiry. Learning is concerned with ideas, their structure and the evidence for them. It is not simply the acquisition of a set of correct responses, a verbal repertoire or a set of behaviours. We believe it follows that learning, like inquiry, is best viewed as a process of conceptual change” (Posner, Strike, Hewson, & Gertzog, 1982).

Conceptual change occurs when pupils assimilate new knowledge, fit it into their pre-knowledge, make sense of it in relation to their pre-conceived ideas and then develop a new set of mental models that makes sense of the new knowledge (Vosniadou, 1994). According to Hewson (1992) conceptual change can take place in one of three ways. Pupils must relinquish one understanding of a concept and replace it with another. This is difficult. Secondly pupils can elevate the status of one concept over another while not relinquishing the original concept. Lastly pupils just extend on the original conceptual understanding. In any event it must be noted that pre-concepts are important for the development of conceptual understanding. Once conceptual development has occurred pupils can use this new knowledge. They can apply the new knowledge in problem

solving situations, they can argue from this base of knowledge. This is not possible if material is only learned by rote.

Novak's Theory of Education (Novak, 1993) refers to the need to assimilate new knowledge into already present cognitive structures before meaningful learning can occur. Meaningful learning allows pupils to feel in control of their learning. They are empowered. Ausubel views knowledge as an integrated system where ideas are linked together in an ordered system (Ivie, 1998). New knowledge must be assimilated into already present cognitive structures in order to attain meaning.

It must be mentioned that the teaching of the topics studied occurs at certain set stages of the pupil's school career. In the context of the South African school syllabus chemical bonding is taught at Grade 10 level and this assumes that all pupils are at a developmental stage that allows the pupil to understand the material being taught. All pupils develop at different rates. Thus, some pupils might not be functioning in the formal operations mode, necessary for full understanding this abstract topic. Teachers need to be aware of this limitation and adjust their teaching methods so as to be able to reach pupils functioning in different developmental stages. Herron (1975) reports that many pupils entering college in the USA are still functioning on the concrete operations phase, which means that the basis for the development of their understanding is from the concrete and tangible. They are not able to think abstractly. Pupils who are still in the concrete operations phase need to begin their journey to understanding from observable facts and measurable data. Those in the formal operations phase can apply mental operations based on concepts, theories and abstractions (Goodstein & Howe, 1978; Adi & Poulos, 1980).

If all knowledge is constructed then the social aspects of learning cannot be ignored. Pupils construct their new knowledge from their existing knowledge base. Cultural aspects of prior knowledge are important, especially in the South African context (Attwater, 1996). Science can be experienced by pupils on two levels. There is the science that they are exposed to through discovery, the physical experiences of everyday science and the science of experimentation in the classroom. Construction of knowledge based on these observations involves an individual process. There is also the world of the models and theories of science that pupils must also be introduced to. Here construction of knowledge involves social interactions and the teacher needs to help the pupils make sense of the tools and conventions of the social world of science. This is a process of

enculturation – learning cultural norms and values (Driver, Asoko, Leach, Mortimer, & Scott, 1994).

Emphasis must be placed on teaching methods that develop concepts and do not just encourage rote learning. Let us consider the process of concept development happening in a pupil's mind, simplified as in the diagram below:



Figure 2.2: Process of Concept Development

Figure 2.2 shows the process that occurs during concept formation. Pupils must build up a mental model which then ensures the development of conceptual understanding. Teaching must be able to help pupils develop the mental model. It is in the process of mental modelling that learning is so often limited.

2.4 MENTAL MODELS and MENTAL MODELLING

A model is a representation of reality. Chemistry makes use of many models to explain those facets of the subject that are not visible. Some are simple, others not. All pupils have naive mental pictures that allow them to make sense of the physical world that they inhabit. Piaget refers to these as schema (Nurrenbern, 2001). Bodner and co-workers defined schema as components of an individual's general knowledge structure that relate to that individual's knowledge of the world (Bodner, Klobucher, & Geelan, 2001). As new information is added to their world this has to be incorporated into the already-held schema, those models must be adjusted to make sense of the new material and then a new model developed.

Vosnaidou (1994) refers to a mental model as "a special kind of mental representation, an analog representation, which individuals generate during cognitive functioning, and which has the special characteristic that it preserves the structure of the thing it is supposed to represent".

Pupils need to build up mental models of the fundamental concepts underpinning the understanding of chemical bonding (Tyson, Venville, Harrison, & Treagust, 1997). Mental models are conservative, resistant to change and are unique to the individual. Pupils already have mental

models of reality and new information must be reconciled with the already held conceptions and mental models. This is where misconceptions arise.

In chemistry, where particles are too small to be seen, models are used by teachers to represent atoms, molecules, ions as well as chemical processes like chemical bonding. We use Lewis diagrams, ball-and-stick diagrams and models, Aufbau diagrams which all have associated terminology to represent the abstract concepts we are trying to make real in pupils' minds. Pupils have to understand our modelling, assimilate these models and then build up their own mental models of these realities.

2.5 CONCEPT FORMATION or CONCEPTUAL CHANGE

What is concept development or conceptual change? In order to measure learning one can determine by how much pupil understanding of concepts changes. This change denotes "conceptual change".

Pupils never begin learning a topic without some sort of pre-concept or misconception. The slate on which a pupil begins to develop a new concept is never clean. There is at best a lack of conception with differing degrees of preconceptions that develop from related topics. In a general sense, conceptual change denotes learning pathways from students' pre-instructional conceptions to the science concepts to be learned (Duit & Treagust, 1998).

Posner et al. talk of accommodation which is this process of conceptual change under the impact of new ideas and new evidence (Posner, Strike, Hewson, & Gertzog, 1982).

The model of conceptual change proposed by Hewson reasons that pupils will change their conceptual model if they perceive that "a new conception is intelligible (knowing what it means), plausible (believing it to be true), and fruitful (finding it useful)" (Hewson, 1992).

The above comments typify the type of learning that must take place in science. Science educators must facilitate the process of moving from pre-conceptions to a sound understanding of a concept while being presented with new ideas and facts. Often the pre-conceptions are a barrier to understanding of the new concepts and have to be confronted and redefined before a new understanding of the concept can develop. In the original conceptual development model proposed by Posner et al. (1982), conceptual change was seen to occur when learners become dissatisfied with the prior conception and are presented with an alternative, replacement

conception that is plausible. The incomplete or erroneous prior conceptual understanding is then replaced by the new one.

Conceptual Change Learning (CCL) is a term applied to this type of learning and “learners are seen as responsible for their own learning, which can only take place if they themselves ‘construct’ new understanding on previous experience”(Georghiades, 2000). Georghiades concludes from his study of primary school pupils that “the role of metacognitive instruction within CCL should also be considered as a potential mediator of improvement.” Metacognitive instruction, teaching methods that improve metacognition will enhance conceptual change learning. I will develop a teaching strategy in this study that focuses pupil attention on what they know and encourages them to consider how to improve their understanding, with a goal in mind. Thinking about how one goes about improving one’s thinking is what is referred to as metacognition. Flavell (1979) refers to metacognitive knowledge (knowledge of people as cognitive beings), metacognitive experiences (experiences related to cognitive enterprise), goals and strategies employed in cognitive activity. An interaction between all of these monitors our cognitive functioning which is what the teaching strategy to be developed is planned to accomplish.

As we have seen learning involves the development of mental models and the re-organisation of intellectual content. These processes must surely involve thinking about what is being learned.

2.6 METACOGNITION

Metacognition is loosely defined as knowing that one knows. It involves being aware of what one should know, what one does know (monitoring one’s learning) and then knowing how one should approach the learning of the related material (managing one’s learning). Metacognition is about understanding how one thinks and about knowing what thinking processes one uses during cognition. Veeneman (2012) distinguishes between metacognitive knowledge (what one knows about one’s ability, what the task requires) and metacognitive skills (how one monitors and controls one’s learning). Gertrude Hennessey (1999) concludes that “Even in the best constructivist environment metacognition does not simply happen, it must be explicitly promoted”. In addition Dawn Rickey has the following to say regarding metacognitive skills and teaching Chemistry: “Thus, infusion of teaching of metacognitive skills in subject matter areas, in addition to general teaching of metacognitive skills in schools, is a promising approach to helping students learn to use their content knowledge more appropriately and flexibly” (Rickey & Stacy, 2000).

In order for metacognition to be effective pupils must know what facts are required for the task, what strategies are necessary, what problem solving techniques are appropriate and how to apply these strategies or processes (Marzano, et al., 1988).

In my study I will develop a set of focused questions that pupils need to consider and answer, at certain stages during the time that they receive instruction on chemical bonding. Pupils receive feedback indicating what they do and do not know about the material they have been taught. Thus metacognitive processes are promoted. Pupils are forced to look at what they do and do not know. The feedback given by the teacher points them to where their understanding is lacking. The interlinking of learning for conceptual change and metacognitive processes is emphasised. Pupils at school level very often do not seem to confront the learning material presented to them in class and so do not try to determine if this is plausible, intelligible and useful. Pupils often do not actively think about the material presented in class. They store it away to be “learned” later when a test is to be written. It is then too late to reflect on the intelligibility of the material in the light of already integrated knowledge structures and so rote learning occurs with little understanding of the material.

Metaconceptual or metacognitive teaching is a teaching technique where pupils are encouraged to become aware of and reflect on their existing conceptions and beliefs and monitor their developing understanding of new concepts. The type of teaching technique that emphasises metaconceptual awareness results in better concept development (Yuruk, Beeth & Andersen, 2009, Georghiades, 2000). Metaconceptual teaching allows pupils to be more reflective, revisiting the learning process. They are given opportunities to consider prior and current conceptions as well as critically analyse the material, their learning process and progress (White & Fredericksen, 1998). Transfer and retention are also improved if metacognitive processes are emphasised.

The Targeted Intervention Questioning strategy to be evaluated in this study should give pupils the opportunity to become aware of their existing understanding of how and why atoms bond, see the interrelatedness of the concepts being studied in class as well as constantly looking at how they are learning and how well they are learning.

2.7 FEEDBACK

“In the purely instructional sense, feedback can be said to describe any communication or procedure given to inform a learner of the accuracy of a response, usually to an instructional question” (Mory, 2004). Feedback can be formative, meaning that it can be used to change, guide or improve learning (Shute, 2008) .

Formative feedback is what gives pupils the information about how they are doing, where they need to get to and, once there, how to proceed further. Formative feedback allows pupils to monitor their own strengths and weaknesses and also to gauge what is an answer of a high standard for the question (Sadler 1989). More specifically “feedback is more effective when it provides information on correct rather than incorrect responses” (Hattie & Timperley, 2007). Formative or task orientated feedback should help pupils see what is expected of them and give them guidelines as to how to get to this state of knowledge of the topic. Nicol & MacFarlane-Dick (2006) refers to the delivery of high quality information to pupils on the quality of their learning as being one of the seven principles of good feedback. In addition, feedback helps clarify what good performance is and aids pupils in developing self-assessment skills. This is the metacognitive function of feedback. Feedback encourages dialogue around learning with peers and teachers allowing pupils to gauge their competence, it enhances self-esteem, and closes the gap between current and desired performance.

According to reports in the literature (Shute 2008; Mory 2000; Hattie & Timperley, 2007) formative feedback has a number of functions that can account for the effectiveness of the feedback and one is the decrease in cognitive load (Cook, 2006).

In the case of the intervention questions that form the basis of this study, the feedback to pupils on the nature of their answers should be considered to be of importance because the questions break the whole chemical bonding topic into more manageable sections which should decrease cognitive load and the feedback should further serve to delineate each subsection. The feedback will point pupils to what it is they do and do not know. They will be given the correct answer and additional information to help them understand why their answer is not correct.

2.8 COGNITIVE LOAD THEORY

Pupils need to process new knowledge in order to build up mental models of new concepts. Paas, Renkl & Sweller (2003) describe working memory as limited but extended by the recall of schema from long-term memory. Cognitive load refers to the amount of information that can be processed in working memory at one time. Overload of working memory results in an inability to process the material. The relevance of Cognitive Load Theory (CLT) to teaching is important (Kirschner, 2002). “CLT is concerned with the instructional implications of this interaction between information structures and cognitive architecture. As well as element interactivity, the manner in which information is presented to learners and the learning activities required of learners can also impose a cognitive load” (Paas et al, 2003). Cognitive load can be divided into intrinsic cognitive load which is determined by the complexity of the material to be learned, extrinsic cognitive load which is unnecessary load which interferes with schema development and germane cognitive load which results in schema development and automation and is determined by instructional design (Paas et al, 2003). Thus the way in which instruction occurs is important and the design of instructional procedures should take CLT into account.

Johnstone (1997) describes this process in his Information Processing Model which is outlined in Figure 2.3.

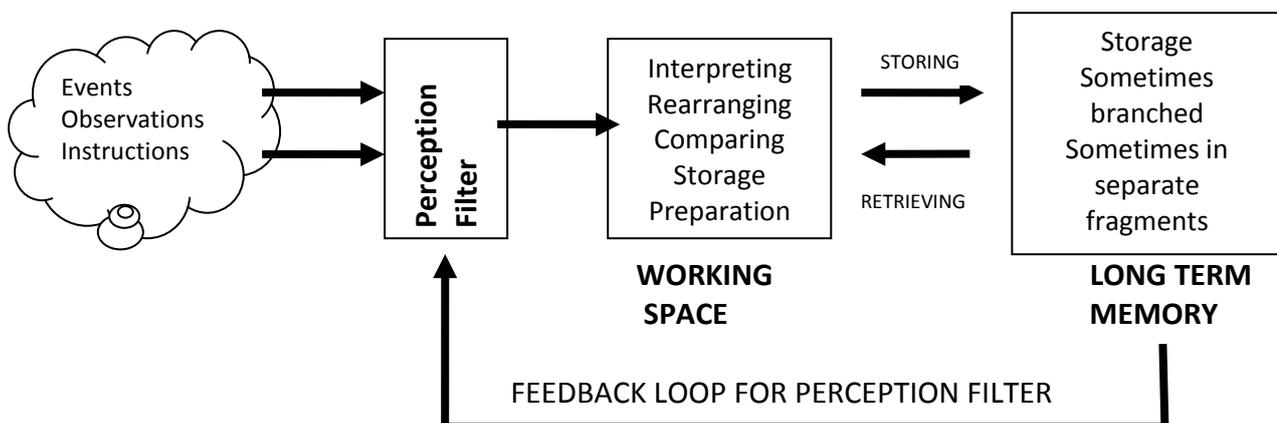


Figure 2.3: Information Processing Model

In this model observed events, instructions are perceived and filtered and appropriate information is taken in to the working memory. Some of this information is transferred to long term memory and additional information is retrieved so as to make sense of the information in the working memory. Information from the long term memory is also used to monitor incoming material in the perception filter.

According to Johnstone (2010) during this process the brain makes use of a working space which is used for thinking about the new material. Preknowledge is retrieved from long-term storage and the new material is worked into this before being stored in the long-term store. The working space has limits to its capacity and so only limited “chunks” of new material are able to be processed at one time.

When pupils are confronted with too much information at one time they discard what they cannot cope with. The intervention questions limit the amount of information that pupils need to process at one time. In addition “Pattern formation is one way of chunking, that is, integrating a larger number of information bits into a smaller number.” (Bunce & Robinson, 1997). New learners still have to learn how to recognize patterns in this new material and so need help processing the information contained in a topic. For this to be successful pupils need feedback. They need information that alerts them to what is right and wrong in their thinking. They need to be given information that tells them what material should be linked together. They need to know how far they are away from the goals. The feedback leads to the development of metacognitive skills which are so important in facilitating information processing.

The principles of feedback and the implications of cognitive load theory as discussed above formed the basis on which I based the teaching method to be developed in this study.

2.9 CONCEPTUAL FRAMEWORK AND RESEARCH QUESTIONS

Consideration of ideas and studies reported in the literature has led me to the development of the Conceptual Framework outlined below in Figure 2.4.

What happens during the teaching and learning for conceptual change?

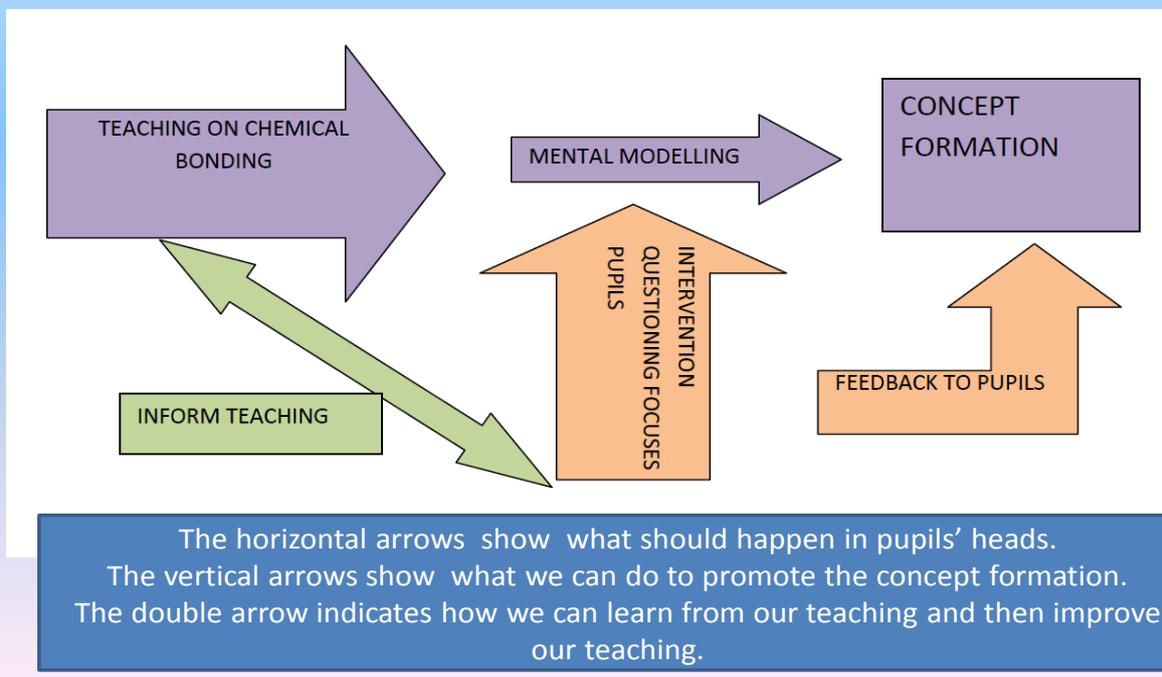


Figure 2.4: Conceptual Framework

I have drawn together aspects from previously reported research and developed a THEORETICAL FRAMEWORK to base this research on:

- There are alternative conceptions / misconceptions developed in pupils minds when studying chemical bonding;
- Meaningful learning only occurs when pupils can relate new learning to knowledge / conceptual structures already laid down;
- Preconceptions / pre-existing knowledge affects new learning;
- Constructivist theories apply – pupils need to take new knowledge, link it to pre-existing knowledge and understanding, build up new models of understanding that encompass all this knowledge.
- Mental Models are developed by pupils during the learning process and an understanding of these models and how they develop is necessary to improve teaching of this topic.
- Metacognition – the knowledge of what you know and how you learn – that influences the learning process.

- Feedback to pupils influences learning.
- Working memory influences the amount of information that can be processed at one time and this in turn affects the teaching and learning process.

Teaching on Chemical Bonding should result in the build-up of a mental model that encapsulates the pupil's picture of how and why all the concepts that have been presented to him fit together. This mental model encapsulates the concept development resulting from the teaching on the topic. This can be seen represented in the horizontal arrows. The intervention questioning process that will be developed targets the mental modelling step of concept development and focusses pupil attention on the most relevant aspects of the topic. Feedback given to the pupil points out to him/her what is known, what should still be learned and mastered and gives pointers as to what skills and thinking processes are necessary to get to the point of a sound mental model (metacognition). This aspect of the process is indicated in Figure 2.4 by the vertical and bent arrows.

Lastly, the double-headed arrow indicates that findings from the study will be fed back into the teaching process and in this way teaching will be changed so as to improve the development of sound mental models and concept development.

In order to direct the study of this process the following research questions are to be answered:

- Do focused intervention questions followed by rapid feedback to pupils foster sound concept formation in chemical bonding?
- Is this new teaching method more effective than traditional methods?

The conceptual frameworks presented above are based on a study of the literature. In the next chapter I will discuss what is taught when the topic chemical bonding is covered.

CHAPTER 3

THE CONCEPTS TO BE TAUGHT

In this chapter I will outline the following:

- The pre-knowledge that pupils should have before they will be able to make sense of concepts taught in the section on chemical bonding;
- The process through which pupils should move in order to gain an understanding of chemical bonding – the concepts that need to be drawn together to get to a picture of bonding;
- The misconcepts that often develop during the process of learning about chemical bonding;
- The thinking processes that are involved in building up a mental model of chemical bonding.

3.1 PRIOR KNOWLEDGE

Chemical bonding as taught at school level focuses on what causes atoms to join together so that compounds are formed. High school science teaching usually begins with knowledge of the particle model of matter and the existence of elements along with their arrangement in the Periodic Table. This knowledge is the required pre-knowledge that pupils should have in order to understand what compounds are and how and why atoms stick together to form molecules.

The sequence of learning at school level takes place as shown in the diagram on the following page (Figure 3.1). The particle model of matter and the difference between elements and compounds, between atoms and molecules should have been taught in Grades 8 and 9 and should be sound concepts in pupils' minds. In the beginning of Grade 10 pupils will learn about the sub-atomic particles and their arrangement, especially electron configuration which is key to understanding chemical bonding.

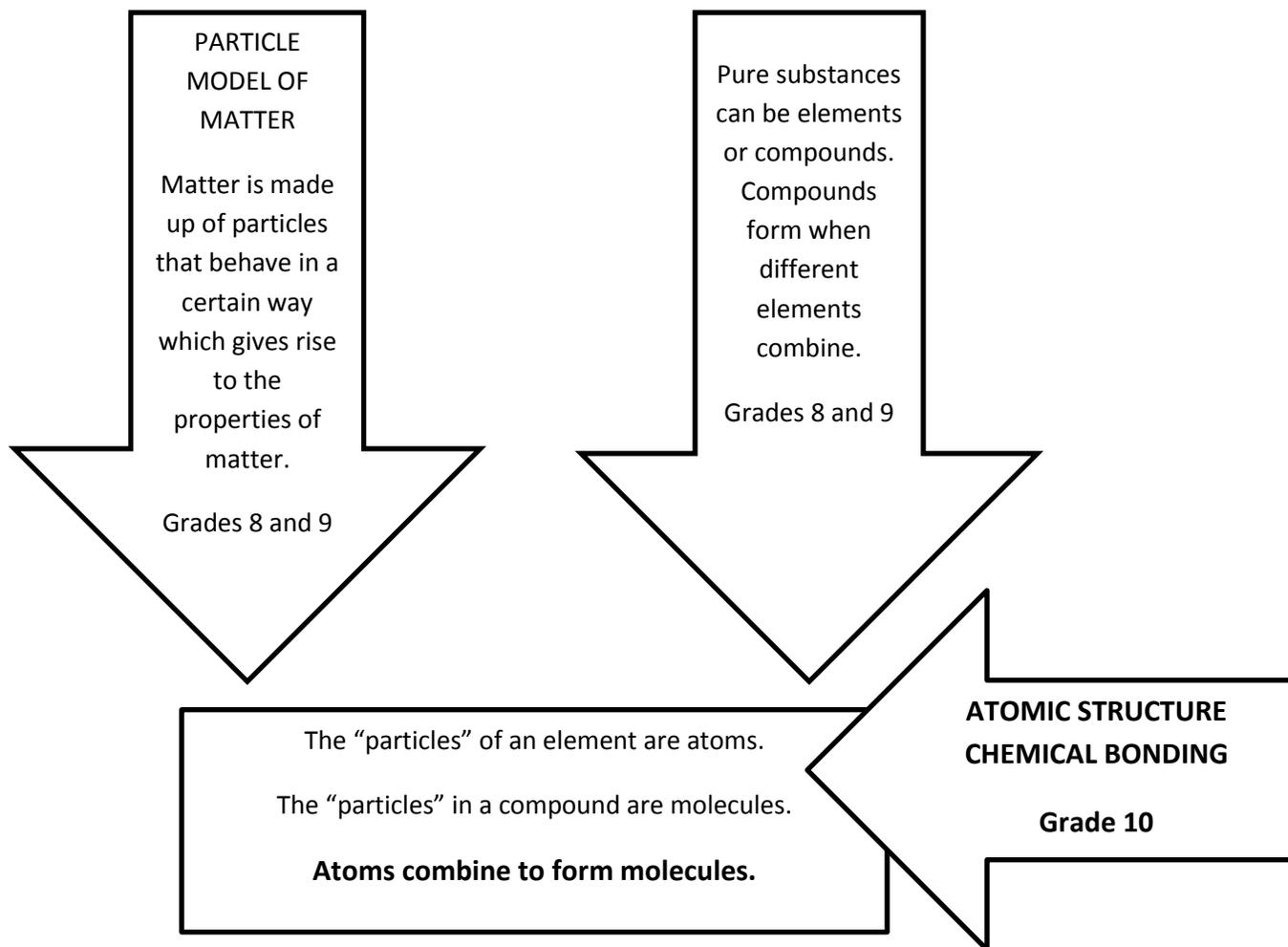


Figure 3.1: Prior Knowledge for chemical bonding

The above concepts should have been assimilated during the Grade 8 and 9 years and make up pupil's basic knowledge of Chemistry thus far. During the Grade 10 year pupils are exposed to the sub-atomic particles and should build up a mental model of an atom as a nucleus with electrons in energy levels and orbitals surrounding the nucleus.

The concept pupils should have grasped in order to begin to understand why atoms bond is that electrons have a certain preferred arrangement in the energy levels of an atom and that certain electron arrangements are more stable than others. Once these foundations have been laid down then pupils can begin to develop their new mental models of how and why atoms join together.

The prior knowledge and experience play an important role. “In order for learning to take place, the pupil must understand the new material presented in terms of the existing cognitive structure.” (Taber, 2001)

According to Taber (2001), there are four impediments to learning because of mis-matches between previously developed cognitive structures and current teaching. These can involve a lack of relevant material in the existing cognitive structure, or the new material is not seen as relevant to the existing material in the cognitive structure, or the material presented and the intuitive, existing structures are inconsistent, or the material presented and cognitive structures due to previously taught material are inconsistent. Braathen & Hewson (1988) refer to the need for new material to be intelligible, plausible and fruitful. Once these criteria have been satisfied then meaningful learning can occur.

All pupils will enter the learning environment with different understandings, different existing cognitive structures, different prior experiences and intuitive concepts. As a result pupils will end up with a slightly different understanding of the topic. Educators must be aware of these difficulties but not limited by them.

3.2 CONCEPTS TO BE TAUGHT

Below is a diagram (Figure 3.2) outlining the expected pre-knowledge and the concepts to be taught to Grade 10 learners, showing their interconnectedness or linking. A key to understanding this diagram is given on the following page.

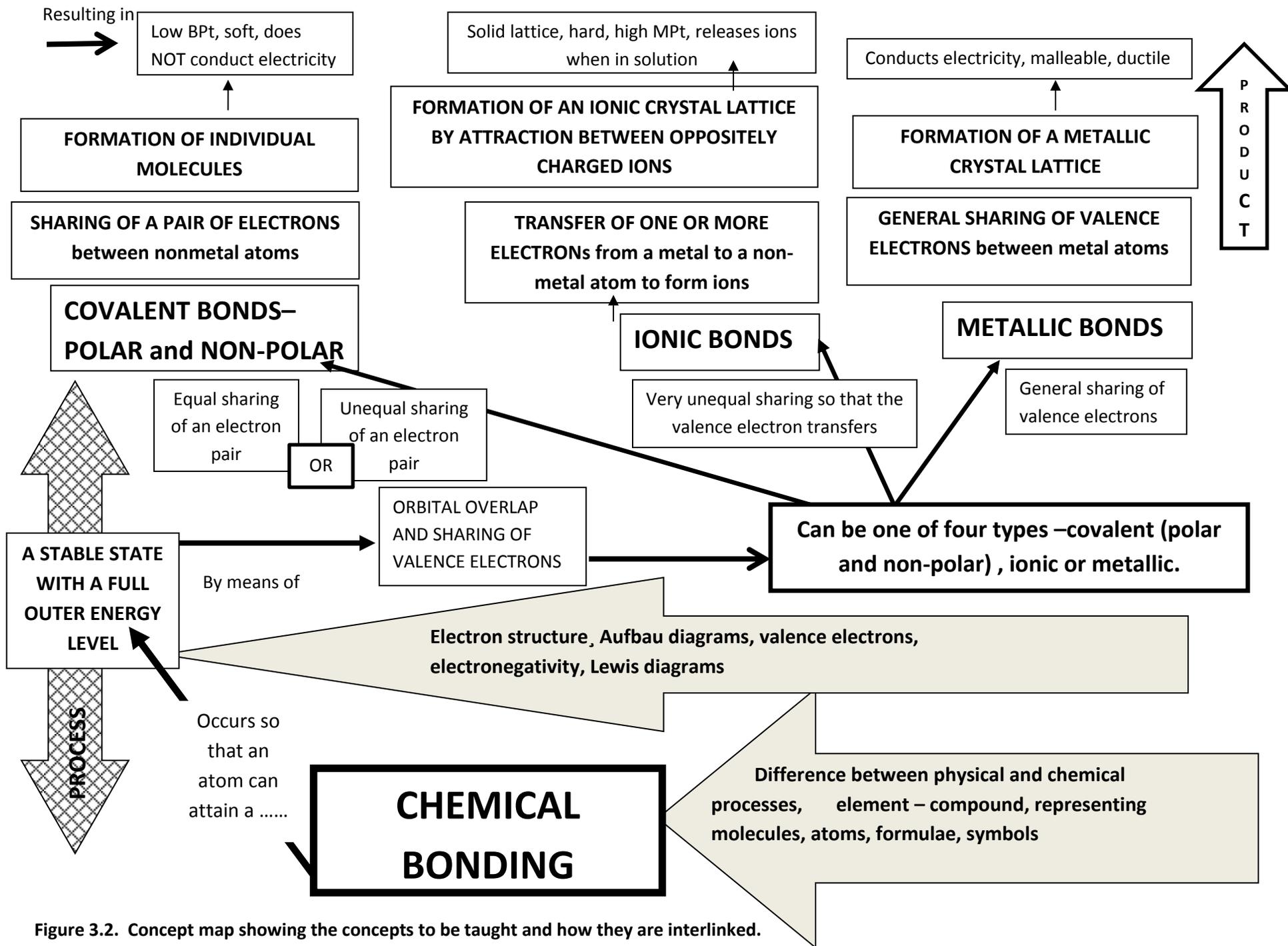
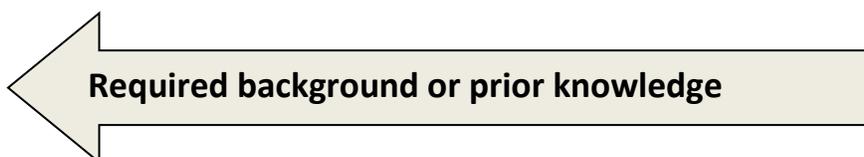


Figure 3.2. Concept map showing the concepts to be taught and how they are interlinked.

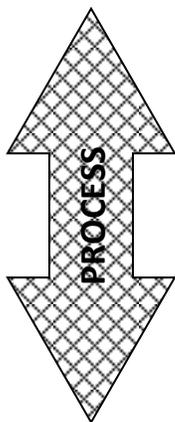
Please read the diagram in Figure 3.2 from the bottom – begin with the big idea – **CHEMICAL BONDING**.

- Why do atoms bond? The reason why bonding occurs (the attainment of a full, stable outer energy level is shown on the bottom left.
- This should be related to pupils' prior knowledge of atomic structure, full energy level stability, valence electrons - the horizontal grey arrows indicate this input of prior learning . This is a one-way input of prior knowledge, a one directional arrow.



- Which atomic properties affect the type and number of bonds formed? How do valence electrons, electronegativity, orbitals, and electron overlap result in the formation of chemical bonds.

PROCESS OF BONDING which can be one of 4 different types (equal, unequal electron pair sharing, electron transfer and general electron sharing)

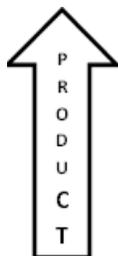


This is indicated by a double ended arrow as this process is not always linear. Pupils progress, revisit material, progress a second time and so on.

- How does the type of element affect the nature of the bonding that occurs?

PRODUCT OF BONDING – THE THREE TYPES OF BONDS (COVALENT, IONIC, METALLIC)

- How do the type of bonds affect the properties of the resulting compounds?



These concepts are developed linearly and are the culmination of the teaching so are at the top of the diagram and are represented by a one-directional arrow.

3.3 MISCONCEPTIONS THAT COMMONLY DEVELOP DURING THE STUDY OF CHEMICAL BONDING

A review of articles dealing with pupils' understanding of and misconceptions of chemical bonding reveals that there are many incorrect and partially correct understandings that creep in during teaching of this topic (Ozmen, 2004). I have referred to this and other articles (Boo, 2001; Coll & Taylor, 2001; de Posada, 1981; Hamza & Wickman 2007) selecting out the following common misconceptions that are relevant to the scope and level of this topic taught in our school:

- Polarity of bonds – pupils have many alternative pictures of this concept. Pupils can view covalent bonds as always involving equal sharing, equate polarity with the number of shared valence electrons or can confuse polar bonds with ionic bonds or see polar covalent bonds as mid-way between a covalent and an ionic bond.
- Octet rule – pupils use this rule to explain why atoms bond. Teachers seem to rely on this rule to explain the number of bonds formed by an atom.
- Nature and structure of lattices – pupils fail to conceptualise a “lattice”. Pupils have differing concepts of the nature of the particles making up the lattice.
- Atoms need to share electrons and a full energy level is the reason for bonding and not the result of bonding.
- Transfer of electrons is the formation of the ionic bond and ions are stable because they have full outer energy levels.

That pupils develop misconceptions is taken as given. Taber (2001) gives two reasons why these misconceptions arise:

- (a) the learner cannot make sense of the presented material in terms of existing ideas; or
- (b) the learner interprets the new material in terms of existing, but alternative, ideas.

In either case the pupil has to process the new material and make sense of it. Learning is an active journey from non- or limited understanding to a fuller understanding.

Chemical bonding is a highly theoretical aspect of Chemistry. There are few “hooks” into everyday life. The precepts and the required preknowledge are concepts that pupils should have gained through teaching in the lower levels of their schooling. Contrast this to other Chemistry topics, for example acids and bases, where pupils can see the substances or have experience of the substances and how they behave. Their new learning can be based on something concrete. Distinguishing between atom, molecules, elements and compounds is often meaningless as pupils do not have daily experience of these nuances of the concept matter. In addition, if pupils are still operating in the arena of concrete operations, they are unable to conceptualise non-concrete information.

The concept map (Figure 3.2) shows how the different aspects of the topic are interlinked. There is the preknowledge which must be linked the next step of the process (overlapping of orbitals and electron sharing/transfer) which then leads to the formation of the different types of bonds. Pupils have to be able to visualize and represent the different types of bonds before they can understand why different classes of compounds behave differently based on the nature of the chemical bonds responsible for the formation of the compound.

3.4 LINKING OF CONCEPTS

The linking of the concepts is a vital part of mental modeling and concept formation. The model of learning based on Working Memory in Figure 3.3 (Johnstone 2010) shows why linking plays such an important role in concept formation. In the Working Memory material is interpreted, rearranged, compared and prepared for storage in Long Term Memory.

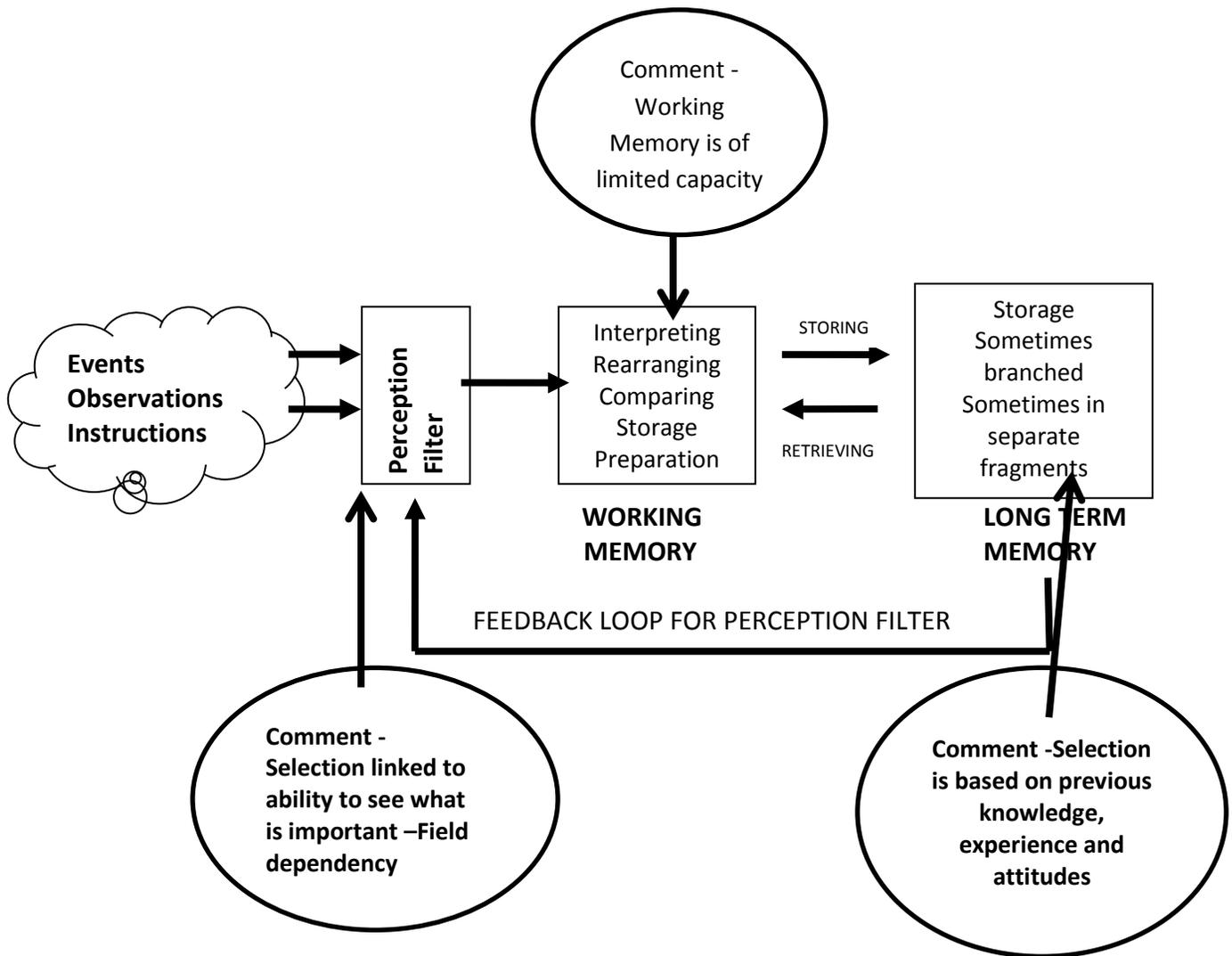


Figure 3.3: WORKING MEMORY MODEL of LEARNING

In the model shown in Figure 3.3 learning occurs when observed events, instructions are perceived and filtered. Information that is seen to be relevant and important is taken in to the working memory. Here the information is rearranged, interpreted, compared and prepared for storage in the Long Term Memory. Only some of this information is transferred to long term memory. Additional information can be retrieved from Long Term Memory so as to make sense of the information in the working memory. Information from the long term memory is also used to monitor incoming material in the perception filter.

Pupils have to compare, rearrange, interpret and then decide which information is important enough to get through to the Long Term Storage. Pupils need to know what is important, what parts of the information are comparable, how should information be rearranged and connected to make sense so that it can be transferred to the Long Term Memory. This process is what is

referred to as linking. Pupils must be led through the process of linking. They do not always see the importance of bits of information, do not see what is comparable, and do not see connections for themselves. In addition, pupils must select from all the information given to them during a lesson that which is important and then line this up with previous knowledge, knowledge retrieved from the Long Term Memory.

3.5 INTEGRATION INTO LONG TERM MEMORY

The following aspects of the theory of chemical bonding are considered to be core concepts to building up a sound and comprehensive mental model of this topic. If pupils focus on these aspects and can see the interactions between the different parts of the theory, it is envisioned that the concepts will be more meaningful and more easily selected and processed into long term memory.

- The reasons for bond formation – full outer energy levels are stable, other electron configurations are not. Full outer energy levels lead to bond formation.
- The formation of covalent bonds occurs through orbital overlap and the sharing of electrons.
- Electronegativity and the effect of this atomic property on the sharing of valence electrons in covalent bonds, resulting in polar covalent bonds.
- The process of formation of ionic bonds and comparison with covalent bond formation.
- Metallic bonds and the effect this bond type has on the properties of metals.
- Distinguishing between solids (ionic, molecular, giant atomic and metallic) using particle diagrams.
- Drawing Lewis diagrams.

Consideration of the complicated and abstract nature of the topic of chemical bonding as well as the need to link many concepts and parts of the topic into a whole led me to envisage a different way of teaching this section. This new method or teaching approach will consist of targeted questions directed at critical concepts followed by rapid feedback on the answers that they provide. By questioning pupils so as to gauge their understanding of these different parts that make up the topic certain key aspects of the theory can be emphasized. By providing

pupils with guidance and feedback regarding their understanding of the theory, it was envisaged that their mental modeling and concept formation would be enhanced.

A set of intervention questions will be designed with the idea that they would help the pupils see what aspects of the material presented in class was important, become aware of these links between the concepts, and lastly relate this to what was already known. Intervention questions will deal with the different tiers of the concept map and the focus on these aspects can improve the pupil's ability to link concepts.

In order to gauge the effectiveness of the intervention questioning process a testing tool will be designed. The testing tool will measure the improvement in pupil's understanding of the topic after learning about chemical bonding.

The testing tool will be designed to test the following:

- Do pupils begin with required background knowledge (preknowledge) carried over from previous teaching?
- Do pupils have an understanding of electron configuration and can they represent this in the form of shell and Aufbau diagrams?
- Can pupils explain bond formation in terms of stable electron configuration?
- Can pupils explain why and how and when atoms form covalent bonds?
- Can pupils explain how electronegativity affects the nature of covalent bonds?
- Can pupils explain why and how and when atoms form ionic bonds?
- Can pupils describe metallic bonds and how these affect electrical conductivity of metals?

In this chapter I have described the topic and the concepts that will be presented when chemical bonding is taught to the pupils. I briefly mentioned the intervention questions that will focus on the concepts to be taught. The design of these questions and of the testing tool that will be used to test how well these concepts have been grasped by the pupils will be discussed in Chapter 5. Chapter 4 will describe the study methodologies.

CHAPTER 4

METHODOLOGY

In this chapter I will describe the rationale behind choosing a methodology for this research and then I will outline the methods used to collect the data in this study. Chapter 5 will deal with the purpose and design of both the intervention questions and the testing tool. In that chapter the way in which these two tools are to be used is discussed.

Initially I assumed that what I was looking at was a straightforward cause and effect linear relationship between my teaching method and the results pupils receive on a test after the teaching. Further reading and thought made me realize that there was a bigger, holistic picture to be considered and my research paradigm shifted to complexity theory which suggests a case study or an action research methodology (Cohen, Manion, & Morrison, 2007). As methodology refers to the theoretical arguments that researchers use in order to justify their research methods and design (Case & Light, 2011) I will discuss the applicability of each of these to this study.

The particular requirements and constraints associated with Action Research and Case Studies are outlined. As both qualitative and quantitative data are to be collected and utilized the design of a mixed methods research method is also discussed.

4.1 METHODOLOGIES APPLIED IN THIS RESEARCH

Over the space of many years in the classroom I have repeatedly changed the way in which I present topics. I will try in this research project to answer the question “was this way really effective” when considering a novel method of teaching chemical bonding. The choice of research method and design was therefore determined by my position as teacher and researcher in my place of teaching. What prompted my research was a desire to acquire an in depth understanding of the effectiveness of my teaching methods. Not only did I want to know if this new method was more effective but also why was it more effective. I wanted to understand the learning process and so I needed to collect data that could tell me if the process was more effective and the reasons for it being more effective. As noted above two different methodologies are particularly pertinent to the study.

My research began in my classroom so I wished to reflect on the practices of my classroom and then implement changes to the practices of my classroom if I found ways of improving these practices. This is what Hunter (2007) refers to as “reflective intervention” and therefore involves action research as research methodology. This methodology will offer “explanations for ongoing improvement of practice, and demonstrating the validity of the explanations” (McNiff & Whitehead, 2010).

Again, according to McNiff and Whitehead (2010) “Action research is open ended. It does not begin with a fixed hypothesis. It begins with an idea that you develop. The research process is the developmental process of following through the idea, seeing how it goes, and continually checking whether it is in line with what you wish to happen.” A more detailed description of action research as a research methodology follows later in this chapter.

My research will take place within my classroom and the classrooms of two of my colleagues. It will involve no more than eighty pupils at a time and will only cover the three to four week period when the pupils are studying chemical bonding giving it the characteristics of a case study. A case study is the study of a particular instance which can illustrate a more general principle (Cohen et al. 2007). Case and Light (2011) describe a case study as being particularly appropriate to address research questions concerned with the specific application of initiatives or innovations to improve or enhance learning and teaching. The strengths of a case study are that they are strongly connected to the reality of a situation, portray the subtleties and complexities of a social situation yet can allow generalisations (Cohen et al. 2007). I reasoned that, if appropriate data and sufficient data were collected the findings of this study could have a wider applicability.

The discussion given above outlines the selection of a case study methodology and action research methodology as appropriate for this study. The methods that will be used to ensure that appropriate data is collected and that sufficient valid data is collected will be discussed below.

I want to evaluate a novel method of teaching chemical bonding. What does this novel method encompass? I will give a brief description of the method here but will elaborate further on the development of the questioning and testing tools in Chapter 5.

4.2 THE TARGETED INTERVENTION QUESTIONING PROCESS

I began with an idea of what can be done to improve learning of chemical bonding in my classroom. In order to facilitate the learning process and link the concepts that need to be taught so that pupils construct a holistic picture of chemical bonding, I plan to develop a teaching strategy that will involve focused intervention questions followed by rapid and constructive feedback. Questions will be administered at certain stages during the teaching programme and pupils will be given feedback by the following lesson. The set of intervention questions will draw the attention of the pupil onto the most relevant aspects of a topic allowing the development of more accurate mental models. The design of the questions will focus on aiding pupils with linking their prior knowledge to the new knowledge and improve assimilation of this new knowledge. I wish to empower pupils, allow them to feel in control of their learning by emphasizing the most important aspects of the topic, helping them realize what is important, what they do know and what they do not know so that the essential aspects of the new knowledge can be assimilated. I hope that this will also develop pupils' metacognition and reduce the cognitive load by breaking the learning material into clearly defined "chunks".

This teaching strategy is designed to be used by any teacher regardless of their classroom practice and is an additional "tool" that can be used that supplements other strategies used by a teacher. In this study teachers will ask pupils to answer the intervention questions in class using their learning material, teacher assistance and peer discussion at certain places during the teaching on chemical bonding. Teachers are given instructions indicating when they should present each question to the pupils and guidelines as to what should have been taught before each question was presented. The Intervention Questions and the teaching sequence are available in Appendix 1 and 3. Teachers will be asked to collect the answers to these questions at the end of the lesson. I will go through the answers and give pupils feedback on their answers by the next day. Pupils will be asked to check their answers and the feedback, discuss any queries with the teacher or their peers during the following lesson. The importance of the feedback is to encourage pupils, point out their errors, show them what they do know and also what they still need to master.

Feedback is given pointing the pupil towards what he can do as well as showing him how to direct his thoughts and showing him what additional aspects of the topic he needs to focus on to complete his understanding. Feedback is not intended to be only an encouragement but is to show pupils what is

required for understanding the various aspects of the topic, what is correct and incorrect thinking when dealing with a concept, how far they are away from answering and understanding correctly. This type of feedback is what is referred to by Hattie & Timperley (2007) as feedback about the task, feedback about the processing needed for the task and about self-regulation. About this these authors state “Feedback has no effect in a vacuum; to be powerful in its effect, there must be a learning context to which feedback is addressed. It is but part of the teaching process and is that which happens second—after a student has responded to initial instruction— when information is provided regarding some aspect(s) of the student’s task performance. It is most powerful when it addresses faulty interpretations, not a total lack of understanding” (Hattie & Timperley, 2007). It is this requirement that teachers correct mis-interpretations that prompted the design of the Intervention Questioning Process with feedback.

Feedback will be given to pupils by the next day. Pupils will be given time in class to look at their feedback, discuss with peers and ask questions regarding their answers and the feedback comments. It is important that pupils confront the feedback given to them.

This Targeted Intervention Questioning method is designed to be used by any teacher and the following guidelines are to be given to teachers to help them apply the principles correctly.

4.3 TARGETED INTERVENTION QUESTIONING METHOD – Guidelines for teachers (Appendix 3)

- A. The intervention questions – pupils should answer these in class at the following instances during the teaching on chemical bonding.

INTERVENTION QUESTION 1:

Give pupils this question after you have covered the reasons for bonding – ie full outer levels are stable..... The intervention question makes pupils reflect on: **What electron configurations are stable, unstable?**

INTERVENTION QUESTION 2

Give pupils this question after you have covered the idea that orbital overlap results in electron sharing and covalent bond – as examples H_2 , F_2 , HCl . The intervention question makes pupils reflect on: **sharing of a pair of electrons can result in a full outer energy level part of the time which is a more stable situation than atoms with unpaired electrons in non-full energy levels; sequence of orbital overlap – electron sharing – covalent bond is emphasised.**

INTERVENTION QUESTION 3

Give pupils this question after you have covered electronegativity and equal/nonequal sharing of bonding electrons. The intervention question makes pupils reflect on : **Electronegativity and sharing of electrons – equal and unequal; definition of polar and non-polar covalent bonds.**

INTERVENTION QUESTION 4

Give pupils this question after you have covered Ionic bonding – description and process of formation of ionic bonds on— electrons are transferred from metal to non-metal and resulting ions attract and form the bond. The intervention question makes pupils reflect on **the difference between ionic and covalent bonds.**

NB **USE QUESTION 4 BEFORE 2 AND 3 IF YOU DO IONIC BONDING FIRST.**

INTERVENTION QUESTION 5

Give pupils this question after you have covered Metallic bonding. This question makes pupils reflect on: **Metallic bonds, general sharing of valence electrons and relate this to properties of a metal.**

INTERVENTION QUESTION 6

Give pupils this question after you have covered the nature of bonds and relation to structure – molecular compounds, ionic lattices, giant covalent/atomic structures (as in diamonds and graphite) metals. This question makes pupils reflect on: **the substances and how the microscopic properties affect the macroscopic properties**

- B. Pupils should be encouraged to use their notes and books to answer the questions. Pupils may ask questions of the teacher and of their peers but should be encouraged to formulate their own answers. The teacher may draw pupils' attention to what the focus of each intervention question is. The purpose of these questions is formative. Pupils are given these additional questions to answer in order to focus their attention on relevant aspects of the concept, to help them find their way through complicated learning material and to break the material down into manageable sections.
- C. No marks are to be given. Pupils will only receive feedback in the form of comment on how they answered the questions.

D. The answers to the questions are returned to me (the researcher) so that I can give the feedback. The feedback is in the form of comment on the answers given by the pupils. Type of comments made:

- You are not using the terminology correctly. Work through the definitions and make a summary of new words.
- You are able to draw an Aufbau diagram, but what does this mean about the electron arrangement?
- Look at the sequence shown in the picture. Atoms approach each other - orbitals overlap – electrons are shared – covalent bond forms. Be able to write this in your own words.

During the development and testing of this new method I was the one who wrote the feedback comments. As this Targeted Intervention Questioning process is designed to be used by other teachers they will have to give the feedback when they use the method. Giving feedback is not always easy but with practice teachers will develop this skill. By giving the feedback themselves teachers will begin to gain a better understanding of how pupils develop their understanding.

As I wished to evaluate the effect of this Targeted Intervention Questioning process and also gain insight into the learning process and the process of concept development I collected and analysed the responses given by the pupils. The methodology of the evaluation process is given below.

4.4 DATA GATHERING PROCESS

In this study learning is considered to result from conceptual change and so must be measured by considering the amount of conceptual change that has occurred as well as the change in the depth of understanding. Two different types of data are needed to illustrate these two different aspects of same picture. Quantitative data will measure the amount of conceptual change. Qualitative data is needed to show change in the depth of understanding. Mixed Methods Research can be defined as research where the researcher collects and analyses both qualitative and quantitative data (Cresswell & Plano Clark, 2011). This study seeks to show that there is an improvement in conceptual gain when using the intervention questions followed by constructive feedback as a teaching strategy as compared to teaching the topic without such an intervention. There are a number of different definitions of conceptual change but according to Tyson et al. (1997) “rather than only considering conceptual changes in knowledge that a student constructs in moving from, say, a prescientific notion

to a scientific view of a concept, a more complete and informative picture would be painted if these changes were viewed from a multidimensional perspective.” In order to address this need to consider conceptual change from more than one point of view pupil responses will be measured quantitatively and qualitatively. The quantitative and qualitative data will complemented each other and result in a richer, more complete picture of the learning process. The need to consider qualitative data to complement data obtained from an experimental or quasi-experimental statistical study has been emphasised by Bodner (2004). Qualitative data allows the richness and depth of the changes measured with quantitative data to become visible.

Quantitative data will be obtained by administering the Conceptual Test tool. The Conceptual Test tool will be administered prior to teaching and then after completion of teaching. Copies of the Conceptual Test tool are available in Appendix 5 and 6. The development and refinement of the tool will be discussed in Chapter 5. The improvement in score from pretest to posttest can be compared for pupils receiving the intervention questions to those who do not. Since the questions included in the tool were designed to probe understanding of concepts, not knowledge, results of the pre- and the posttest data will be interpreted as conceptual gain in the mastery of chemical bonding.

The relatively small sample of pupils along with a non-random assignment of pupils to classes, as will be described below, necessitated a quasi-experimental design. This limitation in the experimental design will be compensated for by the addition of qualitative of data which supplemented the quantitative data.

Qualitative analysis will include:

- Analysis of responses obtained in the intervention questions.
- Analysis of correct and incorrect responses to the free response questions in the Conceptual Testing tool.

Qualitative data will be used to understand how the process of concept development progresses, what common errors are made and what problems pupils experience while learning about chemical bonding. This study seeks to find a way to improve the process of concept development in the teaching and learning of chemical bonding. Any data that leads to a better understanding of this process can be utilized to improve learning and teaching. For this reason qualitative data that paints a

picture of how the development of concepts proceeds, what errors occur, and what misconcepts arise along the way will be valuable. The focus of the intervention questions is to improve this PROCESS of developing an understanding and in this way prevent the development of misconcepts. The intervention questions are designed to focus on the most important aspects of the topic chemical bonding. Instead of the teacher and pupil meandering through the topic with concept development or conceptual change being a hoped for or “nice to have” goal of teaching, sound concept development becomes the focus of the teaching.

4.5 THE TESTING PROCESS

The sample group consisted of 4 classes each with approximately 22 pupils. The pupils are all in Grade 10, between the ages of 15 and 16 years of age, attending a private school for boys. Two classes will be selected as the control group and two classes will make up the test group. This is a quasi-experimental set-up as the pupils are not randomly assigned to the classes. Pupils’ subject combinations determine the classes that they are assigned to. This can result in a non-random spread of pupil abilities in the four classes. Teaching classes are randomly assigned to teachers. Three different teachers teach the four classes. The same three teachers taught the classes for both runs of the experiment. There was some variation in the teachers teaching test and control groups in the two runs of the experiment.

Allocation of pupils and teachers to the Experimental and Control groups and data collection strategy

EXPERIMENTAL	O ₁	X	O ₂	(teacher A)	
	O ₃	X	O ₄	(teacher B)	

CONTROL	O ₅		O ₆	(teacher B)	
	O ₇		O ₈	(teacher C)	(Campbell 1963)

Where O = observation and X = intervention.

O₁, O₃, O₅ and O₇ represent collection of pre-test data and O₂, O₄, O₆ and O₈ the collection of post-test data

The process was repeated twice and the allocation of classes and teachers is outlined below:

RUN 1 2011			RUN 2 2012		
Class	Teacher	Treatment	Class	Teacher	Treatment
1	A	Control	1	A	Test
2	B	Control	2	B	Control
3	B	Test	3	B	Control
4	C	Test	4	C	Test

Figure 4.1: Allocation of teachers and classes to the Test and Control Groups for Run 1 and 2 of the testing process

All teachers are experienced teachers and will be requested to teach their classes in the way they were accustomed to. I was teacher C and was part of the test group in order to oversee and understand the process. The Targeted Intervention Questioning process should be able to be used by any teacher with equal success. For this reason a different combination of teachers was used with the test group in each of the 2 runs of the intervention. This design would prevent “teaching to the test” which would affect the results.

A list of all the questions is given in Appendix 1 and Appendix 2. The teaching and questioning sequence followed by each teacher and the process of giving feedback is discussed above (paragraph 4.3).

4.6 THE CONCEPTUAL TESTING TOOL

This alternative method of teaching has to be evaluated. A testing tool will be developed to track the effectiveness of concept development during the teaching process using this new method. The testing tool involves twenty three questions that are either multiple-choice or free response questions. The test will be administered prior to any new teaching on the topic and then after

teaching is complete. Pupil score on a pre-test using the Conceptual Test tool will be compared to the score on a posttest to measure conceptual gain.

The answers to the questions on the Conceptual Test tool will be graded as correct (1), incorrect (2) or no response (0). The answers to the free response questions are also graded in this way. A memo showing how this will be done is given in Appendix 7. Questions 3 – 13 are designed to test pupils' foundation knowledge – concepts they should already have formed prior to teaching on chemical bonding and fundamental to the understanding of the new material. Questions 14 - 25 are questions testing pupils' understanding of all the other concepts outlined in the concept map describing the topic (Figure 3.2 in Chapter 3).

The test will be administered prior to any new teaching on the topic and then after teaching was complete. The development of the Conceptual Test tool is discussed in Chapter 5.

4.7 APPLICATION OF ACTION RESEARCH METHODOLOGY IN THIS STUDY

Action Research is a cyclical process where there is a problem to be studied so a plan is formulated, implemented, resulting in a better understanding of the problem so that further plans can be implemented and evaluated, all leading to a better understanding of the problem allowing solutions to be found (Hunter 2007). Figure 4.2 below outlines the process:

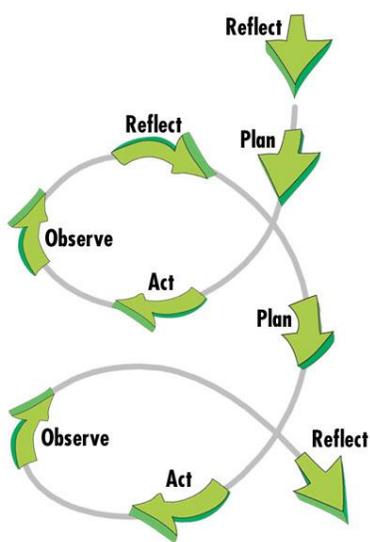


Figure 4.2: The Action Research Cycle

CYCLE 1 - 2011

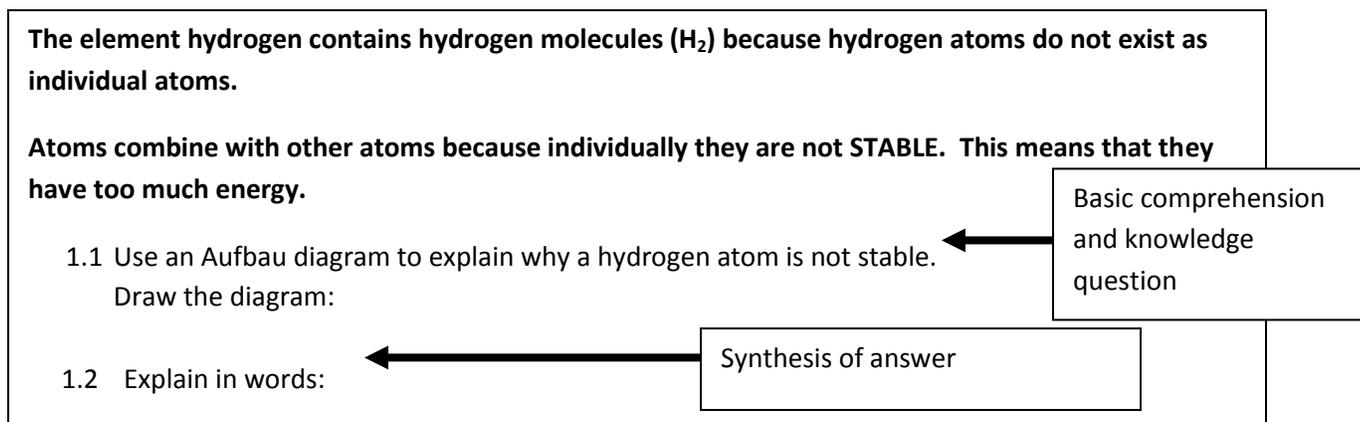
A. PLANNING

The rationale for this study is my observation that pupils do not always know how the information presented during the teaching fits together. The foundation the teacher attempts to lay down is at times lost, forgotten and this causes “gaps” in the mental models that the pupils are trying to build up. In order to improve the teaching process and through this improve pupils’ concept development, a set of conceptual questions will be designed that will be administered to pupils at set places during the teaching of the topic. This is the Targeted Intervention Questioning Process described above.

B. ACTION

A set of intervention questions will be designed to assist in the teaching of chemical bonding. One of these questions is discussed below. Each question addresses one of the important concepts that together lead to the understanding of chemical bonding. The whole set must be worked through and presented to pupils.

The intervention questions will be structured in such a way that pupils should be able to write down some sort of answer that feedback can be based on. Intervention questions are designed to lead pupils into the subsection of the topic from the basic knowledge level to higher levels of comprehension and then synthesis of an answer. There was a stepwise progression from lower to higher cognition.



In order to evaluate the effectiveness of the Targeted Intervention Questioning process I will design a testing tool (the Conceptual Test tool) that can be used as a pre-test and a post-test to measure conceptual development as a result of teaching. This tool will be piloted and refined before being used to gather data.

C. ACTION

The Intervention Questioning Process will be implemented, as described above. The effectiveness of the intervention procedure will be determined by analysing pupil scores on a pre- and a posttest using the Conceptual Test tool described above. Qualitative data will be obtained from analysis of the answers given by pupils to the intervention questions and to the free response questions in the Conceptual Test tool.

D. ANALYSIS AND MODIFICATION AFTER FIRST INTERVENTION

A detailed analysis of the answers given by pupils as well as of the Intervention Questioning process as a whole will be used as opportunities for improving the intervention process and the intervention questions before the second cycle of the process. The Conceptual Test tool will also be reviewed and improved before it is used in the second cycle. Changes will be made to the intervention questions and the process.

CYCLE 2 2012

A. PLANNING

During the planning phase of cycle 2 changes will be made to the intervention questions, the Intervention Questioning Process and the Conceptual Test tool. These changes will be informed by the results and observations from cycle 1 and will be implemented before cycle 2.

B. ACTION

The modified Conceptual Test tool will be used as a pretest for all Grade 10 pupils. Intervention questions will once again be administered to two of four Grade 10 classes during teaching of Chemical Bonding. Feedback will be given as quickly as possible with appropriate comments. Previous experience with providing feedback comments as well as a better understanding of the problems

pupils have in making sense of the concepts will allow for comments that are better able to direct pupils in order to promote concept formation. After teaching is completed the Conceptual Test tool will be used as a post-test

C. ANALYSIS

Results will once again be used to inform and improve teaching practice.

A timeline showing how this strategy was implemented is presented in Chapter 6, paragraph 6.2.

4.8 STATISTICAL METHODS TO BE USED IN THE ANALYSIS OF DATA

Parametric data will be obtained from this study as I have knowledge of the characteristics of the population. The t-test procedure will be used to compare the performance of the two groups on the Conceptual Test. The Test group is the group of pupils who will receive the Targeted Intervention Questioning process as part of their learning experience and the Control group is the group that will not receive this intervention as part of their learning experience.

A paired t-test analysis of the change in raw score from pre-test to post-test using the Conceptual Test tool will be conducted to determine change in pupil total raw score from pre-test to post-test. This allows change in score per pupil to be determined.

The scores for the test group (intervention question group) will be compared to the control group (no intervention questions) using a non-paired t-test. A non-paired t-test will be used because the pupils in the two groups were different.

In addition, because this study is to determine the increase in conceptual understanding instead of simply using the increase in score between the pre-test and the post-test, learning gain can be calculated. According to Hake (1998) conceptual gain, referred to as the Hake factor, is calculated as a percentage, or a fraction of 1.

It shows the fraction of potential gain achieved by a student.

$$g = \frac{\text{Post-test score (\%)} - \text{Pre-test score (\%)}}{100 - \text{Pre-test score (\%)}}$$

The conceptual gain (g) compares the actual change in the pupil's score (Post-test score (%) – Pre-test score (%)) to the pupil's maximum possible gain (100 – Pre-test score(%)). This tells us how much of the possible improvement in score the pupil has actually attained. The actual average percentage gain in score is compared to the maximum possible percentage gain in score. This is referred to as normalization. Learning gain should be a better measure of conceptual development as it will compensate for those who correctly guessed answers in the pre-test and scored higher than expected.

The Learning Gain for the test group (intervention question group) will be compared to the control group (no intervention questions) using a non-paired t-test.

4.9 REFINEMENT OF THE CONCEPTUAL TEST TOOL

In order to determine the reliability of the testing tool a Cronbach Alpha analysis will be performed to determine the internal consistency of the testing tool. This will be performed after Run 1 and Run 2 of the evaluation of the Targeted Intervention Questioning process using the Conceptual Test tool as measuring device. This test provides a coefficient of inter-item correlations for the items (questions) making up the Conceptual Test tool. The score for each item on the test will be correlated with the sum of all other items (Cohen et al 2007). This statistical analysis measures internal consistency among the items on the test, not the people taking the test. It measures the reliability of the tool to test concept development during the teaching on chemical bonding.

To further ascertain the reliability of the testing tool a Rasch analysis will be used to determine the reliability of the testing tool developed to monitor conceptual development during teaching on chemical bonding. Rasch analysis is a technique that allows analysis of test results that is unaffected by the test subjects.

The Rasch model is a probabilistic measuring model that is based on expected probabilities. It allows prediction of the chance of success on answering a question on a test with a certain difficulty for a person of certain ability (Bond & Fox, 2007). Raw score ordinal data is transformed into a measure of person ability (for the persons answering the test) and question difficulty (for the items on the test). Both of these can be represented on the same scale, presented as – a person – item map (Appendix 11).

RUMM2030 Project: F3POSTFIX Analysis: F3FIXRUN4
 Title: FORM 3 FIXED REMOVE 6 ITEMS INCLUDING 9AC Date: 18 Jan 2012 02:41:52 PM
 Display: ITEM MAP

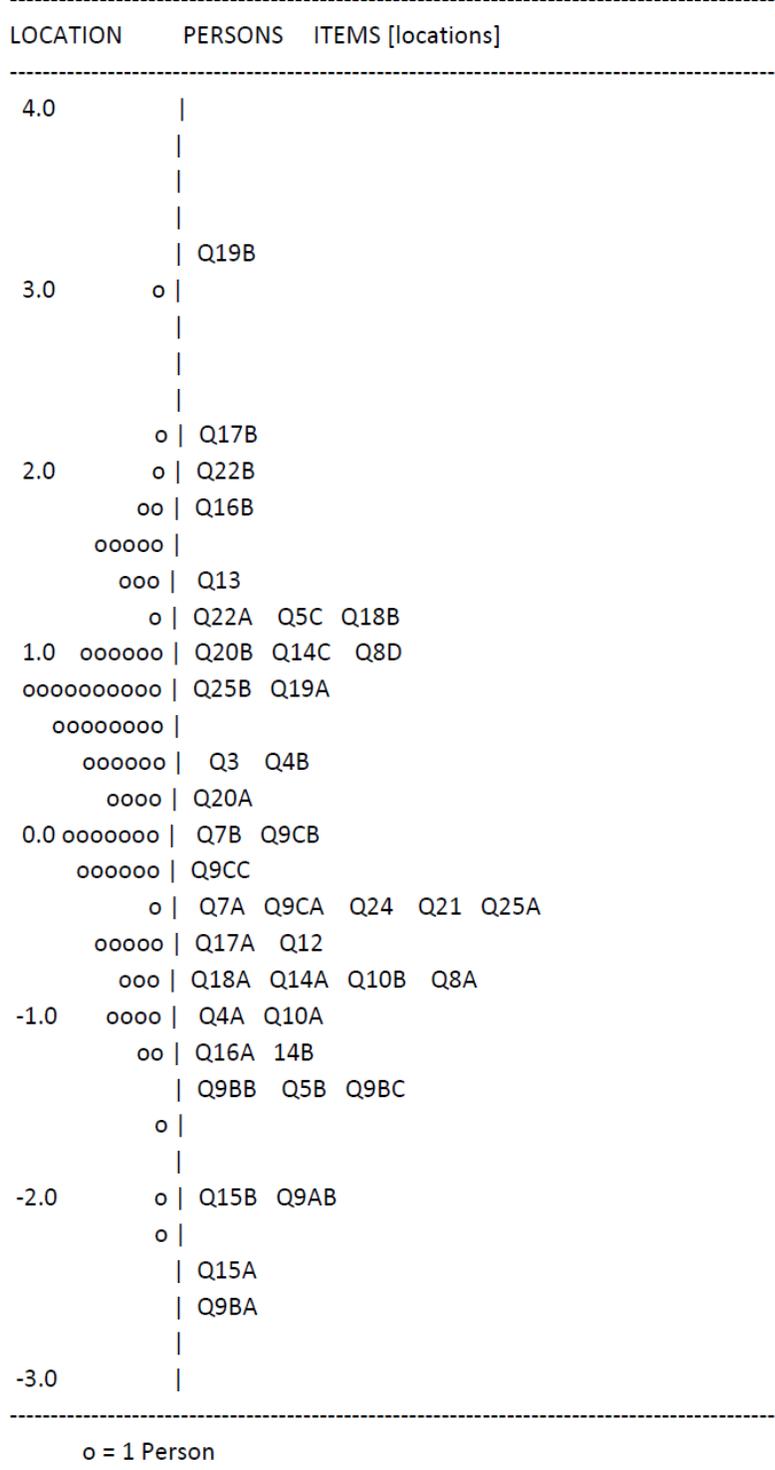


Figure 4.3 Person-Item Map using data from Run 1 of Conceptual Test tool.

In this Conceptual Test the smaller the proportion of correct responses, the higher the difficulty of an item and hence the higher the item's scale location. Once all the item locations are scaled for the test, the person locations are measured on the scale. This gives the probability of a pupil responding correctly to the different questions. As a result, person and item locations are estimated on a single scale as shown in Figure 4.3. In general, the probability of a person responding correctly to a question with difficulty lower than that person's location is greater than 0.5, while the probability of responding correctly to a question with difficulty greater than the person's location is less than 0.5.

The person-item map is therefore a visual representation of the alignment of item difficulty with pupil performance. Thus the respondents can be ranked on their score on the test and this ability can be used to determine their likelihood of correctly answering each item on the test. Similarly each item can be ranked according to its difficulty or likelihood of being answered by both high and low achieving respondents. Items on the test that produce data that does not fit into the data matrix that links items and persons will be deemed to not “fit” the construct that is being tested in the test. In other words, the results obtained from using that item in the test are not contributing meaningfully to the overall test result. In this way reliability of each item on the test can be determined.

Only post-test data from the first run of the Conceptual Test tool will be analysed using the Rasch process because it can be argued that the instrument will be better aligned with student ability after instruction. If pretest data were included in the estimate of item difficulties then items would seem more difficult than what they really are.

The alignment of persons and items shown in the analysis of the Conceptual Test tool indicate that most items on the test that produce data that does fit into the data matrix linking items and persons. Thus these items do “fit” the construct that is being tested in the test.

4.10 ETHICAL CONSIDERATIONS RELATING TO THE TESTING PROCESS

The testing process involves pupils in the school where I teach as the participants in a test – teach – test quasi-experiment. In a school situation where a number of teachers are involved in teaching parallel classes, there must be openness about the research process and a willingness to share research findings so as to maintain good collegial relations. In addition, as Action Research sets out to

change/improve the status quo, other teachers in the same teaching situation should be aware of the aim of the study and also of the impact the results of the findings might have for them. Because of the reflexive critique inherent in action research other individuals who are part of the situation being investigated should also reflect on issues and make interpretations so that current theories can be challenged (Nolan & van der Putten 2007). Thus an open approach involving good communication between teachers affected and participatory decision making is necessary.

In my study I will expose only 2 of 4 classes to a new teaching method. If this new method is, indeed, an improved method, is it ethical to give only certain pupils exposure to improved teaching? Attempts will be made, once the experimentation is complete, to give pupils in the control group opportunities to benefit from the improved teaching method.

Informed consent of pupils is addressed. Pupils have a prior relationship with the teacher and this can limit their freedom to choose whether to participate or not. In addition, pupils are allocated to a particular class and it is not easy for a pupil to move to another class. Is it ethical then to view these pupils as research participants instead of as individuals in one's care? In order to overcome this ethical dilemma I attempt to distance myself from my role as researcher when interacting with pupils in the classroom. Analysis of data will not take place in school and any results reflecting the effectiveness of the process will not be discussed within the school setting. Teachers will be asked to analyse the nature of the answers given by pupils to the intervention questions. This will be part of the data gathering process but this is no different to the normal moderation and discussion that occurs between teachers within our school. While gathering data, in spite of being the researcher, I see my role primarily as the teacher. Parents of the pupils involved will be asked to sign a consent form allowing their children to take part in the study. Permission will be obtained from the school to make use of school facilities in this study. The consent forms that will be used are attached as Appendix 12.

Confidentiality is not an issue in this study. Normal classroom practice will be followed at all times. In a classroom setting pupils regularly receive feedback regarding their work and discuss the feedback with their teacher and peers. Sharing of the intervention question feedback will be encouraged. This is part of the learning experience. As no marks are allocated to the answers to the intervention questions sharing should not be perceived to be a threatening process. They will, however, not be

expected to share their feedback report with others. Test results from the pre- and post-tests will be given to pupils individually. Pupils can share results if they wish to do so. Pupils will be encouraged to discuss results of these tests with the teachers.

Neither pupil nor teacher names will be used in this document or in any subsequent publications. The anonymity of those involved in this study will be assured in this way.

I as researcher did start the research process with a personal bias. This is unavoidable and because Action Research strives to change or improve a situation personal bias can become a problem in reaching an objective conclusion. By constantly questioning my motives when interpreting data, drawing conclusions and evaluating I will strive to minimize the effect of my personal bias.

In this chapter I have described the Targeted Intervention Questioning process which is the focus of the whole study reported here. I have also outlined how I will test the effectiveness of this process so as to answer the research questions (pg. 38):

- Do focused intervention questions followed by rapid feedback to pupils foster sound concept formation in chemical bonding?
- Is this new teaching method more effective than traditional methods?

The development of the intervention questions to be used in the novel teaching method, the Targeted Intervention Questioning process and the tool used to evaluate the effectiveness of this method, the Conceptual Test tool, will be discussed in the next chapter.

CHAPTER 5

DESIGN OF THE INTERVENTION QUESTIONS and THE CONCEPTUAL TEST TOOL

In this chapter I will outline the rationale behind the design of the intervention questions and the testing tool that was used to determine the effectiveness of the Targeted Intervention Questioning process.

So often, after the topic has been taught pupils will come with the statement “I do not get Chemical Bonding”. Once the teacher begins to unpack the problem with the pupil it often transpires that pupils do have a grasp of the topic. However pupils are not sure whether their understanding is correct, they often do not realize what they do actually know and they also often do not realise what will be expected of them in tests and examinations.

Chemical bonding is a section of high school chemistry that most often seems to be incompletely and incorrectly understood. Of all topics taught in high school chemistry this one must be assimilated into long term memory as it forms the basis for so much other material. For this reason a strategy was designed to improve concept development during teaching of this topic.

The Targeted Intervention Questioning process is outlined in Chapter 4. In this chapter the rationale behind and development of the intervention questions and the Conceptual Testing tool will be discussed.

5.1 DESIGN OF THE INTERVENTION QUESTIONS

The strategy I designed consists of a set of intervention questions that will draw the attention of the pupil onto the most relevant aspects of a topic allowing the development of more accurate mental models. These questions are answered by pupils in class at intervals during the teaching of the chemical bonding section of the work. Pupils will have access to their learning material, can ask questions and discuss answers but will be encouraged to answer the questions to the best of their ability on their own. Their answers are not for marks and pupils are encouraged to put as much effort into formulating their answers as the process is to help their understanding. Feedback will be given to each pupil by the following lesson. The importance of the feedback is to encourage pupils, point out

their errors, show them what they do know and also what they still need to master. This performance related feedback helps improve the efficacy of instruction (Brooks, Schraw & Crippen, 2005)

The focus of the intervention questions is to improve this process of developing an understanding and in this way prevent the development of misconcepts. Research has shown that pupils need to link the new work to prior knowledge and construct their new knowledge (Hewson 1992; Bodner et al 2001). The intervention questions were designed to focus on the most important aspects of the topic chemical bonding. They should recall prior knowledge and point to links between the prior knowledge and the new content. Instead of the teacher and pupil meandering through the topic with concept development or conceptual change being a hoped for or “nice to have” goal of teaching, sound concept development becomes the focus of the teaching.

As set out in Chapter 2 this new method of teaching chemical bonding arises from a consideration of learning as Conceptual Change Learning (CCL), the development of mental models, the role of metacognition, feedback and cognitive load theory as determinants of accuracy and robustness of the conceptual understanding developed during learning this topic. According to Posner et al (1982) conceptual change occurs when existing concepts are replaced by new concepts that are more intelligible and acceptable. They refer to this as accommodation. Many factors determine the acceptance (or non-acceptance) of new concepts and students resist changes to their existing conceptual framework, hampering the accommodation of new material. In order to enhance accommodation Posner et al (1982) suggest the development of teaching strategies that deal with errors that occur during accommodation and also enhance accommodation. Teachers should employ strategies that diagnose errors in pupil thinking. The intervention questions are designed to enhance conceptual change (accommodation) by showing pupils where their understanding is lacking.

The intervention questioning process thus has a two-fold purpose. It firstly steers the pupil through the learning process resulting in improved accommodation. Secondly the process allows teachers to gain a better understanding of errors the pupils develop and will be in a better position to correct pupil understanding and enhance the development of sound concepts.

The questioning process will help pupils begin to understand the areas where focus must be given. The feedback allows the pupils to see where they are going wrong, where they have a good understanding and where they should focus their attention to ensure a fuller understanding. Brooks,

Schraw and Crippen (2005) maintain that the effectiveness of instruction is enhanced by performance related feedback. The feedback component of the process is as important as the questioning component. The feedback must be performance related – how well am I doing, how far am I from the goalposts, what can I do to get to the goalpost?

The intervention questions were designed to be used by any teacher, irrespective of their teaching style. Once a teacher had taught the section of work covered in one particular intervention question, the question is to be given to the pupils to answer using their books, notes etc. Guidelines given to teachers for using the Targeted Intervention Questioning process is to be found in Appendix 3. The teacher would then give the pupils feedback by the next lesson.

Six intervention questions were designed and these covered the most important concepts that are taught. The questions are set out in Appendix 1 and three questions will be discussed below.

As an example, the following question is given to pupils early on in the teaching of the topic:

<u>QUESTION 1:</u>	<u>Name:</u>
1.1 Use an Aufbau diagram to explain why a hydrogen atom is not stable.	
1.2 Explain, by referring to the electron configuration, why a neon atom never forms a Ne ₂ molecule.	

This question refers to prior knowledge (the Aufbau diagram). It links this through the concept of the stability of a full outer energy level to the concept that neon atoms, with full outer energy levels do not form chemical bonds.

The purpose of this intervention question was to focus pupil's attention on the fact that electron configuration determines whether atoms form chemical bonds. In order to understand electron configuration pupils should be able to draw Aufbau diagrams (reinforcement of skills). Pupils should also understand the meaning of the terms: stable (relating to atoms), electron configuration, atom, molecule (reinforcement of necessary terminology).

All the above skills, terminology, explanations will have been discussed in class, answers are available in pupils' learning material. The questions focus, reinforce, sequence and link the skills, terminology and discussion into a meaningful "chunk".

Feedback is then given to pupils. This is done by the next lesson and includes pointers to indicate where their understanding and knowledge is lacking and what they can do to improve their understanding.

An example is given below:

**you must learn the terminology - the words I have underlined*

QUESTION 1: **Name:**

1.1 Use an Aufbau diagram to explain why a hydrogen atom is not stable.

0/8



** which are the valence e⁻s*

It does not have enough valence
Electrons

1.2 Explain, by referring to the electron configuration, why a neon atom never forms a Ne₂ molecule.

It is not balanced enough to form Ne₂

** the question asks you to refer to the electron configuration - show an aufbau diagram in your answer & explain why that electron arrangement is stable.*

In another of the intervention questions (question 4) as shown below pupils' attention is focused on:

- The concept of the formation of an ionic bond that occurs when certain criteria (type of atom, electronegativity) are met (recall of prior knowledge).
- Terms that are important – *electronegativity, ionic bond, transfer of electrons, bonding electrons* (knowledge of terminology).
- The importance of the process of bond formation.

- Representing bond formation using diagrams (a skill).
- The links between ionic and covalent bonding (linking of concepts) .

In addition to drawing attention to the above pupils have to verbalise or sketch their own answers, an important step which helps the development of the mental models.

QUESTION 4

4.1 An ionic bond forms between a sodium atom and a fluorine atom. This is because:

A. sodium is a metal and fluorine a non-metal;

B. sodium atoms do not share electrons;

C. fluorine atoms have a much higher electronegativity than sodium atoms and so attract the bonding electrons into the fluorine atom, resulting in the transfer of an electron from the sodium to the fluorine atom.

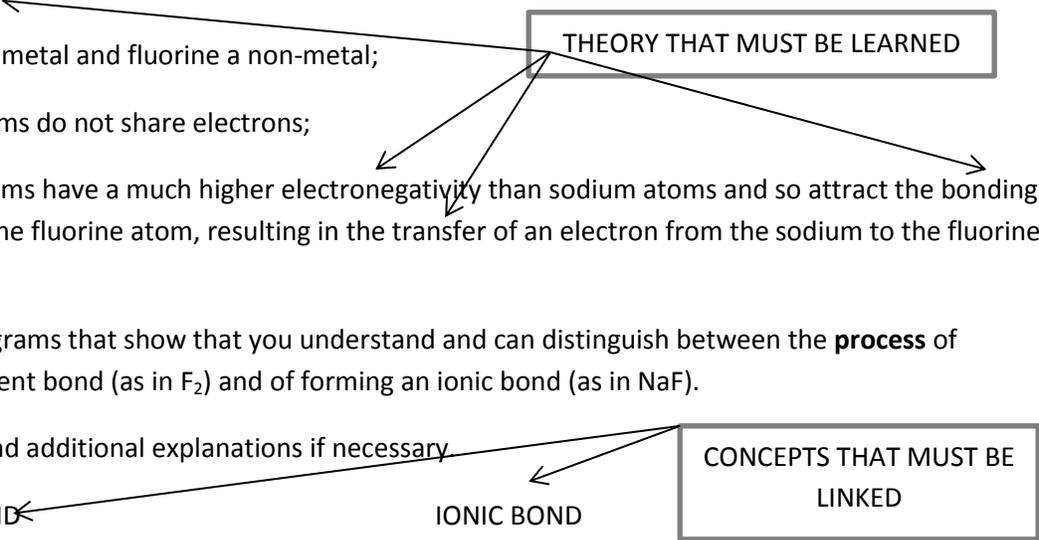
4.2 Draw 2 diagrams that show that you understand and can distinguish between the **process** of forming a covalent bond (as in F_2) and of forming an ionic bond (as in NaF).

Supply a key and additional explanations if necessary

COVALENT BOND IONIC BOND

THEORY THAT MUST BE LEARNED

CONCEPTS THAT MUST BE LINKED



Question 4 contains a multiple choice section that tests whether pupils have focused and understood the basic theory (an ionic bond forms between a sodium and a fluorine atom because the large difference in electronegativity values results in electron transfer and the formation of ions) and a free response section where pupils have to use diagrams to explain how a covalent bond differs from an ionic bond.

Both answers A and C in the multiple choice question can be considered to be correct. When feedback is given this is indicated to the pupils. What is important is whether they get to an understanding of how atoms of metals and non-metals interact. The feedback that is given is to alert pupils to what is the correct thinking. It is not just to see whether they can select the correct answer.

Do pupils see that A is correct but that C describes what happens when a metal and a non-metal atom form a chemical bond?

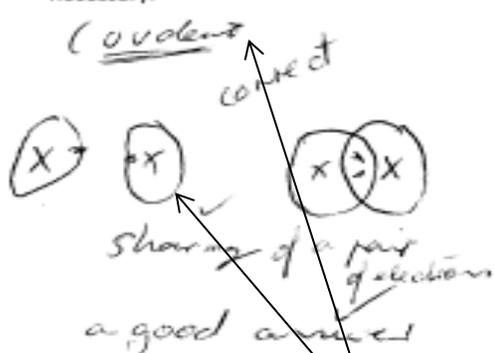
The feedback given:

QUESTION 4

4.1 An ionic bond forms between a sodium atom and a fluorine atom. This is because:

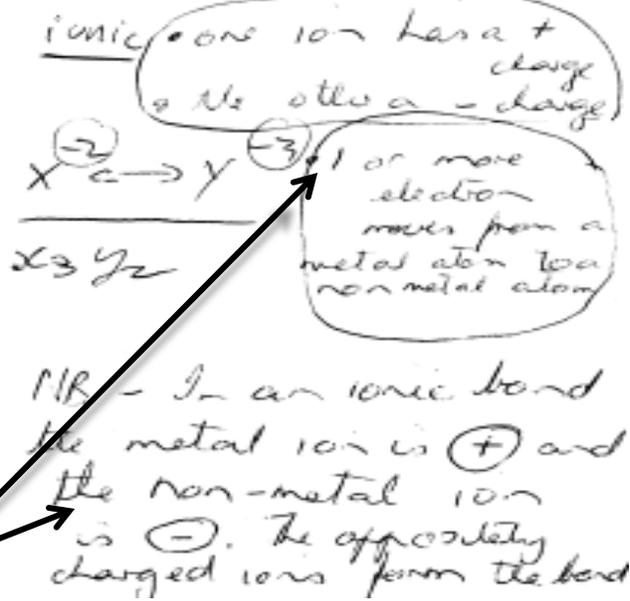
- A. sodium is a metal and fluorine a non-metal;
- B. sodium atoms do not share electrons;
- (C) fluorine atoms have a much higher electronegativity than sodium atoms and so attract the bonding electrons into the fluorine atom, resulting in the transfer of an electron from the sodium to the fluorine atom. *correct ✓ This is because*

4.2 Draw 2 diagrams that show that you understand and can distinguish between the process of forming a covalent bond and of forming an ionic bond. Supply a key and additional explanations if necessary.



Positive reinforcement when answers are correct.

Pupil shown what a correct answer is. This helps pupils to know what the correct theory is.



In question 6 of the intervention questions attention is paid to the fact that pupils have difficulty linking the macroscopic and sub-microscopic aspects of chemistry to each other:

QUESTION 6

Name:

Look at the diagrams below showing different types of solids.

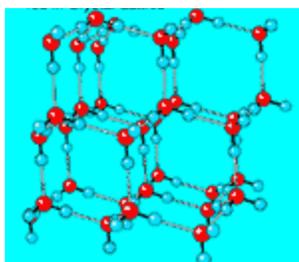
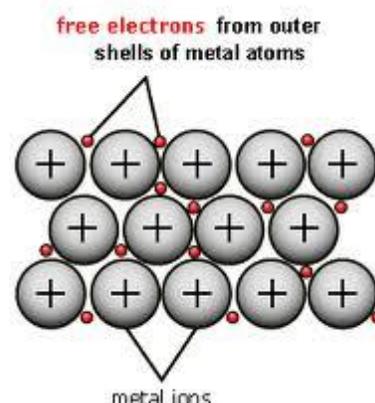
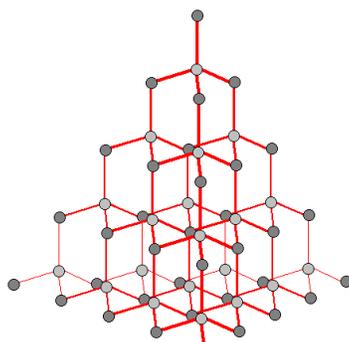
1. Link each of the substances given below to one of the diagrams.
2. Draw a line from the name to the diagram.
3. Give a reason for your answer.

A. Silver

B. Potassium fluoride

C. Ice

D. Diamond



The names of the substances are given – pupils should be able to decide what types of bonds hold particles together in these substances as these examples have been used during classwork. Pupils then have to link the substances to the diagrams of the particles. If pupils are able to relate the macroscopic and sub-microscopic representations of matter then a better understanding of why the bonds occur is developed (Talanteur, 2011; Treagust, Chittleborough, & Mamiala, 2003; Johnstone, 2006). Intervention question 5 (Appendix 2) similarly links the macroscopic properties of metals to their sub-microscopic properties for the same reasons as given for Question 6.

To summarise the intervention questions were designed in the way outlined above to serve many functions and these are listed along with a pointer to how the answering the questions promotes conceptual development:

- each question points out the aspects of the theory that are important to the topic. Improves the formation of mental models.
- the skills required to explain answers. Improves metacognition.
- the sequence of the questions indicates the development of the thinking that should underpin the topic. Improves metacognition.
- the questions break the topic up into manageable chunks. Prevents cognitive overload.
- the questions help pupils process the different aspects of the theory and see the links between sections and with prior knowledge. Improves concept formation.
- the questions allow pupils to see how they will be questioned on the topic. Pupils are exposed to an example of how questions are asked. Knowing what types of questions could arise in tests does help pupils when they are making their own summaries, structuring their learning notes.

The feedback helps pupils see:

- What they do know about the topic, what in their mental model is correct (task level feedback);
- What is lacking in their understanding, how far are they from having a complete picture (self-regulation feedback);
- What skills and terminology should they master (process level feedback);
- How the sections link together (eg how do ionic and covalent bonds differ, how are they the same) (process level feedback);
- How they should answer questions (process level feedback).

The types of feedback are as defined by Hattie and Timperley (2007) and serve to reduce the discrepancy between current and desired understanding. In addition the feedback is given in small chunks because each intervention question is analysed and feedback given. Many small sets of feedback have been shown to be more effective (Brooks, Schraw, & Krippen, 2005).

It is important to note that when designing the intervention questioning process it was envisaged that any teacher should be able to use the questions, irrespective of their approach to teaching. The

questions are to be answered by pupils using their notes. The intervention questions are not a type of “test”. They serve as a guide to help pupils get to grips with difficult concepts. The feedback aspect is considered to be just as important to the pupils as answering the questions. The feedback points out to the pupils where their understanding falls short and what they are doing that is correct. The questions plus the feedback must be seen as a whole.

The intervention questions were refined after the first run of the Intervention Questioning – Testing process. The analysis of the answers given by pupils in Run 1 of the Intervention Questioning process revealed instances where changes could be made in order to improve the questions. This will be discussed in Chapter 6.

The big question now is – how effective is this intervention questioning process? I wanted to evaluate the process and so needed some way of measuring pupils’ conceptual development during the teaching on chemical bonding.

In order to accomplish this evaluation a testing tool (referred to hereafter as the Conceptual Test tool) was designed that could measure pupils’ understanding before teaching and then after teaching. Once I had a tool to measure conceptual development I was in a position to test the effectiveness of the intervention questioning process by measuring pupil scores using the Conceptual Test tool.

5.2 DEVELOPMENT OF THE CONCEPTUAL TEST TOOL

This test is a summative test which tests pupils’ understanding of the topic of chemical bonding. As the intervention questions focused on the development of concepts, the testing tool contained a series of questions that probed pupils’ grasp of concepts rather than recall of facts.

By using the tool as a pre-test, pupils’ level of understanding before teaching, because of informal exposure to the topic, or because of an intuitive insight into the topic could be measured. Comparison of pre-test score with post test score would indicate the increase in pupil understanding due to teaching on the topic.

A number of principles were applied when the Conceptual Test tool was designed (Tan, Goh, Chia & Treagust 2002). Multiple choice and free response questions were used. Even though care was taken in designing the multiple choice questions pupils are still able to select correct responses without having a sound understanding of concepts. Free response questions were used to complement the multiple choice questions. Explanations of how and why are able to provide a better gauge of pupil understanding.

Prior knowledge and understanding was probed. The development of an understanding of chemical bonding is determined by the understanding of foundation principles – the nature of atoms, molecules, atomic structure. The most important aspects of bonding were tested and an attempt was made to test all cognitive levels – according to Bloom’s Taxonomy (Krathwohl, 2002). Bloom’s Taxonomy was used to analyse questions as this taxonomy is a commonly understood method of communicating objectives and assessments and will have meaning for other educators. An analysis is given below.

BLOOM’S TAXONOMY LEVELS USED:

1. KNOWLEDGE – pupils can recall knowledge – terminology and facts.
2. COMPREHENSION – pupils can apply their knowledge in a known context (translation), pupils can interpret their knowledge, and extrapolate their knowledge.
3. APPLICATION – pupils can apply their knowledge in an unknown situation.
4. ANALYSIS – pupils can break down a situation into its parts and understand how these fit together.
5. SYNTHESIS – pupils can create new meaning from related pieces of knowledge.
6. EVALUATION – pupils can compare and rank parts of the situation/knowledge.

Table 5.1 below shows a list of the questions making up the Conceptual Test tool. Copies of the test tools are to be found in Appendices 4 to 6. The analysis is based on the refined test, used for run 2 (Appendix 6). The content covered is listed as are the difficulty levels, noted and explained. The abbreviations: Know, Comp, Appl, Anl, Syn and Eval are used to indicate each of these levels in Blooms Taxonomy. The subtopic is given as it refers to the classification of the questions by topic as given in Table 6.4. Table 5.1 should be read in conjunction with Figure 3.2 in Chapter 3. Questions 1 and 2 asked for pupil name and type of assessment (Grade and pre- or post–test).

Table 5.1: List of the questions comprising the Conceptual Test tool.

Q nr	Subtopic	Content	Difficulty level	No of marks	Explanation
3	A	Prior knowledge	3	1	Appl – distinguishing between particles in an unfamiliar diagram
4	A	Prior knowledge	2	2	Comp – definition of a compound well known
5 a	A	Prior knowledge	1	1	Know
5 b	A	Prior knowledge	2	2	Comp – application of known definitions to known situations.
6	A	Prior knowledge	2	1	Comp – recognising a particle diagram representing an element
7	A	Prior knowledge	2	2	Comp – application of known definitions to known situations.
8	A	Prior knowledge	2	1	Comp - classifying substances as elements or compounds, identifying processes as physical or chemical.
9	B	Sub-microscopic knowledge Prior knowledge	2	9	Comp - interpreting a formula, synthesising a particle diagram but the formulae used were well known to pupils.
10	C	Atomic Structure Process of Bonding	1	1	Know - defining valence electrons
11	C	Atomic Structure Process of Bonding	1	1	Know – defining core electrons
12	C	Atomic Structure Process of Bonding	3	4	Appl– drawing an Aufbau diagram
13	D	Reasons for bonding Process of Bonding	2, 4	3	Know, appl
14	E	Writing a formula Process of Bonding	2	4	Know
15	E	Describing bonds Process of Bonding	4	2	Anl - decide what type of bond and then describe the bond type
16	E	Describing bonds Process of Bonding	4	2	Anl - decide what type of bond and then describe the bond type
17	E	Distinguish between covalent and ionic bonds Process of Bonding	2 / 4	2	Comp– distinguish between non-metal and metal and type of bond and draw diagrams to represent the differences between covalent and ionic bonds. Simple classification of known bond types and examples. However, producing a diagram could be construed to mean a higher order thinking skill.
18	F	Distinguish between covalent and ionic bonds	2	2	Comprehension as pupils had to describe covalent bonds as non-

		Product of Bonding			metal to non-metal atom bonds and ionic as metal – non-metal atom bonds
19	F	Distinguish between polar and non-polar bonds Process of Bonding	4	2	Anl - Difficult question as it involves an understanding of electronegativity and then application of this concept to polarity of bonds and then the explanation of how this affects bond type.
20	F	Definition Process of Bonding	1	1	Know
21	F	Explanation of properties Product of Bonding	2	2	Understanding of a concept – more difficult than straight recall.
22	G	Description of why atoms bond	2	1	Comp
23	G	Describing metallic bonds Process of Bonding	2	1	Appl
24	G	Describing metallic bonds and link to properties of metals. Product of Bonding	3	2	Difficult question as pupils had to link the microscopic properties (metallic bond) to the ability of a metal to conduct electricity.

The number of marks is an indication of the weighting of each question.

Three versions of the Conceptual Test tool were developed. The first version (Appendix 4) was piloted in 2010 with a group of Grade 11 pupils. The tool was refined and version 2 (Appendix 5) was used with the first test group in 2011 (run 1). The initial refinement of the testing tool was based on observation of responses given by pupils and was primarily to determine whether the expected responses to questions were in fact obtained. This was not a statistical analysis but rather an analysis based on the teacher knowledge and experience. The modified test was used for run 1 in 2011 (Version 1, Appendix 5) and was further modified after Rasch analysis of the results obtained in run 1. Version 2 (Appendix 6) was used in 2012 (run 2). A discussion of the methods used to refine the Conceptual Test tool is given in Chapter 4.

The planning - testing - evaluation and modification - testing - evaluation cycle fits in with the action research methodology utilised in the study. The testing tool was modified after each run (pilot and run 1) so as to improve the tool by taking into consideration the analysis of pupil answers to the questions. Revision of the tool was to improve teaching and evaluation of teaching. The validity and reliability of this tool will be discussed further in Chapter 6.

The Rasch analysis pointed to items in the Concept Test tool (version 1 Appendix 5) that were not performing as intended. The value of this analysis was that the Concept Test tool was modified before being used in the 2012 test. A discussion of the results of the Rasch analysis and the resulting modifications to the Conceptual Test tool are given below:

Items with unacceptably high misfit statistics: Questions 6 and 11.

Items with poor discrimination because they are too easy: Q5A, Q9AA, Q9BA and Q23

These items may be redundant; they do not discriminate between better and poorly performing students, they do not make a meaningful contribution towards person separation in post-test data.

The following changes were made to the Conceptual Test tool version 1

Question 6 –

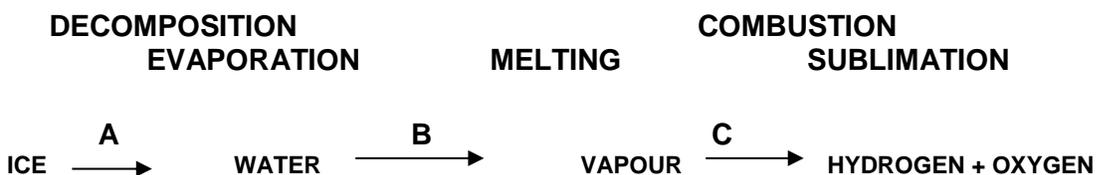
Mark the statement which best explains why this particle diagram shows that iron is an element:

- A. The atoms are all packed in an ordered arrangement.
- B. The atoms are identical.
- C. Iron is a metal.

Changed to:

- A The particles are in an ordered arrangement
- B There is only one type of particle meaning the substance is made up of atoms
- C The spaces between the particles are very small
- D There is only one type of particle meaning this is not a mixture

Choose terms from the list below to replace the symbols **A - C** in the sequence below:



Changed to the following which should prevent guessing and is considered to be more difficult:

Consider the following changes that the substance water can undergo:



- A. Which of these changes is a chemical change?
B. Explain the difference between a “phase change” and a “chemical change”.

Question 9:

Run 1:

Represent:

- a. One molecule of hydrogen gas (H_2)
b. One molecule of carbon dioxide gas (CO_2)
c. $3H_2O_{(l)}$

Was changed to the following in Run 2:

- a. Represent $5H_{2(g)}$
b. Represent 3 molecules of carbon dioxide gas.
c. Represent $5H_2O_{(l)}$

This will make the questions more difficult and discriminate better between pupils. This is an easy question for pupils to answer but as it tests prior knowledge the results from this question will be valuable in describing and explaining changes in prior knowledge due to new teaching.

Question 23 (Question 22 in Run 2)

Run 1:

Do you expect the light bulb to light up? Pupils can guess at answer.

Change to a free response question in Run 2:

Why does the light bulb light up when the switch is closed? Requires knowledge of what is required for a light bulb to glow (free moving charged particles).

These changes were made to the Conceptual Test tool and Version 2 was implemented in the second run of the Targeted Intervention Questioning process.

5.3 VALUE OF THE CONCEPTUAL TEST TOOL

The Conceptual Test tool will allow a quantitative analysis of progress made by the pupils as a result of the teaching and learning. Data from the testing tool will allow test and control groups to be compared for equivalence and also for conceptual development as a result of the teaching intervention. The value of the Conceptual Test tool is that it can at any stage be used to assess pupils' level of conceptual development and the extent of pupils' misconceptions regarding the topic. The data that were generated by the tool were analysed using Rasch analysis which confirmed that the questions were working together to assess a single construct, namely conceptual understanding of chemical bonding. As a result we concluded that the test is a valuable tool that can be used with confidence for Grade 10 pupils.

In addition valuable qualitative data could be garnered from the answers to the descriptive questions. This type of data can point out areas where individual or groups of pupils experience difficulties and where remedial teaching is needed. The test allows weaknesses in teaching practice to be revealed. It also allows instances where the teacher is relaying incorrect understanding of science to be picked up. Here the Conceptual Test tool has been used to track conceptual development in pupils but it can be used as a diagnostic tool to assess teacher and pupil performance.

This chapter has outlined how the intervention questions were developed and the Conceptual Test tool likewise so as to determine whether the Targeted Intervention process was actually worthwhile. Both tools were developed based originally on my intuition after many years of teaching this topic and being frustrated as my pupils did not make the progress I expected them to make. Subsequent reading allowed me to understand why this method could work and also allowed me to make improvements. The next chapter will present the results obtained when pupils were exposed to the Targeted Intervention process and their conceptual development was measured.

CHAPTER 6

THE RESULTS OF THIS STUDY

This project involves the evaluation of the Targeted Intervention Questioning process I will present and discuss the data collected during the implementation of the process and the subsequent evaluation of the process. As the methodology used is action research data from both the cycles of testing (Run 1 and Run 2) that were implemented will be presented and discussed. Through this study I have tried to understand my teaching practice and the effectiveness of this practice and the results presented below are reported from this perspective. Thus the type of data collected and the interpretation of the data will hopefully allow for the evaluation of the novel teaching method but also allow for a greater understanding of how learning occurs so as to improve teaching practise.

6.1 TYPES AND SOURCES OF DATA

Data and information were gathered from a number of sources and in a number of ways in this study. The purpose of the data gathering was to ascertain whether the teaching method involving intervention questions with rapid feedback to the pupils, was indeed effective in promoting concept formation. This chapter reports these results.

In this study I wanted to see whether the use of a Targeted Intervention Questioning process where questions were answered by pupils at certain intervals during the teaching on chemical bonding would improve concept development. The intervention questions were followed up with feedback to the pupils by the following lesson. In order to evaluate the intervention question – feedback process pupils' level of understanding before receiving teaching on the topic was determined using a testing tool (referred to as the Conceptual Test tool) which was made up of a batch of questions probing their level of understanding. The pupils re-wrote this test after receiving teaching in order to determine the gain in understanding.

There are therefore two sources of data in this study. Firstly there was the data from the Conceptual Test tool. This is in the form of answers to multiple choice questions as well as free response answers. The Conceptual Test tool was used as a summative test. Pupils were given this test after teaching was completed and pupils had had a chance to revise the

material. They were not allowed to make use of their learning material when answering the Conceptual Test tool. The second source of data is the answers given by pupils to the intervention questions. The intervention questions were used formatively, meaning they were used to gain information regarding pupils' level of understanding at that point of the teaching process. Pupils were allowed to use their notes, books, learning material to help them answer these intervention questions. Marks are not given or used to assess the pupil.

The answers from the Conceptual Test tool can be used to determine the gain in understanding after the pupils have been taught the section on chemical bonding if the scores for the test prior to teaching are compared to the score after teaching. Qualitative data can also be collected from the Conceptual Test tool as the nature of the answers given by pupils to free response questions is a measure of their depth of understanding. Similarly, pupil answers to the intervention questions can be used to gather data regarding the nature and depth of their understanding.

Both qualitative and quantitative data can be used to evaluate the teaching method that is the focus of this study. Qualitative and quantitative data were collected and analysed as these two types of data complement each other. The purpose of the collection of the quantitative data was to provide evidence of the effectiveness of the intervention process for a group of pupils in terms of learning gain. This is a numerical analysis and statistical methods can be applied. This would go towards answering the question "Is this intervention questioning process, along with the rapid feedback effective enough to be used as a standard teaching technique?" Quantitative data is based on pupils' scores on tests which is a measure of teaching effectiveness. However, test scores are also determined by other factors which include for example pupil ability and pupil preparedness for the test.

This study looks at the effectiveness of this particular method in promoting concept development. It is therefore important to measure concept change or development as accurately as possible and so teaching effectiveness can also be measured by the richness and completeness of understanding of concepts. Test scores cannot always measure the process of and depth of conceptual understanding. The analysis of qualitative data allowed me to gain insight into the way in which pupils develop concepts while learning about chemical bonding and also the completeness of the understanding.

Data from the two sources was used as follows:

- The intervention questioning process – both quantitative and qualitative data was obtained from this source and both types of data are discussed below (6.3.1, 6.3.2 and 6.3.3).
- The Conceptual Test tool – both quantitative and qualitative data was obtained from this source and both types of data are discussed below (6.3.4 and 6.4).

6.2 ACTION RESEARCH CYCLE APPLIED

This is an action research study and so the data from these two sources was collected in two cycles of PLAN – ACT – OBSERVE - REFLECT – MODIFY and the timing of this process is set out in the timeline shown below.

2010:

November – December PLAN	Preliminary Design of a Research Procedure to study the proposed topic. Action Research using mixed-methods data collection was selected as the research method. INTERVENTION PROCESS designed and intervention questions compiled.
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2011

January - March PLAN	Consolidation of Research Design Design of Conceptual Test Tool for Grade 10 pupils in order to quantitatively evaluate the effectiveness of the intervention process. A 25 question Conceptual Test tool was developed.
March ACT	Pilot Run of Grade 10 Conceptual Test Tool using Grade 11 pupils. This was to determine whether the test was effective and whether there were any hidden problems in the tool. Modification of Conceptual Test tool after review of pilot run results
May – June OBSERVE	RUN 1 of Grade 10 INTERVENTION PROCESS Conceptual Test tool administered as a pre-test. Intervention questions administered to test group of Grade 10 pupils Conceptual Test tool administered as a post-test. QUANTITATIVE AND QUALITATIVE DATA COLLECTED
July – August REFLECT	Processing of Grade10 RUN 1 data Statistical analysis of the pre- and post-test performance data Qualitative analysis of the answers pupils gave to intervention questions.
September – November PLAN	Modification of Conceptual Test Tool and Intervention Questions based on results from RUN 1

2012

May – June ACT	RUN 2 of Grade 10 INTERVENTION PROCESS Conceptual Test tool administered as a pre-test. Intervention questions administered to test group of Grade 10 pupils. Conceptual Test tool administered as a post-test. QUANTITATIVE AND QUALITATIVE DATA COLLECTED
July – August OBSERVE	Processing of Grade10 RUN 2 data Statistical analysis of the pre- and post-test performance data. Qualitative analysis of the answers pupils gave to intervention questions.
September – November REFLECT	Complete write-up and identify ways of proceeding based on the findings of the study.

6.3 QUALITATIVE DATA:

The rationale for this study is my observation that pupils do not always know how the information presented during the teaching fits together. The foundation the teacher attempts to lay down is at times lost, forgotten and this causes “gaps” in the mental models that the pupils are trying to build up. In order to improve the teaching process and through this improve pupils’ concept development, a set of conceptual questions was designed that were administered to pupils at set places during the teaching of the topic.

The intervention questions were designed to be answered individually by pupils with the use of their learning material. There was a two-fold purpose in this, namely that these intervention questions were not a “test” but rather a chance for pupils to reflect on what had been taught and to see whether they did actually understand the material. It also gave pupils the opportunity to see what material in their notes, textbooks was actually the essence of the topic being studied – namely chemical bonding or intermolecular forces.

The intervention questions were structured in such a way that pupils should be able to write down some sort of answer that feedback can be based on. Intervention questions were designed to lead pupils into the subsection of the topic from the basic knowledge level to higher levels of comprehension and then synthesis of an answer. There was a stepwise progression from lower to higher cognition.

Answering these questions and receiving feedback on the correctness of their answers should improve the process of concept development irrespective of the teaching method

employed by the teacher. Qualitative data in the form of the type of answers given and the type of errors pupils made was gathered as it was able to add depth to the picture of concept development painted by the quantitative data harvested during a run of the intervention process. The qualitative data recorded and analysed during the first run of the intervention process was used to evaluate the whole process so that improvements could be implemented.

6.3.1 QUALITATIVE DATA FROM THE INTERVENTION QUESTION RESPONSES.

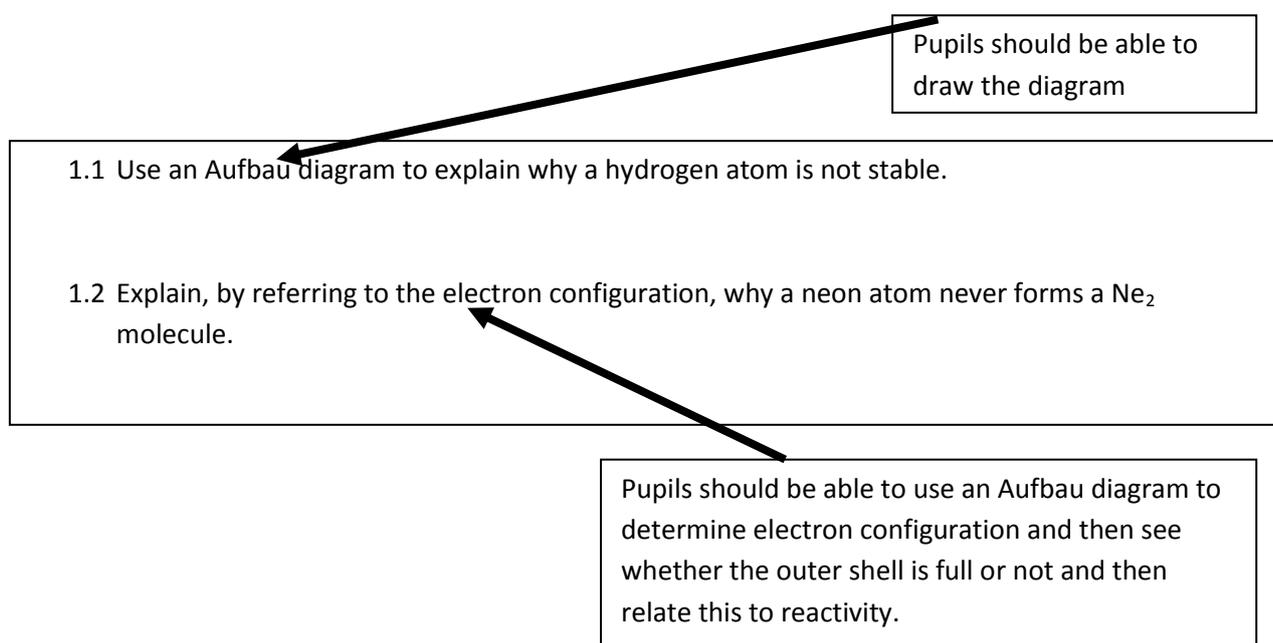
Qualitative analysis of the answers given by pupils served two purposes. Primarily the answers given by pupils to each of the intervention questions were analysed as this is an important source of information regarding the learning process that pupils go through as they master the concepts. Secondly this study is the evaluation of a method designed to improve concept formation and so any information that can be used to improve the teaching method is valuable.

These observations were made while considering the type of answers given by the pupils to the intervention questions and the type of feedback that was necessary in order to correct the errors made by pupils when answering the intervention questions. This type of inference is often made by teachers while reviewing the nature of answers made by pupils. It is difficult to quantify this type of data where the number of different answers is almost as many as the number of pupils in the sample. After analysing the answers given by pupils to the intervention questions I realised that pupils did not have the vocabulary or the command of the necessary terminology to answer the questions scientifically. Pupils were able to use their books and notes while answering the questions yet still did not use the terminology correctly. Rudimentary explanations, displaying an unsophisticated understanding were often given. These incomplete answers could be because pupils have not yet developed an understanding of the terms and so find it difficult to use them. My feeling is that if pupils are directed to the correct terms to use to explain certain aspects of the topic, and also what contexts different terms are used, their understanding of the terms will be enhanced. The guidance provided will help them develop the ability to explain scientific concepts scientifically.

Changes were made to the intervention questions to ensure that pupils began to grasp and use the new terminology associated with chemical bonding. Repetition of terminology that is assumed to be known after teaching is included in the intervention questioning process.

A discussion of each of the questions that make up the Targeted Intervention Questioning Process is given below. For each question changes and reasons for changes between run 1 and run2 are given. An analysis of the correct and incorrect responses to these questions is also presented and then summarised at the end.

INTERVENTION QUESTIONS FIRST RUN OF INTERVENTION PROCESS:



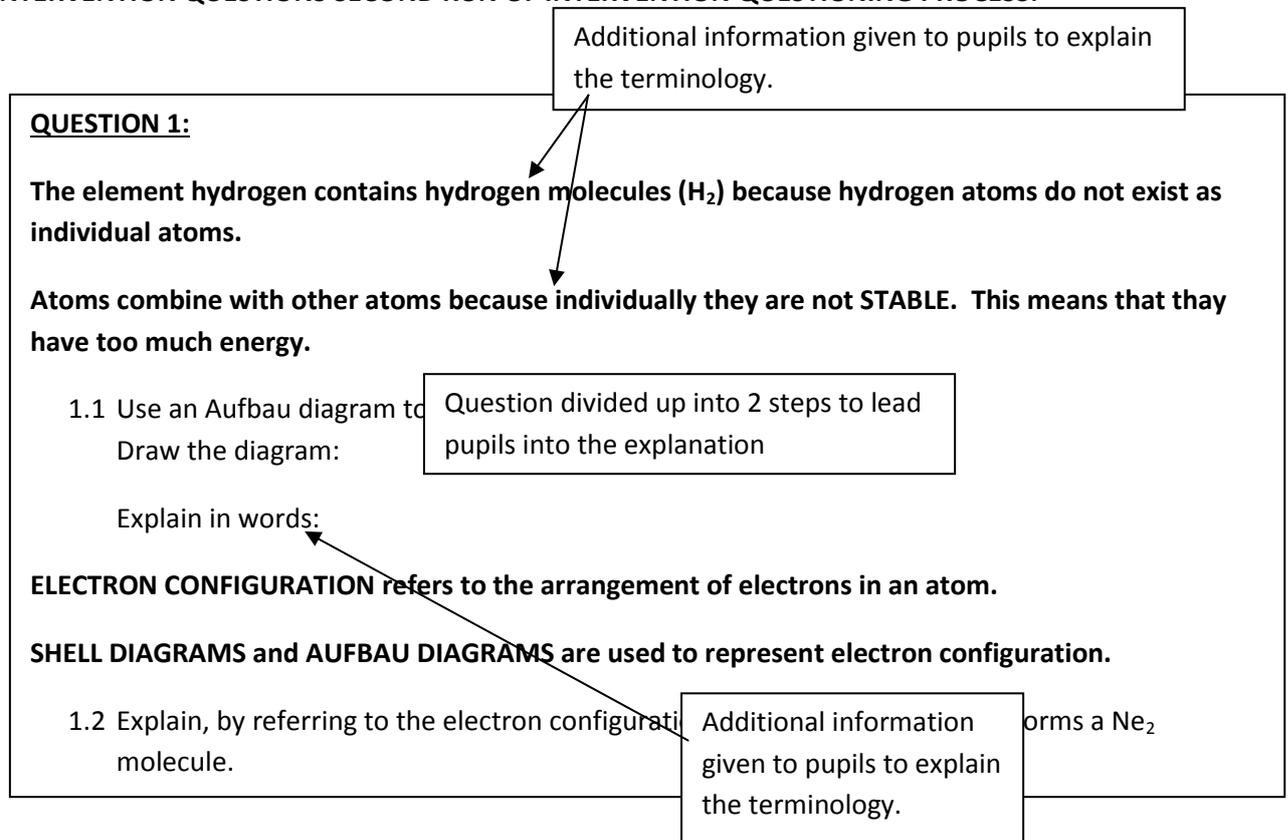
Once I realised that pupils needed assistance understanding the terminology I modified the questions and the changes are shown below.

Intervention questions were given to pupils early on in the teaching of chemical bonding. They need help and direction in formulating their answers. The intervention questions are a part of the learning process, not an assessment tool. For this reason the scaffolding was put in place.

The responses from run 1 were used to refine the Intervention questions and ensure that the pupils understood the questions, that the questions elicited the required responses and that the questions were at the correct cognitive level – neither too easy nor too difficult.

Once the changes were made to the Intervention questions I felt that the responses that were obtained could be used as a measure of pupils' level of conceptual awareness with confidence.

INTERVENTION QUESTIONS SECOND RUN OF INTERVENTION QUESTIONING PROCESS:



This rationale was applied to all the intervention questions and changes were made to the questions. The two versions of the questions are available in Appendix 1 and Appendix 2.

The following changes were made to the intervention questions between run 1 and run 2:

Question 1 – pupils were given definitions and extra information about the terms used to help them to think about what causes atoms to bond.

Question 2 – pupils were asked to write down definitions of relevant terms. This was to direct their thinking so that they knew where to begin their answer.

Question 3 – the original question was broken up into 3 questions. Pupils were asked to define electronegativity, explain what electronegativity means in terms of electron sharing and then to answer the question about types of bond. By starting with a definition of electronegativity pupils should begin to understand what this new term means, this

understanding should be reinforced through describing how electronegativity affects electron sharing and then pupils should apply their knowledge in the third section.

Question 4 – no change made

Question 5 – no change made

Question 6 – minor changes to ensure that pupils understood the question – no changes to the actual question.

6.3.2 ANALYSIS OF QUALITATIVE DATA FROM RUN 2 OF THE INTERVENTION QUESTIONING PROCESS

The responses were selected randomly from the collected responses for each intervention question after run 2 of the Intervention Process. As only the test group received the Intervention questions the responses were from pupils in the test group. Responses from run 2 were used for this analysis as any design problems in the questions used in Run 1 had been rectified and any trends observed are not due to ambiguities in the questioning process. Forty four pupils made up the Test group in Run 2, and allowing for absentees on the day, the total sample size for the analysis of qualitative data was between 35 and 44 responses.

a. INTERVENTION QUESTION 1:

QUESTION 1:

The element hydrogen contains hydrogen molecules (H_2) because hydrogen atoms do not exist as individual atoms.

Atoms combine with other atoms because individually they are not STABLE. This means that they have too much energy.

1.1 Use an Aufbau diagram to explain why a hydrogen atom is not stable.

Draw the diagram:

Explain in words:

ELECTRON CONFIGURATION refers to the arrangement of electrons in an atom.

SHELL DIAGRAMS and AUFBAU DIAGRAMS are used to represent electron configuration.

1.2 Explain, by referring to the electron configuration, why a neon atom never forms a Ne_2 molecule.

A sample of 35 responses was analysed and in this sample there were 31 correct Aufbau diagrams. However only 6 pupils were able to give a correct explanation of why the hydrogen atom is unstable. Teachers of these pupils had spent time explaining this particular concept in depth as this is fundamental to understanding why chemical bonds form. Pupils also have this information in their learning material. Eight pupils could extend this knowledge to explain why a neon molecule never occurs. Pupils were not able to use correct terminology when answering intervention questions – despite having access to notes and books while answering.

Pupils are required to master a number of new terms in order to understand the concepts in this section. The words *electron configuration*, *Aufbau diagram*, *stable* (when referring to an atom), and *energy levels* are new terms and describe unfamiliar concepts. Understanding of the meaning of these new terms was vague and they could not use these terms accurately even though they had the use of definitions and descriptions of the new terms. Their understanding appeared to be superficial as they could not make use of the new terms in subsequent answers.

Most incomplete or incorrect answers were considered to be so because pupils used incorrect terminology (non-scientific terminology) or were so confused that they gave no answer or an irrelevant answer.

b. INTERVENTION QUESTION 2:

Write down definitions for the following terms:

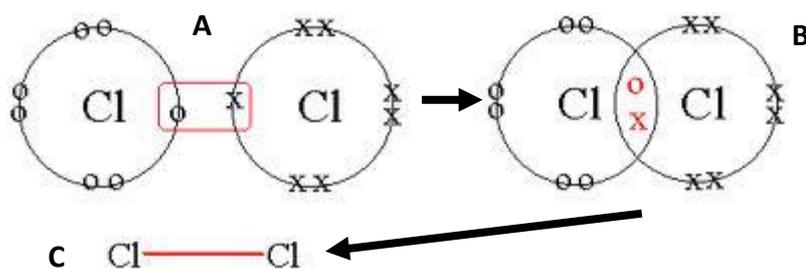
- Unpaired electron:

- Orbital:

2.1 A hydrogen molecule forms when:

- A. the unpaired electrons in 2 hydrogen atoms form a bond.
- B. the s orbital in one hydrogen atom overlaps with the s orbital in a second hydrogen atom, the electrons are shared and form a covalent bond.
- C. the electrons in the two hydrogen atoms join to form a chemical bond.

2.2 This diagram shows the formation of a chlorine molecule:



Explain what is happening in each step (A – C) of the sequence shown here.

A sample of 40 responses was analysed. It was found that 39 pupils answered the multiple choice question correctly but only 6 were able to correctly answer 2.2. On reflection the choice of distractor B as the correct answer could have been because it appears to be “more correct” due to the length of the answer compared to A and C. The correct answers may not always reflect a correct understanding. Distractor A can also be considered correct and when giving feedback pupils were alerted to this, likewise when pupils selected distractor C as correct they were alerted to the fact that A was also correct. As this was not a “test” and because the intervention questions are to lead the pupils to a better understanding, having two correct answers was not a problem.

Answers to 2.2 that were considered correct had to include an understanding of:

- ✓ the presence of unpaired electrons in the valence shell of each Cl atom.
- ✓ the overlap of the orbitals and sharing of the unpaired electrons.
- ✓ covalent bond resulting from the sharing of the electrons.

Pupils can recognise and have a superficial understanding of the process of formation of a chemical bond. Their understanding seems to be too superficial to allow them to describe this process using the correct terminology. Pupils do not seem to be able to distinguish between the terms unpaired electrons, orbital overlap and electron sharing. Most often feedback was to point out the differences between these terms and to indicate the correct sequence. The sequence followed during bond formation, namely orbital overlap and then electron sharing appears to be difficult for pupils to understand.

c. INTERVENTION QUESTION 3

This question required pupils to define the term electronegativity and then explain how this quantity affects the type of bond formed:

Hydrogen atoms have an electronegativity value of 2,1. Chlorine atoms have an electronegativity value of 3,5.

- 3.1 What is meant by the term **electronegativity**?
- 3.2 How do electronegativity values affect the sharing of electrons in a bond?
- 3.3 Explain how the electronegativity values of hydrogen and chlorine affect **the type** of chemical bond that forms between a hydrogen atom and a chlorine atom.

Please use diagrams in your answer.

Electronegativity is a concept that most pupils find difficult to understand and this was evident in the answers given by pupils to question 3. Despite using their learning material most pupils were not able to write down a definition of this term. It seems as if the definition of a concept is not accessible to pupils before the meaning of the term is real to them. Even fewer were able to apply their knowledge of the concept in answering questions 3.2 and 3.3.

A sample of 40 answers was analysed. Fourteen pupils were able to write down a correct definition, and only four were able to expand on this and explain polar covalent bonds.

Feedback to pupils was largely to point out that electron sharing (equal or non-equal) was affected by the quantity known as electronegativity.

d. INTERVENTION QUESTION 4

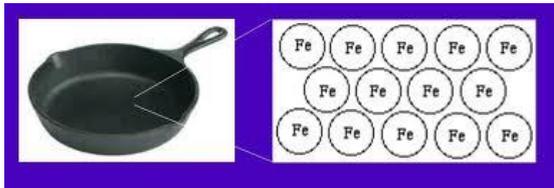
4.1	An ionic bond forms between a sodium atom and a fluorine atom. This is because:	
A.	sodium is a metal and fluorine a non-metal;	
B.	sodium atoms do not share electrons;	
C.	fluorine atoms have a much higher electronegativity than sodium atoms and so attract the bonding electrons into the fluorine atom, resulting in the transfer of an electron from the sodium to the fluorine atom.	
4.2	Draw 2 diagrams that show that you understand and can distinguish between the process of forming a covalent bond (as in F_2) and of forming an ionic bond (as in NaF). Supply a key and additional explanations if necessary.	
COVALENT BOND:		IONIC BOND:

As in question 2, pupils could select the correct answer from a multiple choice question when asked to distinguish between ionic and covalent bond types (question 4.1) but very few were able to answer question 4.2 correctly. A sample of 41 answers was analysed, 38 of these had correct answers to 4.1 (the multiple choice question), but only eight pupils could give a correct explanation in question 4.2. Correct answers could have been given in 4.1 (distractor C) because this distractor “seems more correct” due to the length of the answer compared to A and B.

Feedback in response to incorrect answers was most often to indicate to pupils the need to show electron sharing in the case of the covalent bond and the formation of ions in the case of the ionic bond.

e. INTERVENTION QUESTION 5

Question 5 was answered by pupils after they had received teaching on the metallic bond. The effect of the nature of the bond on the properties of metals is emphasised at this stage. Question 5 requires answers that indicate pupils’ understanding of this aspect of chemical bonding.

QUESTION 5
Name
Diagram of iron particles


- 5.1 For each of the following statements decide whether it is correct or not. For each incorrect statement, please explain **what is incorrect** about the statement.
- A. Iron has the type of bonding called metallic bonding, holding the particles together.
- B. In iron metal each iron atom is bonded to each of the other atoms surrounding it.
- C. Iron conducts electricity because some of the atoms can slip past others and move through the metal.
- D. Chemical bonds are not needed to hold the iron atoms together because the atoms are identical.
- E. Iron expands when heated and this is because the atoms get bigger when heated.

A sample of 37 answers was analysed and questions C and E were seen to be poorly answered. Reports in the literature conclude that: “The idea that solids are composed of atoms, molecules, or ions is counterintuitive to them: It seems to contradict the evidence of their sensory observation (no particles are observed) and personal experiences (solids don’t seem compressible).” (De Posada, 1981) This misconception would give rise to the answers encountered in Intervention question 5.

Only 9 pupils correctly explained that free, delocalised electrons move through the metal. Many pupils used the words atom in place of electron. Twelve pupils could explain that E is incorrect because atoms do not expand but just get further apart because they vibrate faster.

Statement D showed that pupils regard an element as not requiring bonds to hold identical atoms together. Of the 37 scripts reviewed 18 pupils indicated that “Chemical bonds are not needed to hold the iron atoms together because the atoms are identical.” However only 3 pupils indicated that question A (Iron has the type of bonding called metallic bonding, holding the particles together.) was incorrect. These results seem to indicate a great deal of confusion in

pupils' minds regarding bonding in an element (a metal) and also in their understanding of metallic bonding. De Posada (1997) reports that "Students perceive metals as continuous, strong, rigid, and opaque at the macroscopic level, and they transfer this idea to the microscopic level." This misconception could account for the contradictory answers to questions A and D.

The results reported here have implications for teaching practice and this will be discussed in the following chapter.

f. INTERVENTION QUESTION 6

Pupils are required to interpret diagrams that show the nature of the particles in a substance and the forces between the particles. Pupils find this very difficult with few pupils being able to consistently answer this type of question correctly. Particle diagrams representing solids seem to be particularly difficult for pupils to interpret.

Pupils have great difficulty understanding metallic bonding and few are able to relate the properties of metals to the nature of the metallic bond. Likewise, pupils find it difficult to identify particle diagrams showing ionic, molecular, atomic and metallic solids and relate them to the names of substances.

Look at the diagrams below showing different types of solids.

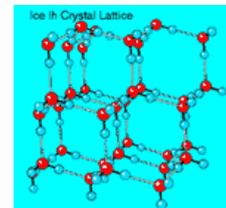
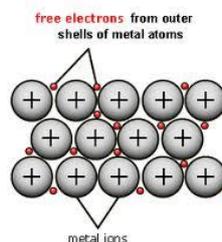
1. Link each of the substances given below to one of the diagrams.
2. Draw a line from the name to the diagram.
3. Give a reason for your answer.

A. Silver

B. Potassium fluoride

C. Ice

D. Diamond



In the sample of 37 answers to the question below that were analysed only 5 pupils correctly identified all 4 diagrams. The results of the analysis of Intervention questions 5

and 6 were cause for concern when considering the implications for teaching. This will be discussed in chapter 7.

This particular question was included as one of the intervention questions because the process of linking macroscopic and sub-microscopic properties of matter is difficult for pupils (Talanteur, 2011) and the results shown here reinforce this finding.

A summary of the qualitative results arising from analysis of the answers given to the intervention questions is given in the table below:

Table 6.1: Summary of Qualitative data from the Intervention Questions

Question	Total no of responses	Correct	Comments
1.1	35	31 (89%)	Drawing skill – Aufbau diagram
1.2	35	6 (17%)	Explanation of why atoms bond
2.1	40	39 (98%)	Distractors A and C were considered correct and this was indicated to pupils in the feedback.
2.2	40	6 (15%)	Sub-microscopic diagram
3.1	40	14 (35%)	Definition required
3.2	40	4 (10%)	Explanation of what electronegativity means
3.3	40	4 (10%)	
4.1	41	38 (93%)	Distractors A and C were considered correct and this was indicated to pupils in the feedback.
4.2	41	8 (20%)	Sub-microscopic diagram
5 A	37	34 (92%)	A and B were correct statements and so no additional statement was required. C, D and E were incorrect statements and required a reason reflecting why they were incorrect. Only correct reasons are considered here to be correct.
5B	37	28 (76%)	
5C	37	9 (24%)	
5D	37	19 (51%)	
5E	37	12 (32%)	
6A	37	5 (14%)	Most pupils at this stage of the development of their knowledge were not able to answer this question correctly. Correct answers were taken as correct association and explanation.
6B	37	3 (8%)	
6C	37	3 (8%)	
6D	37	2 (5%)	

All of the trends noted above describe shortcomings in pupil understanding and ability to formulate answers to questions despite pupils receiving adequate teaching, having their learning material available and being encouraged to make use of the learning material to answer the questions. Pupils always answered the intervention questions as part of the learning process and not as a summative exercise.

It must be noted that numbers have been assigned to correct answers in this analysis. Many of the free response answers recorded by pupils were vague and could not be classified accurately. These answers were given by pupils at a stage of teaching where pupils were still attempting to understand and were in the process of developing concepts.

From the qualitative analysis of the answers to the intervention questions it would seem that answering these questions was of little value to pupils. Answers revealed partial understanding of the concepts and at times, confusion. However, each incorrect answer received a feedback comment from the teacher and pupils were encouraged to peruse their answers and the associated feedback. It would seem that the feedback given by the teacher is the important aspect of the process that facilitated learning and this will be discussed in Chapter 7.

6.3.3. VALIDATION OF QUALITATIVE ANALYSIS OF INTERVENTION QUESTION ANSWERS

In order to validate the qualitative results reported above, two experienced teachers were asked to look at pupil responses recorded on the intervention questions in order to see if any trends were evident. The teachers were given pupil responses to four of the Intervention questions (questions 1, 2, 4 and 5 of the Intervention questions – Appendix 2). These questions were chosen because the questions required descriptive answers. Descriptive answers give a better insight into pupils understanding and analysis of these would be a richer source of information. Questions 3 and 6, while being valuable to assist pupils in concept formation, were not used in this validation process because the answers given by pupils were too vague to allow analysis.

Teachers were asked to analyse the answers given by pupils for common trends in answering, especially regarding types of errors, omissions, misconceptions, incorrect science. Each teacher reviewed the same sample (30 responses (scripts) to each of

questions 1, 2, 4, and 5, selected randomly). Only 30 responses were analysed by other teachers because of time constraints. Teachers are busy and I wanted the analysis to be carried out thoroughly. The observations reported by each teacher were added to my own analysis. The observations recorded by all 3 teachers were discussed and common trends were identified. The answers given by some pupils show more than one type of trend as reported here.

These were consolidated (numbers were averaged) and the trends can be reported. It must be noted that some scripts were classified under more than one of the observations. Some scripts were answered in such a way that they are not included in the error trend analysis.

Some common prevalent misconceptions were noted. As this was not a study of misconceptions an in-depth analysis of the prevalence of the misconceptions was not carried out.

Table 6.2: List of types of answers given to Intervention questions

OBSERVATIONS	Question 1	Question 2	Question 4	Question 5
Inadequate knowledge (this refers to the incorrect use of terminology)	21 pupils used incorrect terminology describing why hydrogen atoms bond	12 pupils muddled concepts	Use of specific terminology not required for answer.	Use of specific terminology not required for answer.
Skills inadequate	4 pupils could not draw an Aufbau diagram)	Skills not required to answer this question	Skills not required to answer this question	Skills not required to answer this question
Inadequate understanding (this refers to answers that did not make sense or were grossly incorrect)	7 pupils could not even attempt an explanation	24 pupils could not correctly explain sequence of bonding	20 pupils cannot draw diagrams showing difference between covalent and ionic bonds	25 answers showed that pupils had inadequate understanding
Misconceptions	2 pupils referred to octet structure	4 – “electrons fill spaces in other energy levels”	28 pupils could explain the formation of ions but not the attraction of opposite charges to form the bond	18 stated that atoms expand when heated

Classification of an ionic bond as the formation of ions and not as the attraction between oppositely charged ions has been classified as a misconception here simply because pupils seem to have great difficulty in being able to add this extra step to their mental model.

Initially one of the teachers had “language skills a problem” as one of the observations. Discussion surrounding this resulted in these scripts being classified as “inadequate knowledge”. There was agreement that pupils were not able to use the correct language (terminology) because they had a limited understanding of the terminology not because they were limited in their use of English.

This validation of the qualitative answers from the intervention questions was carried out in order to ascertain whether my classification of the observations were similar to other educators so that I am able to report my observations objectively. Of all the observations made from the intervention questions there are 3 that need to be highlighted.

- a. Pupils showed a slow development of knowledge of terminology and understanding of new terms. Pupils were not able to use these terms if they had a limited understanding of them. Even if they had access to definitions or descriptions of the terms, if the understanding was limited the knowledge was not useful.
- b. Pupils experienced difficulties in formulation of descriptive answers to questions. Descriptive answers usually require application of understanding and synthesis of new answers. If the development of understanding is a slow process then the ability to formulate new answers will also be slow.
- c. Pupils experienced difficulties interpreting “particle diagrams” and relating the nature of the chemical bond to the properties of the substance. The ability to link together the macroscopic and submicroscopic levels of Chemistry

The observation a and c were for me as a teacher unexpected. Learning terminology and being able to draw and interpret diagrams are not the aspects of the learning process that I would have considered to be the most challenging for pupils. I did expect pupils to have difficulties writing descriptive answers as this involves a higher order cognitive skill with analysis and synthesis, based on knowledge and understanding.

6.3.4 QUALITATIVE RESULTS FROM THE CONCEPTUAL TEST TOOL

Data that reflects the level of concept formation was obtained from analysing the types of answers given by pupils when answering free-response questions in the post-test using the Conceptual Test tool. This is not a quantitative treatment of the findings from the Conceptual Test tool but rather observations that were made when the Conceptual Test tool scripts were marked. A random sample of 40 Conceptual Test tool scripts was used to validate these observations. The scripts that were analysed were from run 2 of the process as I felt that these would give more accurate results because any problems with the testing tool had been minimised. I hope that by giving insight into the type of incorrect answers that were given a fuller picture of concept development would be made possible.

The following observations were made from pupils' answers to the free response questions in the Conceptual Test tool (Appendix 6) during the post-test. This was a summative test and pupils had the opportunity to revise their work prior to the test. A summary of the analysis of the free response questions from the Conceptual Test tool (run 2 data) is given below. Only completely correct answers were considered to be correct for this purpose.

Table 6.3: Correct answers (number and percentages) for free response questions in the Post-test for the Test and Control groups in Run 2 *.

Question	Test Group n = 40	Control Group n = 41	Comment
4	25 (63%)	20 (50%)	Pre-knowledge – explanation of the difference between an element and a compound.
5	20 (50%)	18 (44%)	Prior knowledge – explanation of the difference between a physical and a chemical change.
7	23 (57%)	25 (61%)	Prior knowledge – explanation of why a particle diagram represents an element.
13	33 (83%)	16 (39%)	Explanation of why atoms that have unpaired electrons form chemical bonds.
18	21 (53%)	19 (46%)	Explanation of why a covalent bond differs from an ionic bond.
19	25 (63%)	16 (39%)	Explanation of why a polar covalent bond differs from a non-polar covalent bond.
21	19 (50%)	4 (10%)	Explanation of the effect of electronegativity in a chemical bond.
24	23 (57%)	10 (24%)	Explanation of a metallic bond.

*Class average for this test was 76% (Test Group) and 57% (Control Group)

Questions 4, 5, 7, 13, 18, 19, 21, and 24 were the only free response questions used in this analysis as they are the questions that require explanations based on knowledge that pupils should have.

The following observations can be made from the data in Table 6.3:

- a. The free response questions which tested pupil's foundation knowledge necessary for building up an understanding of Chemical bonding are Questions 4, 5 and 7 of the Conceptual Test tool (Appendix 6). These concepts were tested in order to determine whether pupils had the required understanding on which to base the development of their understanding of Chemical bonding. I also wished to see whether this fundamental knowledge improved after pupils had been taught more advanced concepts about chemical bonding. This foundation knowledge included being able to discriminate between elements and compounds as well as between a physical and a chemical change. If one considers that the concepts being tested in these questions have been taught in previous years and reinforced during the teaching of Chemical bonding the score is low, between 44% and 63% (Table 6.3). This can be understood by considering work done by Taber (1998) where he states that "If a learner holds frameworks of understanding that are at odds with accepted knowledge, these alternative frameworks may act as suitable anchors for new knowledge. When the learner makes sense of the presented material in terms of an alternative framework, it will be a different sense from that intended". Pupils do not change their previous knowledge structures but rather warp the new material to fit in with and support their prior incorrect understanding. The resistance of pupils to changing their conceptions has been reported (Chi, Slotta, & de Leeuw, 1994; Coll & Taylor 2001; Birk & Kurtz 1999). Comparable scores were obtained by both test and control groups. Learning from previous years is not retained as well as expected and new teaching does not correct the incorrect understanding of the prior knowledge. This could be as teaching to correct prior misconceptions was not explicitly addressed. Test and control groups both produced low scores on the post-test for these items. The intervention questions appeared to have little effect on improvement of understanding of prior knowledge.

- b. Question 13 related to “Why do atoms bond?” required a descriptive answer. A relatively low score (16 out of 41 scripts) was registered by the pupils in the control group but a much higher score (33 out of 40) is seen in the test group. This could be because pupils could not verbalise their answers, not because they did not know the answer. Free response answers require higher cognitive functioning and more pupils find this difficult. In a similar way question 18, 19, 21 and 24 require descriptive answers with application of knowledge and scores were low for the control group but much better for the test group. The Targeted Intervention Questioning process has caused a greater improvement in understanding as can be seen in the higher score on the free response questions in the test group. In order to answer free response questions pupils must have a sound knowledge of terminology and an understanding of concepts. Pupils in the test group have developed better knowledge.
- c. Pupils find explaining the properties of metals, in this case the ability of metals to conduct electricity to be difficult (question 24). In the control group 24% of pupils were able to answer question 24. However, 57% of pupils in the test group answered this question correctly. The results of the control group correlates with the qualitative analysis of the intervention questions which recorded pupil inability to relate bond type to type of substance (see 1.1 above) and with reports in the literature (Talanteur, 2011; Treagust, Chittleborough, & Mamiala, 2003; Johnstone, 2009). The test group managed these questions far better, again pointing to the effectiveness of the Targeted Intervention Questioning process

To summarise there were 3 main observations from the Conceptual Test tool answers that should be highlighted and that will be discussed in the next chapter:

- a. Pupils had difficulty formulating descriptive answers;
- b. There was poor understanding of foundation knowledge (prior knowledge needed for understanding the next step);
- c. Pupils had difficulty relating the nature of the metallic bond to the properties of metals.

I did expect pupils to experience difficulty formulating descriptive answers because this is a higher order cognitive skill and requires analysis and synthesis. The slow development of foundation knowledge hampers the development of application of knowledge. These findings complement those from the intervention questions.

These findings will be discussed further in Chapter 7.

6.4 QUANTITATIVE DATA

Quantitative data was obtained by analysing pupil answers to the Conceptual Test tool questions. Because this test was used as a pre-test (before teaching) and again as a post-test (after teaching) any change in score can be used to evaluate the teaching that occurred after the pre-test and before the post-test. The answers recorded by pupils on the Conceptual Test tool were scored as correct, incorrect or missing. Missing answers were treated as incorrect answers. The same type of data was obtained from both run 1 and run 2 of the study. This data was analysed in three different ways:

- a. The change in the number of correct responses per question from pre-test to post-test as an indication of group achievement per question.
- b. The change in the percentage score from pre-test to post-test per pupil as an indication of individual achievement.
- c. Determination of Learning Gain as the measure of conceptual development per individual and per group .

As outlined in Chapter 4 an increase in conceptual understanding was measured by calculating learning gain. According to Hake (1998) conceptual gain, referred to as the Hake factor, is calculated as a percentage, or a fraction of 1.

It shows the fraction of potential gain achieved by a student.

$$g = \frac{\text{Post-test score (\%)} - \text{Pre-test score (\%)}}{100 - \text{Pre-test score (\%)}}$$

The conceptual gain (g) compares the actual change in the pupil's score (Post-test score – Pre-test score) to the pupil's maximum possible gain (1 – Pre-test score). This tells us how

much of the possible improvement in score the pupil has actually attained. The actual average percentage gain in score is compared to the maximum possible percentage gain in score. This is referred to as normalization.

The learning gain for pupils in the test group was compared to the learning gain in the control group. The two groups were then compared using a non-paired t-test.

6.4.1 QUANTITATIVE ANALYSIS OF DATA FROM THE CONCEPTUAL TEST TOOL ANALYSED PER QUESTION

The Conceptual Test tool was used to measure the change in conceptual understanding as a result of teaching of the topic. A number of concepts make up the whole topic of chemical bonding at high school level and these different concepts were tested in separate sections in the Conceptual Test tool. By analysing the data per question and per subtopic a richer picture of the learning process was obtained. A summary of the analysis of the data from the testing tool tests is given below. Topics A to G refer to the separate concepts making up the topic Chemical Bonding. This table should be perused along with Table 5.1.

The change in the number of correct answers from pre-test to post-test is recorded per group for the control and the test group. The difference between the change in score for the two groups is compared and recorded in the table. Similarly, the improvement in learning gain for the two groups (test and control) is compared and recorded.

Table 6.4. Data from the Conceptual Test tool analysed per question – change in the number of correct responses and change in Learning Gain per group.

Sub-Topic		Change in the number of correct responses (given as a %) from pre-test to post-test for each set of responses. Values are calculated per group.		Diff in % change between groups	Learning gain from pre-test to post-test for each set of responses. Values are calculated per group.		Diff between groups (Learning Gain) *
		Control	Intervention		Control	Intervention	
A. Foundation knowledge	Run 1	-2	7	9	-0.39	0.01	0.40
	Run 2	12	7	-5	0.21	0.05	-0.16
B. Particle diagrams (Foundation knowledge)	Run 1	1	8	7	0.09	0.36	0.27
	Run 2	15	16	1	0.38	0.40	0.02
C. Electron Configuration	Run 1	5	13	8	0.09	0.14	0.05
	Run 2	45	23	-22	0.58	0.54	-0.04
D. Why do atoms bond?	Run 1	22	12	-10	0.39	0.22	-0.17
	Run 2	45	54	9	0.49	0.86	0.37
E. Distinguishing covalent – ionic bonding	Run 1	33	39	6	0.44	0.51	0.07
	Run 2	42	65	23	0.49	0.77	0.28
F. Distinguishing polar – nonpolar bonds	Run 1	16	47	31.0	0.16	0.47	0.31
	Run 2	23	67	44	0.23	0.67	0.44
G. Metallic bonding	Run 1	20	36	16	0.33	0.57	0.24
	Run 2	30	57	27	0.34	0.64	0.30

*A negative value indicates that the learning gain for the test group was less than for the control group

At first glance it would appear that the results obtained in run 1 and run 2 are different. Closer scrutiny allows one to see that the differences between the groups are greatest for subtopics A to D, which are the sections dealing with prior knowledge. Differences between the two runs were not as marked in the subtopics dealing with new material. It must be noted that the groups of pupils do differ in their abilities from year to year. Between run 1

and 2 the Conceptual Test tool was refined and so the measurements made in run 2 present a clearer picture as they were made with a better tool.

Sub-topics A, B, C and D indicate discrepancies between Run 1 and Run 2. These sub-topics involve concepts that should have been consolidated before the teaching on Chemical bonding started. Sub-topic D requires that pupils have a sound understanding of electron configuration and the implications of full and non-full energy levels. These 4 sub-topics also show, in some instances, decreases in score from pre-test to post-test, indicating that pupils became confused and the mental models that they did have of the sub-topics was no longer as clear in their minds. As a teacher this was an interesting observation as it has implications for teaching in future.

Topics E, F and G show increases in score from pre-test to post-test in all instances recorded here. For all three of these sub-topics pupils had received no exposure to the material prior to the pre-test. So the change in score was mostly from 0 to a positive score. On any test some pupils will try to write down an answer of some sort if he/she thinks they should know the answer. Pupils guess answers. Pre-test scores could be skewed for questions in Topics A to D as a result of this. The learning gain experienced in sections that had been taught before the pre-test was administered was less than the learning gain experienced in the topics taught for the first time after the pre-test. In all the sections that were “new” to pupils the learning gain in the test group (those who answered the intervention questions) was higher than the control group as evident in the data in the last column of the table.

As a teacher this analysis is of value and a great deal of extra information relating to the learning process is obtained through this analysis. Change in % score and normalised learning gain are both reported, to be in line with the data obtained from the t-tests.

Three main observations can be made:

- a. There was a decrease in the score (negative values for the difference between the score on pre- and post-test) or a very low increase in score on some questions after teaching. The sections where this was noted includes those sections of the work that were considered foundation knowledge – previously taught but fundamental to this section of work.

- b. There is a difference in score between groups of pupils. The values obtained for run 1 and run 2 were not similar. The difference between run 1 and 2 is the pupil composition.
- c. There was an increase in score on the post-test (compared to the pre-test) as well as a positive learning gain for new material involving chemical bonding for all groups (run 1 and 2). The increase in score and learning gain was greater in the test group than in the control group.

The Conceptual Test tool was designed to see whether there was significant improvement in pupils concept development due to the Targeted Intervention Questioning process. Sections A, B and C, as outlined in the table above, test fundamental knowledge necessary for understanding chemical bonding. Conflicting results were obtained from these questions which demonstrate the convoluted nature of the learning process. The linking of different concepts is so important in Chemistry and the opportunity to demonstrate to pupils this very fact through the test should not be passed over lightly. In addition it is important for teaching practise to understand that learning new concepts can interfere with existing knowledge structures. However, the nature of the prior knowledge has an important effect on learning of new, related concepts and according to Braathen & Hewson (1988) “Evidence from this investigation suggests that if prior knowledge is situated very much toward the rote end of the rote/meaningful continuum, qualitative (conceptual) changes (meaningful learning) are unlikely to occur.” The results from this study suggest that the prior knowledge was not correctly understood, the concepts were not fully developed with sound mental models and because of this the new learning caused an “unlearning” of the original concepts.

6.4.2 QUANTITATIVE ANALYSIS OF CONCEPTUAL TEST TOOL DATA

The Targeted Intervention Questioning process was repeated and the two testing instances are referred to as Run 1 (2011) and Run2 (2012). Each time there was a control group that did not receive the Intervention Questioning process and a test group that did.

Sample sizes for the two interventions are given in Table 7.

Table 6.5: Sample sizes for Run 1 and 2 of the Targeted Intervention Questioning process.

Pupil Group	Run 1	Run 2
Test Group	32	40
Control Group	33	41
Total number of Pupils	65	81

A. Paired t-test analysis of the change in raw score from pre-test to post-test

A paired t-test analysis of the change in raw score from pre-test to post-test using the Conceptual Test tool was conducted to determine change in pupil total raw score from pre-test to post-test. (Appendix 8).

Table 6.6: Comparison of sample size and mean change in score on paired t-test for test and control groups in Run 1 and Run 2.

	Sample size		Change in Mean Score from pre-to post-test	
	Test	Control	Test	Control
Run 1 2011	33	32	10.9	5.3
Run 2 2012	41	40	17.5	14.2

Data and a summary of the data is given in Appendix 8 and Appendix 9.

The scores for the test group (intervention question group) were compared to the control group (no intervention questions) using a non-paired t-test. A non-paired t-test was used because the pupils in the two groups were different.

Table 6.7: Non-Paired t-test results using change in test score for the control and test groups

Change in score (post – pretest)	Control Group	Test Group	t-test results
Run 1 2011	5.4	10.9	T 0.83, df 63 prob = 0.41
Run 2 2012	14.2	17.6	T 5.0 , df 71 prob < 0.0001

For the 2011 intervention the following can be reported:

The mean score of the test group on the variable “The test group (with intervention process) score higher on the Conceptual Test tool in the post-test” (mean = 10.9, N = 32) is not statistically significantly higher ($p = 0.41$) than the control group on the same variable (mean = 5.3, N = 33) .

It should be noted that the two groups of pupils (Control group and Test group) were not equivalent in the 2011 run of the Intervention process. The Test group score on the pre-test was statistically significantly lower than the Control group. This was not apparent in the 2012 group. This can be seen in Table 6.7 above and in the data presented in Appendix 9.

For the 2012 intervention the following can be reported:

The mean score of the test group on the variable “The test group (with intervention process) score higher on the Conceptual Test tool in the post-test ” (mean = 17.56, N = 41) is statistically significantly higher ($p = 0.0001$) than the control group on the same variable (mean = 14.23, N = 40) .

Because of the differences in the results for Run 1 and Run 2 using the raw scores on the Conceptual Test tool, normalised learning gain was used for comparison. This is a paired t-test that corrects for the differences between groups in pre-test knowledge.

B. Paired t-test analysis of the average learning gain using the Conceptual Testing tool.

The difference between raw scores on a pre-test and a post-test were used for each pupil. Intervention test group and control group (no intervention) were compared (Appendix 10).

Table 6.8: Paired t-test results using average learning gain for the control and test groups.

Learning Gain	Control Group	Test Group	t-test results
Run 1 2011	0.19	0.36	T -3.5 df 63 prob = 0.0009
Run 2 2012	0.41	0.60	T -4.74 df 79 prob < 0.0001

For the 2011 intervention the following can be reported:

The mean score of the test group on the variable “The test group (with intervention process) show a greater learning gain on the Conceptual Test tool between the pre-test and the post-test” (mean = 0.36, N = 32) is statistically significantly higher ($p = 0.0009$) than the control group on the same variable (mean = 0.19, N = 33) .

For the 2012 intervention the following can be reported:

The mean score of the test group on the variable “The test group (with intervention process) show a greater learning gain on the Conceptual Test tool between the pre-test and the post-test” (mean = 0.60, N = 41) is statistically significantly higher ($p < 0.0001$) than the control group on the same variable (mean = 0.41, N = 40) .

The statistically significant greater learning gain in the test group is highly significant. It confirms the fact that the test group demonstrated an increase in learning and conceptual understanding that was superior to that achieved by the control group in both years of implementation. It also confirms that upon refinement the intervention was even more successful in the second year of implementation. It is also important to note that the success of the intervention could not be demonstrated based on raw score performance data alone because of the disparity between the groups in terms of their level of pre-knowledge. However, once this disparity has been corrected for by means of the Hake factor the success of the intervention could be claimed with high confidence.

The analysis and evaluation of the Targeted Intervention Questioning process depended on the performance of the Conceptual Test tool. This was measuring instrument used to collect the data. In order for the data to be reliable the test tool must be also be reliable. In order to demonstrate this reliability a number of tests were performed using the Conceptual Test tool and the results of these tests are reported here as this was only possible after the first run of the Targeted Intervention Questioning process when data for analysis was available. According to action research methodology the results of the first intervention process are used to inform and improve the process before the second run is undertaken. For this reason the results of the analysis of the Conceptual Test tool must be considered as part of the reported results of the study and are discussed here. The results from the second run of the cycle can be used to further improve the testing tool which can be a valuable resource in a classroom in future.

6.5 ANALYSIS of the CONCEPTUAL TEST TOOL

Reliability indicators

A correlation analysis was performed on the data from the testing tool to determine the validity and reliability of the testing tool. The results are as follows:

Table 6.9: Cronbach Coefficient Alpha

Variables - Alpha	Run 1 2011	Run 2 2012
Raw	0.83	0.89
Standardised	0.83	0.89

Changes were made to the Conceptual Test tool between the 2011 and 2012 tests. A description of the modifications and the reasons for this are outlined in Chapter 5 and all versions of the test are available in Appendices 4 - 6.

Rasch analysis of the output data was performed on the 2011 (Run 1) test data and the result of this analysis was that changes were made to the Conceptual Test tool. Results of the Rasch analysis are reported in Chapter 5.

The results of the two runs of the Targeted Intervention Questioning process have been described in this chapter. These results will be discussed in the next chapter and conclusions will be drawn from the results. In line with action research methodology the results of the study are to be used to improve classroom practice and this aspect of the study will be discussed.

CHAPTER 7

DISCUSSION of RESULTS and CONCLUSION

The following research questions were posed in Chapter 1:

- Do focused intervention questions followed by rapid feedback to pupils foster sound concept formation in chemical bonding?
- Is this new teaching method more effective than traditional methods?

I will show how I have answered the questions in this study.

The results of this study, presented in the previous chapter, indicate that there is a statistically significant improvement in pupils' conceptual gain when the Intervention questions were used compared to pupils not using the intervention questions. A greater learning gain between the pre-test and the post-test for pupils who did go through the Intervention Question process does indicate that sound concept formation occurs.

The study involved action research and two cycles of the Planning – Action – Analysis – Evaluation were completed allowing refinement of methods and tools to ensure valid results. The complexities and subtleties of the learning situation were captured by a study of a relatively small sample resulting in the collection of rich data. Overall a very detailed and objective picture of the learning process that occurs when chemical bonding is taught.

In this discussion of the results I will consider five separate aspects of the findings of the study:

- The contribution of action research methodology to answering the research questions.
- The development of an understanding of how Grade 10 pupils build up mental models of the concepts related to chemical bonding during the learning process.
- The effectiveness of the intervention questioning and feedback process in fostering sound concept formation.
- A comparison of the intervention questioning and feedback process to traditional teaching methods.
- What are the implications for teaching in future?

7.1 THE CONTRIBUTION OF ACTION RESEARCH METHODOLOGY

This project is an action research project and the discussion will describe how the planning – action – analysis and evaluation – planning – action – analysis and evaluation process was followed.

I began this study after many years observing pupils progressing through their Physical Science curriculum, and especially the section on chemical bonding, and often exiting with a poor understanding of what they had been taught. As a teacher I had to ask myself “where do we go wrong?”

As stated earlier, for the purpose of this study, learning is considered from the constructivist perspective and is measured by the effectiveness of concept development. According to this premise teachers should, therefore, strive to facilitate concept development by giving pupils opportunities to construct their own knowledge, to build up mental models and develop sound concepts.

Teachers, working on intuition do revise and refine their teaching practice continually. As an action research study this refining process was done systematically, by gathering and interpreting data to investigate the effectiveness of the refined teaching practice.

Experience has also shown me that teachers are usually very busy and carry heavy workloads limiting their enthusiasm and opportunity for improving their teaching practice. This study has led to the development of a “teaching method” that can be used by other teachers to improve their teaching practice. I have shown that this novel teaching method is transferable, that it can fit in with the teaching styles of other teachers. The section of the syllabus that I used as the topic for the study was chemical bonding. The method can be applied to other topics in future. Suitable intervention questions can be developed, keeping the process the same.

The effectiveness of the teaching method was evaluated in terms of its effectiveness in developing concept formation. The intervention questions were designed with this in mind. The testing process evaluated the degree of concept formation the intervention questions fostered.

The action research methodology was followed and two cycles of the following steps were carried out:

- Planning
- Action
- Data evaluation and modification

After the first cycle of data gathering the whole intervention questioning process and the Conceptual Test tool were modified and improved. By planning the intervention process and then testing and evaluating it I was not only able to measure the effectiveness of the procedure but I was also able to observe answers the pupils gave to questions that tested conceptual understanding. Analysing the answers given by pupils from the viewpoint of a researcher and not as their teacher provided me with a very different picture of how learning occurs and what pupils find difficult at each step of the learning process. As a teacher to view the results of the testing process from a different perspective, that of a researcher, was liberating as I was looking for the “why” and not just wondering why the pupils were not achieving as expected.

During the development of the intervention questions I started with the experience I have gained teaching this topic for a number of years. The intervention questions were refined based on the extra understanding I gained from the literature review. Initially when I started developing the questions I was asking “what questions should pupils be able to answer” and ended up asking “what questions will best link prior learning, consolidate new material and promote understanding of concepts”. My understanding of conceptual change/development changed and this allowed subtle changes in the questioning so that the questions reinforced conceptual change.

The refinement of the Intervention Questioning Process came about as my understanding of how pupils learn developed. Despite changes in education which emphasise outcome learning, promote the use of technology and encourage pupil participation when pupils have to come to grips with complex concepts as occurs in Chemistry, we as teachers still have to master the technique of guiding pupils through the process of developing the mental models associated with chemical bonding that lead to solid concept formation.

Thus, following on from the first run of the Intervention Questioning Process, I became aware that pupils very often did not have a realistic idea of what they did know and understand or what they should know or focus on to develop conceptually. For this reason I altered most of the intervention questions to include “scaffolding” questions or information to direct pupils thought processes, as

shown in the examples below. The complexity of the learning process and of conceptual development was highlighted for me during my analysis of the pupil responses.

Further changes to the intervention questions were a result of the development of my understanding of cognitive load theory. As a result I added scaffolding to many of the questions in order to limit the load on the working memory. As an example the question below was originally used:

QUESTION 3

- 3.1 Hydrogen atoms have an electronegativity value of 2.1. Chlorine atoms have an electronegativity value of 3,5. Explain how these values affect the type of chemical bond that forms between a hydrogen atom and a chlorine atom. You will have to explain what “electronegativity” means. Please use diagrams in your answer.

In the first run of the process Question 3, presented after teaching of electronegativity and its effect on the sharing of electrons, was used as shown above. When I realised that there were too many concepts included in this question that needed to be unpacked before the question could be answered I amended the question to read as follows:

QUESTION 3

Hydrogen atoms have an electronegativity value of 2.1. Chlorine atoms have an electronegativity value of 3,5.

- 3.1 What is meant by the term **electronegativity**?
- 3.2 How do electronegativity values affect the sharing of electrons in a bond?
- 3.3 Explain how the electronegativity values of hydrogen and chlorine affect **the type** of chemical bond that forms between a hydrogen atom and a chlorine atom.

In a similar way an analysis of the answers to the Conceptual Test tool revealed questions that were ambiguous, that did not provide answers or information that was relevant to the study. These questions were modified for the second run of the testing process. Not only did I gain insight that enabled me to make changes to the intervention questions but also to change the questioning approach I use when routinely testing pupils.

The most important lesson I learned from the analysis of responses from run 1 was that my understanding of questions posed to pupils was often very different from their understanding of the questions. As a teacher I was aware of this but looking at the same problem as a researcher presented a bigger, more objective picture that is very valuable to me as a teacher.

The initial design of the Conceptual Test tool required that I look at testing as a researcher not as a teacher. I had to focus on the essential concepts, how to elicit answers that tested pupil understanding of concepts. Usually teachers set tests asking – what should they know, what should they be able to understand, are there questions testing knowledge, comprehension, analysis and synthesis of knowledge. This is quite different from designing a testing tool where only understanding of concepts is tested.

The development of this testing tool ensured that I, as teacher, work through the material and separate out the most important concepts in order to include these in the Conceptual Test tool. This required that I was very sure of my own understanding of the topic. As an experienced teacher, well trained in the subject of chemistry, I found that there were some concepts that I did not have sufficiently clear mental models to ensure effective teaching.

The second run of the Intervention Questioning Process reinforced the findings of the first run. In addition the qualitative analysis of the pupil responses allowed me to make more valuable inferences regarding the depth of understanding that pupils had because I had confidence in the design of the intervention questions and the Conceptual Test tool.

The following qualitative results reported in the previous chapter arise from the analysis and evaluation of results from the second run of the process. Their implications for teaching and learning are discussed below.

- a. Pupils showed a slow development of knowledge of terminology and understanding of new terms. Pupils were not able to use these terms if they had a limited understanding of them. Even if they had access to definitions or descriptions of the terms, if the understanding was limited the knowledge was not useful. This can be attributed to pupils having to assimilate this new knowledge into their existing knowledge structures. This requires re-organisation of existing structures and takes time (Novak, 1984). Teachers need to be aware of this and

should spend a greater amount of time helping pupils come to terms with new knowledge. As a teacher I very often leave the “learning” up to pupils. Teachers give guidance through the new material, structure consolidation, help pupils to know how to go about answering questions. We do not help them with the learning and through developing an understanding of the complexity of the learning process, I now know that this is where teachers should put their energies and emphasis.

- b. Pupils experienced difficulties in formulation of descriptive answers to questions. Descriptive answers usually require application of understanding and synthesis of new answers. If the development of understanding is a slow process then the ability to formulate new answers will also be slow. Greater structuring and scaffolding of questions is needed to ensure that pupils do get to a place where they can write descriptive answers.
- c. Pupils experienced difficulties interpreting “particle diagrams” and relating the nature of the chemical bond to the properties of the substance (Chittleborough & Treagust, 2007). The ability to link together the macroscopic and sub microscopic levels of chemistry at Grade 10 level is limited and this is a cause for concern as teachers are largely unaware of this problem. Teachers assume that pupils can “see” how particle diagrams fit with the observable properties of substances. This, according to the findings of this study, is far from the truth.

7.2 THE DEVELOPMENT OF AN UNDERSTANDING OF HOW GRADE 10 PUPILS BUILD UP MENTAL MODELS OF THE CONCEPTS RELATED TO CHEMICAL BONDING DURING THE LEARNING PROCESS.

Observations from the intervention questions seem to indicate that pupils initially learn by rote – or rather in a superficial way (observation a above). This early, superficial learning develops into more meaningful learning later after repeated exposure to the learning material. Pupils take time to get to understand new terminology and until they have an understanding of the new words have difficulty using these new words and terms. Initially pupils do not have a mental model associated with these terms. Only once the terms become familiar and pupils understand the associated concepts can one

really say that they have grasped the meaning of the new terms. Once this understanding is consolidated they pupils have to see the links between the concepts, see the bigger picture.

Contrary to this I had always thought that once pupils had been taught a concept – for example in a single lesson the concept of partially filled orbitals with unpaired valence electrons being unstable and by sharing these electrons with another atom a full valence shell was obtained which was stable – that pupils understood. By going through their notes and answering consolidation questions their understanding would develop further – no problem!! If they could not answer questions in a test it was because they had not learned. Going through the intervention question answers I realised that this was not true. At the end of the “teaching” most pupils do NOT have a grasp of what has been taught. When new terminology is introduced or new concepts are linked to assumed prior knowledge pupils might “understand” but this understanding is so superficial that they are not able to retain or use this understanding to develop sound, new mental models. The importance of ensuring the development of sound mental models during class time is evident from this finding. Pupils at Grade 10 level who have incomplete mental models will find it difficult to remedy this on their own. This also accounts for pupils not retaining what was learned and not being able to transfer and apply their knowledge.

Chemistry is a language and pupils have to constantly learn new terminology. As a teacher I always assumed that learning new words was the easier part of the learning process. Reflection on pupils’ answers to the intervention questions has given me insight into the need for pupils to develop an understanding of the concept before they are able to use the terminology correctly. Care should be taken to ensure that pupils appropriate necessary Chemistry vocabulary. The intervention questions give pupils the opportunity to use the new terms and develop their understanding before being asked to use their knowledge. The slow development of the language used to describe the topic will hamper pupil’s ability to answer descriptive questions.

What I now understand is that pupils receive “teaching” in the classroom and hear new terminology. These new words, explanations, descriptions have to be assimilated and new mental models developed before real concept formation can occur. Only then can the pupil use and apply his/her new knowledge. The new words have to be assimilated, built in to mental models before pupils can learn and make use of the words.

So often I have despaired when pupils, after good teaching, still are not able to use their knowledge. I now understand that this is because they have not been able to build up good mental models and so have not been able to develop concepts.

Chemical bonding is a theoretical topic and is usually approached very much from the theoretical aspect. There is little relevant practical work that pupils can carry out that helps them bridge the divide between the theory of matter and the properties of matter. The following intervention question reveals this:

Look at the diagrams below showing different types of solids.

1. Link each of the substances given below to one of the diagrams.
2. Draw a line from the name to the diagram.
3. Give a reason for your answer.

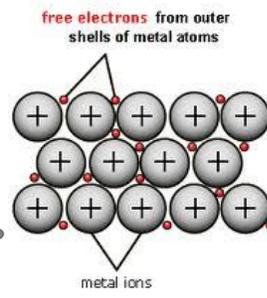
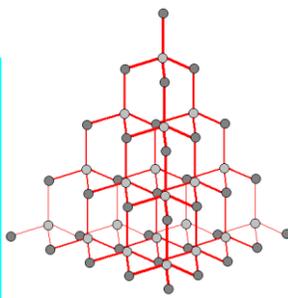
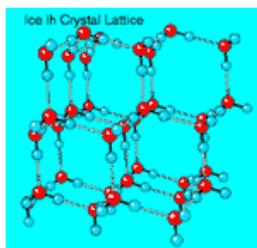
A. Silver

B. Potassium fluoride

C. Ice

D. Diamond

B.



Pupils found this question very difficult. Visualising the particles that make up different types of solids is a higher order thinking skill. I was aware of this to an extent but did not realise fully how difficult pupils find this. The pupils who participated in this study have been taught about the particle model of matter and have spent a great deal of time drawing “particle diagrams”. They are largely able to describe microscopic characteristics of substances but linking them to the macroscopic properties of a substance is a difficult process which must be addressed in order for teaching of this topic to be effective.

Reports in the literature refer to this “while novice learners mainly operate at the macro level and struggle to meaningfully relate the other levels. Unfortunately, most chemistry teaching is focused on the sub micro–symbolic pair of the triplet and rarely helps students to build bridges to comfortably move between the three levels” (Talanteur, 2011)

If this is the case then the mental models built up by pupils will be lacking in this fundamental aspect of Chemistry, namely the picture of how particle diagrams, models of the sub-microscopic, relate to what they can see and feel.

Chemical bonding is a set of abstract concepts and, as mentioned before, there are few ways of concretely introducing the pupils to these concepts. Teachers need some way to bridge this divide for pupils operating in the concrete operations phase. Piaget referred to a process of self-regulation where a pupil searches for patterns and relationships so as to progress to the next phase of operation. During self-regulation pupils learn to intentionally and deliberately direct their thinking and problem solving activities (Fox & Riconscente, 2008).

All of the above have implications for teaching and these findings can be used to improve teaching in future.

7.3 THE EFFECTIVENESS OF THE INTERVENTION QUESTIONING AND FEEDBACK PROCESS IN FOSTERING SOUND CONCEPT FORMATION.

Why did the intervention questioning process work? There are a number of reasons and the following will be discussed below:

- Development of mental models.
- Chunking of information.
- Reinforcement by the feedback.
- Metacognition.
- Guidance regarding what is knowledge is required.

The conceptual framework that I started with is shown in figure 7.1 below.

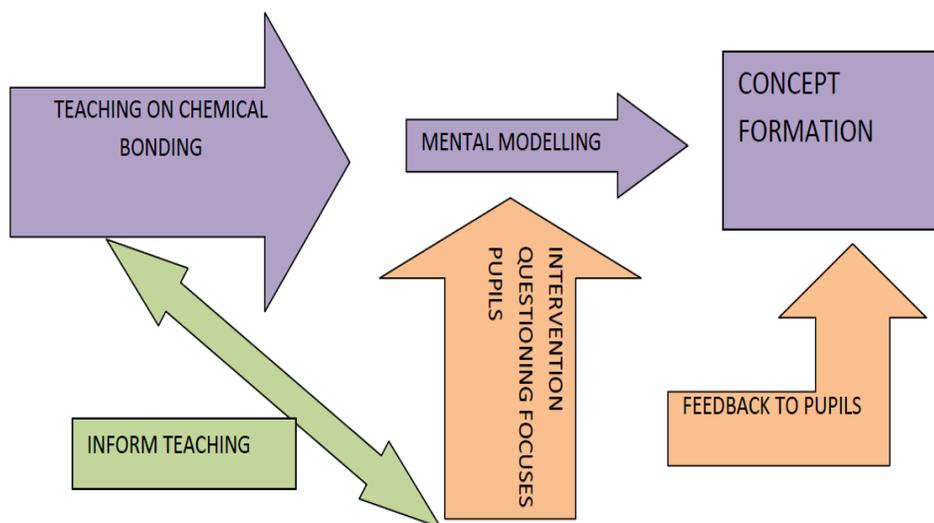


Figure 7.1 Conceptual Framework

As discussed in the previous section the Targeted Intervention Questioning process fosters the development of mental models. The questions help pupils construct their own knowledge by giving them the stepping stones to the development of sound concepts. The stepping stones include pointers towards what the correct science is, an opportunity to challenge their existing mental models, an understanding of how they are thinking and how their learning techniques work and do not work. The qualitative analysis of the answers given by pupils to the intervention questions (Table 6.4 pg. 86) reveals a very poor ability to answer the questions. It must be emphasised that the intervention questions are not given to pupils to see how well they can score. They provide pupils with an opportunity to use their learning material and attempt an answer. The feedback then points them to how far they are from the “answer” and gives them pointers as to how to get there. This is the task oriented feedback referred to by Hattie & Timperley (2007)

A reflection on the very poor scores that pupils obtained on the intervention questions requires that one asks “why bother?” However, the better performance of the pupils in the test group when considering improvement in score, learning gain and also ability to answer free response questions (Table 6.3, pg 81; Table 6.7, Pg 89; Table 6.8, pg. 90) must surely indicate that there is value in the Targeted Intervention Questioning process.

Klausmeier (1992) discusses focused concept instruction where attention is focused on what is to be learned and recall is required early in the instructional process and comments on the power of this method to develop concepts. The Targeted Intervention Questioning process shares similar attributes. Attention is focused on what is to be learned by the intervention questions and the feedback and pupils are asked to recall (with the help of their learning material) what has been introduced, discussed and explored in class early in the teaching of the topic. This process is repeated each time pupils are asked to answer an intervention question.

I think that “chunking” of information is one of the reasons why the intervention questioning process is successful. The questions break the topic into manageable chunks which pupils can process and make sense of. A report by Reid (2008) states “The key thing to note is that working memory causes a problem when too much has to be thought about at the same time. By careful sequencing of ideas, by reminder and illustration, by a stepwise approach, the working memory is not faced with too much at the same time. It is predicted that learning will increase.” The intervention questions sequence ideas for the pupils and reduce the amount of information that the pupil has to process at one time. For example by breaking the one question down into three separate questions (intervention question 3) the three important concepts – *electronegativity*, *electron sharing* and *type of chemical bond* (*viz* polar or non-polar covalent) are separated so that pupils can process them separately but still have to see the links between the three.

In addition, the intervention questions presented to pupils at certain stages during the teaching of the topic serve to compartmentalise the different sections of the topic making each more manageable.

The importance of the feedback must also be emphasized. Unless pupils can see where and why they have made mistakes there can be no learning from the questions. Pupils were initially given a mark for their answers but then I realised that there was little value in this and only gave pupils comments that told them what they did correctly, what they had left out, how they could correct their thinking. Copies of pupil answers with feedback are available in Appendix 6.

Feedback serves to build up pupil confidence during the initial process of mastery of concepts. In Science, considered to be a difficult subject, pupils are often unsure of their ability to actually master the subject. My experience has shown me that lack of confidence is one the biggest stumbling blocks to achievement in Science. By pointing out to pupils what they can do and indicating how close they

are to the correct answer, the feedback boosts confidence and gives pupils small interim goals to strive towards. Pupils can develop a realistic picture of their own abilities as well as come to understand the thinking skills demanded of them in learning this section of Science.

The feedback told the pupils they could do this and that they could not do that and gave them pointers as to what they should do to master the material. Through this pupils become aware of what is right and wrong with their thinking thus affecting their metacognition. According to Rickey (2000) “Metacognition is generally thought to be a key to deeper, more durable, and more transferable learning.” In the learning of chemistry it is important for the understanding of ideas and in problem solving. The thought process that moves from “knowing material” to “what are the implications of this knowledge” to “how do I use this knowledge” does not always develop easily and naturally. Metacognitive processes have to be consciously developed in 15 – 16 year old pupils. The intervention questions, along with the feedback, were used to achieve the metaconceptual development.

Answering questions in isolation is purposeless and so feedback must be given to the pupils. In order for feedback to be effective it should be given as soon as possible and it should point out to pupils what they have done that is correct and incorrect and then point them to ways in which they can improve their performance. Because teaching goes on day after day pupils should receive this feedback before the teacher moves on to the next bit of work. In this way the layers and layers of sub-topic or mini-concepts are built up with pupils understanding each layer, developing a whole picture with no gaps and so ending up with a solid mental model of the topic.

My experience has shown me that pupils do not like engaging with their mistakes and errors. Pupils need to confront their lack of understanding in order for conceptual change to occur. Studies have shown that “students will be able to learn science concepts and principles only if they are aware about the shift of their initial metaconceptual views towards the metaconceptual perspectives of science knowledge” (Duit & Treagust, 2010) Viewing the correct answers to the intervention questions along with their answers helps pupils shape and reshape their metaconceptual views so as to develop sound mental models and develop conceptually. It is therefore important that part of the intervention questioning process also involves a time where pupils are encouraged to actively engage with the questions, their answers and the teacher feedback. The review of the feedback is an

important part of the Intervention Questioning Process and the whole process can be improved by placing greater emphasis on this metaconceptual development aspect.

Very often pupils are unaware of how to approach learning Chemistry. They do not fully understand the outcomes expected of them. In chemistry the facts are to be learned and understood but have to be integrated and the information applied to situations, often unknown. Pupils have to learn the “rules” of bonding and then apply these in many different situations. The intervention questions are able to give pupils an idea of how to structure their thinking on the topic so as to be able to see the links, develop a whole picture of the topic and so be able to apply this knowledge.

It is also important that pupils realise the value of the questions and of the feedback and use the questions, along with the feedback that points to the correct answers, when learning for subsequent tests and exams. The questions serve a formative function when used in class with teacher feedback. The questions can also be used summatively by pupils when preparing for tests and examinations.

7.4 A COMPARISON OF THE INTERVENTION QUESTIONING AND FEEDBACK PROCESS TO TRADITIONAL TEACHING METHODS.

The results of the evaluation of this method show that there is a statistically significant improvement in pupils score on the Conceptual Test tool when they use the intervention questions during the teaching phase.

Three different teachers in the same school taught in the way they normally do but used the intervention questioning process as an additional teaching strategy. All three have different by teaching styles – one uses a chalk and talk approach, another a “discovery oriented and pupil centred guided by the teacher” approach and the third a “structured talk – consolidation questioning – talk combination”.

The results seem to indicate that the teaching style of the teacher does not determine the effectiveness of the method and that using the intervention questioning process still does promote conceptual development. The two classes making up the test group were considered as a group and the results do not indicate whether there was a difference between the two classes. and whether one

teacher. The statistically significant learning gain in the test group is too great to be attributed to the teaching of one of the teachers. It is therefore attributed to the method used. It must be noted that I was the teacher who gave all the feedback commenting on the answers given to the intervention questions. Feedback was comment on the correctness of the science. Similar comment would be given by any teacher.

The statistical analysis of score and learning gain using a pre-test and post-test scenario indicated that there is a statistically significant difference between the test and control groups with the test groups (those that received the Targeted Intervention Questioning process) scoring higher on the Conceptual Test tool. It must be noted that this study had the characteristics of a case study as a small sample was used but as with a case study, the complexities and subtleties of this particular situation are highlighted. Table 6.4 shows an analysis of the gain in score and learning gain between pre- and post-test for run 1 and run 2. There appear to be inconsistencies and anomalies in this data but, considering the individual characteristics of the learners in each group, the precise positioning of the teaching in the normal day to day activity of a school these point to the complexity of a study of the learning process taking place in school. Generalisations can still be made – overall the test group did perform better and did experience greater conceptual development, but note should be taken of the complexities of a classroom.

Conventional teaching methods rely on presenting pupils with information, assuming understanding and learning occur, consolidation of what has been taught, followed by summative testing. Teaching does not traditionally consider pupil prior knowledge, the development of mental models and the concept formation.

According to the literature “Thus, when rudimentary student ideas interact with teacher demonstrations; scientific language, laws, and theories; and the students’ own experiences, students will try to reconcile their mental models (often referred to as conceptions or mental models by many investigators) and ideas with the accepted scientific concepts. The outcome of this reconciliation can result in the science concept being distorted into an alternative conception”(Harrison & Treagust, 1996).

An article by Hennessey (1999) states: “Even in the best constructivist learning environment metacognition does not simply happen. It must be explicitly promoted.” Here the Targeted

Intervention Questioning process provides the conceptual models and experiences for pupils to measure their own thinking thus promoting metaconceptual thinking.

So, why is this method better?

It is better because it adds an extra dimension to classroom practice. A teacher can be comfortable teaching in the way that he/she is comfortable with and can use the Targeted Intervention Questioning process to enhance the learning experience in a way that has been proved to be sound and which also has its origin in theory. It has to be emphasised that the structuring of the questions is critical.

7.5 WHAT ARE THE IMPLICATIONS FOR TEACHING? ACTION RESEARCH

Construction of the concept map that outlines the concepts to be taught was the most valuable part of the process for me as a teacher. Before I started this project I felt that I had a good understanding of Chemistry and I knew and understood all the concepts that I was teaching. However, the construction of concept map, working out and sequencing all the interlinked concepts was invaluable in deepening my understanding of the topic and in allowing me to see what difficulties pupils could encounter as they constructed their own personalised view of chemical bonding. It allowed me to see better ways and sequences in which to present material.

I shared the concept map with colleagues who were to use the intervention questions in their classes as part of this study. Reading a concept map constructed by another person was not at all effective in changing teaching practice or in developing teacher understanding. The process of constructing the concept map is the valuable part of the exercise, not merely reading an already constructed map. Concept mapping is difficult, even for adults, but should be encouraged amongst teachers as this deepens insight into a topic and reveals the difficulties pupils will most likely experience.

Following on from my experience with concept mapping, I have attempted to use concept mapping as a tool in the classroom for pupils to consolidate their knowledge of a topic. Pupils resist engaging in concept mapping. It is a difficult process and many pupils do not understand hierarchical structures, organisation of information and the need to organise information. Teaching pupils to gain benefit from concept mapping is the difficult part. Once pupils realise the power of concept mapping as a learning method and tool they are willing to make use of the methodology.

Following on from the difficulties encountered in using concept mapping the use of the intervention questions to lead pupils through the structure and interrelatedness of the topic of chemical bonding is a valuable tool for developing understanding. The questions can be used as a structure that pupils can build their own concepts on.

During this study I was the teacher who reviewed and gave feedback on pupils' answers to the intervention questions for all teachers teaching a "test" class. The review of pupil answers led to discussions on what was taught and how it was taught. This became a valuable tool for teacher mentoring and transfer of methodology. It also allowed me to quickly ascertain any conceptual errors that were being taught. Teachers can sometimes pass on conceptual errors they themselves have but more commonly, I think, the way in which material is relayed to pupils leads to the formation of conceptual errors.

Overall, I think that the Intervention Questioning process along with the use of the Conceptual Test tool can be a valuable way in which Science teachers at school level can monitor each other and together improve their subject knowledge and understanding of concepts.

This Conceptual Test can be used in future as a summative test once teaching on chemical bonding has been completed. Test results will allow comparison of successive groups of pupils. This test can be used to measure pupil readiness when starting to teach the section on intermolecular forces in Grade 11 as knowledge of chemical bonding is a prerequisite. I also used the test (not under test conditions but as a discussion document) to help other teachers refine and consolidate their own understanding of the topic.

The Conceptual Test tool includes a number of questions that probe pupil understanding of the prior knowledge or concepts that underlie the concepts that make up chemical bonding. These questions can be used on their own to gauge pupil readiness for the teaching of chemical bonding before teaching begins. Now that I understand the process of conceptual development better I realize that the most important aspect of teaching Chemistry is to ensure that the precepts pupils have are sound and based on good scientific understanding.

A problem encountered in schools currently is that pupils attend endless extra lessons in order to achieve well in Science. The need for extra lessons points to the fact that pupils are not reaching the

required level of understanding or learning during class time. Many times teachers will get to the end of a section only to find that somewhere during the teaching process they have “lost” the pupils. Class time is limited, pupils are pressured, there is an emphasis on results and not on sound understanding, pupils expect instant gratification of needs. All these factors mean that a very different way of teaching is required for current pupils. An alternative to the traditional “teacher talk, pupil homework, summative test” approach is needed. This Targeted Intervention Questioning process, along with the feedback could help solve this problem.

An analysis of results has repeatedly shown that pupils take longer than expected to master new terminology. Teaching methodologies should be altered to take this in to account. By putting in the effort to ensure that solid foundations, linked to prior knowledge, are built, pupils will have a better chance of being able to write descriptive answers and apply their knowledge. This is the mental modelling described in the literature (Harrison & Treagust, 1996) and is necessary for concept development to occur.

Pupil inability to link the submicroscopic properties of matter to the macroscopic, two aspects of the Chemistry Triplet as reported (Hilton & Nichols, 2011) has been highlighted in this study. Teachers should take this into account and ensure that a great deal of focus is put on methods that link these two aspects of the property of matter.

The implications for teaching outlined above mirror what is reported in the literature regarding what is needed in order to teach for conceptual change:

“- know the phenomena, the methods, and the concepts, principles, and theories that constitute the science they are teaching;

- know what conceptions their students hold about the units to be taught, and the extent to which they are scientifically acceptable;

- be aware of the role played by students’ existing knowledge in understanding new material;

- be convinced of the need to use conceptual change teaching strategies particularly when students’ existing conceptions conflict with those being taught; and

- be able to plan and perform teaching actions that give effect to these strategies.” (Hewson, 1992) (p 12)

7.6 RESEARCH LIMITATIONS

This study was carried out in the setting of the school where I teach – a private, boys only, relatively small school. Consequently, it can be argued that the result of the study cannot be generalised to the South African population as a whole.

The study has, however, shown that the method developed and tested is effective in fostering good concept development which is what every science teacher strives for. What was tested was a method, a framework that can be developed and further improved depending on circumstance. For this reason it is more suited for generalisation than it appears to be.

As this study involved action research the criticism aimed at action research in general – namely the robustness of the methods (Bodner et al 2001) can be applied here. I have tried to eliminate this by developing a stringent testing tool (the Conceptual Test tool) and by collecting quantitative data as well as qualitative data.

Personal bias can always be considered a problem in action research. However, as this was an evaluation of a method of teaching the topic is not an opinion laden subject of study and the effect of personal bias will be minimized.

The small sample gave this study some of the characteristics of a case study and as such the results can be considered to not be generalizable unless others see the applicability of the results (Cohen et al 2007). The study evaluated a method that should be of interest to other science teachers as the method serves to improve science teaching at a time when this is much needed in our country.

7.7 AREAS FOR FUTURE RESEARCH

Arising from this study a number of questions that require further research can be asked.

- How can more effective linking to prior knowledge be achieved?
- How can teaching be modified to improve prior knowledge during teaching of new content and to prevent muddling of prior knowledge even further?

- How can teachers of the chemistry improve pupil understanding of the links between the macroscopic, sub-microscopic and representational aspects of chemistry?

7.8 CONCLUSION

I began this study as I wanted to evaluate a different method of teaching the section on Chemical bonding to Grade 10 pupils. Over the years teaching this section has led me to realize that it is a difficult section for pupils but up until now I have not really found a way of making the material accessible to pupils so that the majority of them come out with a well-developed mental model of the concepts. Well-developed mental models mean that there has been sound concept formation. If the concepts developed are sound then pupils will retain this knowledge and will be able to apply their knowledge in other situations. To me as a teacher the ultimate goal in teaching is to have pupils remember their work so well that it is “part of them” and so be able to use this knowledge to solve problems.

Discussions with pupils have led me to realize that there are “gaps” in pupils’ understanding of the topic. The teacher paints the picture of the concept while teaching but somewhere during this process pupils miss parts of the whole picture. After teaching on a topic is completed and pupils ask for extra help to master the topic they will say things like “I did not know that” or “Where did that come from” or “I must have been absent when you taught that”. Despite being in the classroom, concentrating and applying themselves to learning pupils miss things. As a result the big picture is lacking in detail and pupil understanding does not develop fully.

As I was investigating teaching as it was happening and as the project was designed with improvement of teaching in mind action research was used as a research methodology. This methodological approach was chosen as it suits my situation, in a school, researching my teaching methods. I have made use of the aspects of action research listed in McNiff and Whitehead (2010). Action research differs from other types of research by being based in practice, especially teaching practice, in this instance. I strove to enhance understanding of teaching practise and the effectiveness of this practice. This study has not been just about teaching practice but rather about the thorough research of teaching practice so as to revise and refine it with the aim of improving our understanding of how pupils learn and in so doing also improve pupil learning.

The statistical results and the analysis have pointed to a teaching method that promotes conceptual development and add value to traditional methods of teaching. Reasons cited in the literature for improved concept learning and teaching have been addressed and encapsulated in the Intervention Questioning process resulting in a method that can be used by any teacher to improve concept development.

Over and over the complex nature of the learning process has been made evident in this study. For me as a teacher this has been the most exciting finding. It has helped me understand why pupils sometimes (very often?) do not understand chemistry. It gives me reason to keep on striving to improve the teaching of this subject. It is not the inability of pupils to understand chemistry that is the problem, it is rather the teachers' inability to understand how learning is happening that hampers their progress.

CHAPTER 7

DISCUSSION of RESULTS and CONCLUSION

The following research questions were posed in Chapter 1:

- Do focused intervention questions followed by rapid feedback to pupils foster sound concept formation in chemical bonding?
- Is this new teaching method more effective than traditional methods?

I will show how I have answered the questions in this study.

The results of this study, presented in the previous chapter, indicate that there is a statistically significant improvement in pupils' conceptual gain when the Intervention questions were used compared to pupils not using the intervention questions. A greater learning gain between the pre-test and the post-test for pupils who did go through the Intervention Question process does indicate that sound concept formation occurs.

The study involved action research and two cycles of the Planning – Action – Analysis – Evaluation were completed allowing refinement of methods and tools to ensure valid results. The complexities and subtleties of the learning situation were captured by a study of a relatively small sample resulting in the collection of rich data. Overall a very detailed and objective picture of the learning process that occurs when chemical bonding is taught.

In this discussion of the results I will consider five separate aspects of the findings of the study:

- The contribution of action research methodology to answering the research questions.
- The development of an understanding of how Grade 10 pupils build up mental models of the concepts related to chemical bonding during the learning process.
- The effectiveness of the intervention questioning and feedback process in fostering sound concept formation.
- A comparison of the intervention questioning and feedback process to traditional teaching methods.
- What are the implications for teaching in future?

7.1 THE CONTRIBUTION OF ACTION RESEARCH METHODOLOGY

This project is an action research project and the discussion will describe how the planning – action – analysis and evaluation – planning – action – analysis and evaluation process was followed.

I began this study after many years observing pupils progressing through their Physical Science curriculum, and especially the section on chemical bonding, and often exiting with a poor understanding of what they had been taught. As a teacher I had to ask myself “where do we go wrong?”

As stated earlier, for the purpose of this study, learning is considered from the constructivist perspective and is measured by the effectiveness of concept development. According to this premise teachers should, therefore, strive to facilitate concept development by giving pupils opportunities to construct their own knowledge, to build up mental models and develop sound concepts.

Teachers, working on intuition do revise and refine their teaching practice continually. As an action research study this refining process was done systematically, by gathering and interpreting data to investigate the effectiveness of the refined teaching practice.

Experience has also shown me that teachers are usually very busy and carry heavy workloads limiting their enthusiasm and opportunity for improving their teaching practice. This study has led to the development of a “teaching method” that can be used by other teachers to improve their teaching practice. I have shown that this novel teaching method is transferable, that it can fit in with the teaching styles of other teachers. The section of the syllabus that I used as the topic for the study was chemical bonding. The method can be applied to other topics in future. Suitable intervention questions can be developed, keeping the process the same.

The effectiveness of the teaching method was evaluated in terms of its effectiveness in developing concept formation. The intervention questions were designed with this in mind. The testing process evaluated the degree of concept formation the intervention questions fostered.

The action research methodology was followed and two cycles of the following steps were carried out:

- Planning
- Action
- Data evaluation and modification

After the first cycle of data gathering the whole intervention questioning process and the Conceptual Test tool were modified and improved. By planning the intervention process and then testing and evaluating it I was not only able to measure the effectiveness of the procedure but I was also able to observe answers the pupils gave to questions that tested conceptual understanding. Analysing the answers given by pupils from the viewpoint of a researcher and not as their teacher provided me with a very different picture of how learning occurs and what pupils find difficult at each step of the learning process. As a teacher to view the results of the testing process from a different perspective, that of a researcher, was liberating as I was looking for the “why” and not just wondering why the pupils were not achieving as expected.

During the development of the intervention questions I started with the experience I have gained teaching this topic for a number of years. The intervention questions were refined based on the extra understanding I gained from the literature review. Initially when I started developing the questions I was asking “what questions should pupils be able to answer” and ended up asking “what questions will best link prior learning, consolidate new material and promote understanding of concepts”. My understanding of conceptual change/development changed and this allowed subtle changes in the questioning so that the questions reinforced conceptual change.

The refinement of the Intervention Questioning Process came about as my understanding of how pupils learn developed. Despite changes in education which emphasise outcome learning, promote the use of technology and encourage pupil participation when pupils have to come to grips with complex concepts as occurs in Chemistry, we as teachers still have to master the technique of guiding pupils through the process of developing the mental models associated with chemical bonding that lead to solid concept formation.

Thus, following on from the first run of the Intervention Questioning Process, I became aware that pupils very often did not have a realistic idea of what they did know and understand or what they should know or focus on to develop conceptually. For this reason I altered most of the intervention questions to include “scaffolding” questions or information to direct pupils thought processes, as

shown in the examples below. The complexity of the learning process and of conceptual development was highlighted for me during my analysis of the pupil responses.

Further changes to the intervention questions were a result of the development of my understanding of cognitive load theory. As a result I added scaffolding to many of the questions in order to limit the load on the working memory. As an example the question below was originally used:

QUESTION 3

- 3.1 Hydrogen atoms have an electronegativity value of 2.1. Chlorine atoms have an electronegativity value of 3,5. Explain how these values affect the type of chemical bond that forms between a hydrogen atom and a chlorine atom. You will have to explain what “electronegativity” means. Please use diagrams in your answer.

In the first run of the process Question 3, presented after teaching of electronegativity and its effect on the sharing of electrons, was used as shown above. When I realised that there were too many concepts included in this question that needed to be unpacked before the question could be answered I amended the question to read as follows:

QUESTION 3

Hydrogen atoms have an electronegativity value of 2.1. Chlorine atoms have an electronegativity value of 3,5.

- 3.1 What is meant by the term **electronegativity**?
- 3.2 How do electronegativity values affect the sharing of electrons in a bond?
- 3.3 Explain how the electronegativity values of hydrogen and chlorine affect **the type** of chemical bond that forms between a hydrogen atom and a chlorine atom.

In a similar way an analysis of the answers to the Conceptual Test tool revealed questions that were ambiguous, that did not provide answers or information that was relevant to the study. These questions were modified for the second run of the testing process. Not only did I gain insight that enabled me to make changes to the intervention questions but also to change the questioning approach I use when routinely testing pupils.

The most important lesson I learned from the analysis of responses from run 1 was that my understanding of questions posed to pupils was often very different from their understanding of the questions. As a teacher I was aware of this but looking at the same problem as a researcher presented a bigger, more objective picture that is very valuable to me as a teacher.

The initial design of the Conceptual Test tool required that I look at testing as a researcher not as a teacher. I had to focus on the essential concepts, how to elicit answers that tested pupil understanding of concepts. Usually teachers set tests asking – what should they know, what should they be able to understand, are there questions testing knowledge, comprehension, analysis and synthesis of knowledge. This is quite different from designing a testing tool where only understanding of concepts is tested.

The development of this testing tool ensured that I, as teacher, work through the material and separate out the most important concepts in order to include these in the Conceptual Test tool. This required that I was very sure of my own understanding of the topic. As an experienced teacher, well trained in the subject of chemistry, I found that there were some concepts that I did not have sufficiently clear mental models to ensure effective teaching.

The second run of the Intervention Questioning Process reinforced the findings of the first run. In addition the qualitative analysis of the pupil responses allowed me to make more valuable inferences regarding the depth of understanding that pupils had because I had confidence in the design of the intervention questions and the Conceptual Test tool.

The following qualitative results reported in the previous chapter arise from the analysis and evaluation of results from the second run of the process. Their implications for teaching and learning are discussed below.

- a. Pupils showed a slow development of knowledge of terminology and understanding of new terms. Pupils were not able to use these terms if they had a limited understanding of them. Even if they had access to definitions or descriptions of the terms, if the understanding was limited the knowledge was not useful. This can be attributed to pupils having to assimilate this new knowledge into their existing knowledge structures. This requires re-organisation of existing structures and takes time (Novak, 1984). Teachers need to be aware of this and

should spend a greater amount of time helping pupils come to terms with new knowledge. As a teacher I very often leave the “learning” up to pupils. Teachers give guidance through the new material, structure consolidation, help pupils to know how to go about answering questions. We do not help them with the learning and through developing an understanding of the complexity of the learning process, I now know that this is where teachers should put their energies and emphasis.

- b. Pupils experienced difficulties in formulation of descriptive answers to questions. Descriptive answers usually require application of understanding and synthesis of new answers. If the development of understanding is a slow process then the ability to formulate new answers will also be slow. Greater structuring and scaffolding of questions is needed to ensure that pupils do get to a place where they can write descriptive answers.
- c. Pupils experienced difficulties interpreting “particle diagrams” and relating the nature of the chemical bond to the properties of the substance (Chittleborough & Treagust, 2007). The ability to link together the macroscopic and sub microscopic levels of chemistry at Grade 10 level is limited and this is a cause for concern as teachers are largely unaware of this problem. Teachers assume that pupils can “see” how particle diagrams fit with the observable properties of substances. This, according to the findings of this study, is far from the truth.

7.2 THE DEVELOPMENT OF AN UNDERSTANDING OF HOW GRADE 10 PUPILS BUILD UP MENTAL MODELS OF THE CONCEPTS RELATED TO CHEMICAL BONDING DURING THE LEARNING PROCESS.

Observations from the intervention questions seem to indicate that pupils initially learn by rote – or rather in a superficial way (observation a above). This early, superficial learning develops into more meaningful learning later after repeated exposure to the learning material. Pupils take time to get to understand new terminology and until they have an understanding of the new words have difficulty using these new words and terms. Initially pupils do not have a mental model associated with these terms. Only once the terms become familiar and pupils understand the associated concepts can one

really say that they have grasped the meaning of the new terms. Once this understanding is consolidated they pupils have to see the links between the concepts, see the bigger picture.

Contrary to this I had always thought that once pupils had been taught a concept – for example in a single lesson the concept of partially filled orbitals with unpaired valence electrons being unstable and by sharing these electrons with another atom a full valence shell was obtained which was stable – that pupils understood. By going through their notes and answering consolidation questions their understanding would develop further – no problem!! If they could not answer questions in a test it was because they had not learned. Going through the intervention question answers I realised that this was not true. At the end of the “teaching” most pupils do NOT have a grasp of what has been taught. When new terminology is introduced or new concepts are linked to assumed prior knowledge pupils might “understand” but this understanding is so superficial that they are not able to retain or use this understanding to develop sound, new mental models. The importance of ensuring the development of sound mental models during class time is evident from this finding. Pupils at Grade 10 level who have incomplete mental models will find it difficult to remedy this on their own. This also accounts for pupils not retaining what was learned and not being able to transfer and apply their knowledge.

Chemistry is a language and pupils have to constantly learn new terminology. As a teacher I always assumed that learning new words was the easier part of the learning process. Reflection on pupils’ answers to the intervention questions has given me insight into the need for pupils to develop an understanding of the concept before they are able to use the terminology correctly. Care should be taken to ensure that pupils appropriate necessary Chemistry vocabulary. The intervention questions give pupils the opportunity to use the new terms and develop their understanding before being asked to use their knowledge. The slow development of the language used to describe the topic will hamper pupil’s ability to answer descriptive questions.

What I now understand is that pupils receive “teaching” in the classroom and hear new terminology. These new words, explanations, descriptions have to be assimilated and new mental models developed before real concept formation can occur. Only then can the pupil use and apply his/her new knowledge. The new words have to be assimilated, built in to mental models before pupils can learn and make use of the words.

So often I have despaired when pupils, after good teaching, still are not able to use their knowledge. I now understand that this is because they have not been able to build up good mental models and so have not been able to develop concepts.

Chemical bonding is a theoretical topic and is usually approached very much from the theoretical aspect. There is little relevant practical work that pupils can carry out that helps them bridge the divide between the theory of matter and the properties of matter. The following intervention question reveals this:

Look at the diagrams below showing different types of solids.

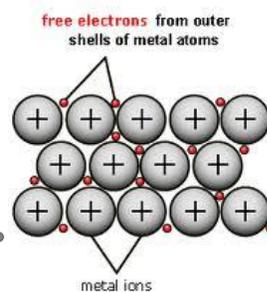
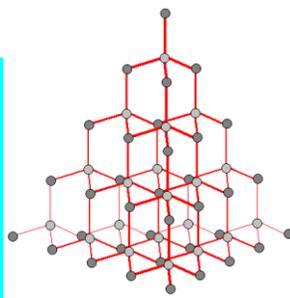
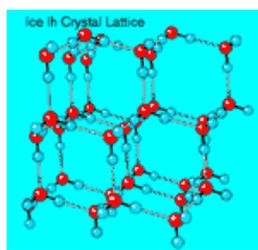
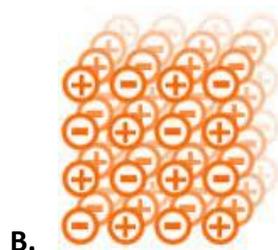
1. Link each of the substances given below to one of the diagrams.
2. Draw a line from the name to the diagram.
3. Give a reason for your answer.

A. Silver

B. Potassium fluoride

C. Ice

D. Diamond



Pupils found this question very difficult. Visualising the particles that make up different types of solids is a higher order thinking skill. I was aware of this to an extent but did not realise fully how difficult pupils find this. The pupils who participated in this study have been taught about the particle model of matter and have spent a great deal of time drawing “particle diagrams”. They are largely able to describe microscopic characteristics of substances but linking them to the macroscopic properties of a substance is a difficult process which must be addressed in order for teaching of this topic to be effective.

Reports in the literature refer to this “while novice learners mainly operate at the macro level and struggle to meaningfully relate the other levels. Unfortunately, most chemistry teaching is focused on the sub micro–symbolic pair of the triplet and rarely helps students to build bridges to comfortably move between the three levels” (Talanteur, 2011)

If this is the case then the mental models built up by pupils will be lacking in this fundamental aspect of Chemistry, namely the picture of how particle diagrams, models of the sub-microscopic, relate to what they can see and feel.

Chemical bonding is a set of abstract concepts and, as mentioned before, there are few ways of concretely introducing the pupils to these concepts. Teachers need some way to bridge this divide for pupils operating in the concrete operations phase. Piaget referred to a process of self-regulation where a pupil searches for patterns and relationships so as to progress to the next phase of operation. During self-regulation pupils learn to intentionally and deliberately direct their thinking and problem solving activities (Fox & Riconscente, 2008).

All of the above have implications for teaching and these findings can be used to improve teaching in future.

7.3 THE EFFECTIVENESS OF THE INTERVENTION QUESTIONING AND FEEDBACK PROCESS IN FOSTERING SOUND CONCEPT FORMATION.

Why did the intervention questioning process work? There are a number of reasons and the following will be discussed below:

- Development of mental models.
- Chunking of information.
- Reinforcement by the feedback.
- Metacognition.
- Guidance regarding what is knowledge is required.

The conceptual framework that I started with is shown in figure 7.1 below.

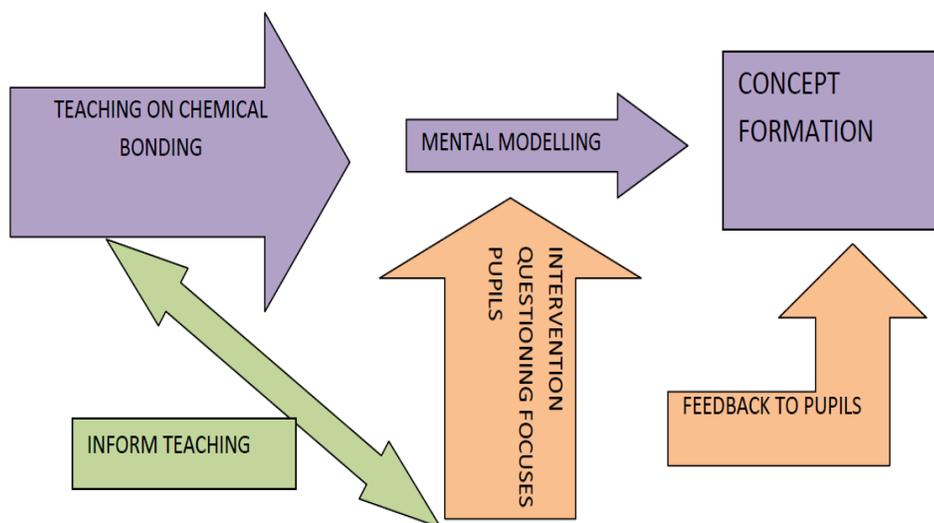


Figure 7.1 Conceptual Framework

As discussed in the previous section the Targeted Intervention Questioning process fosters the development of mental models. The questions help pupils construct their own knowledge by giving them the stepping stones to the development of sound concepts. The stepping stones include pointers towards what the correct science is, an opportunity to challenge their existing mental models, an understanding of how they are thinking and how their learning techniques work and do not work. The qualitative analysis of the answers given by pupils to the intervention questions (Table 6.4 pg. 86) reveals a very poor ability to answer the questions. It must be emphasised that the intervention questions are not given to pupils to see how well they can score. They provide pupils with an opportunity to use their learning material and attempt an answer. The feedback then points them to how far they are from the “answer” and gives them pointers as to how to get there. This is the task oriented feedback referred to by Hattie & Timperley (2007)

A reflection on the very poor scores that pupils obtained on the intervention questions requires that one asks “why bother?” However, the better performance of the pupils in the test group when considering improvement in score, learning gain and also ability to answer free response questions (Table 6.3, pg 81; Table 6.7, Pg 89; Table 6.8, pg. 90) must surely indicate that there is value in the Targeted Intervention Questioning process.

Klausmeier (1992) discusses focused concept instruction where attention is focused on what is to be learned and recall is required early in the instructional process and comments on the power of this method to develop concepts. The Targeted Intervention Questioning process shares similar attributes. Attention is focused on what is to be learned by the intervention questions and the feedback and pupils are asked to recall (with the help of their learning material) what has been introduced, discussed and explored in class early in the teaching of the topic. This process is repeated each time pupils are asked to answer an intervention question.

I think that “chunking” of information is one of the reasons why the intervention questioning process is successful. The questions break the topic into manageable chunks which pupils can process and make sense of. A report by Reid (2008) states “The key thing to note is that working memory causes a problem when too much has to be thought about at the same time. By careful sequencing of ideas, by reminder and illustration, by a stepwise approach, the working memory is not faced with too much at the same time. It is predicted that learning will increase.” The intervention questions sequence ideas for the pupils and reduce the amount of information that the pupil has to process at one time. For example by breaking the one question down into three separate questions (intervention question 3) the three important concepts – *electronegativity*, *electron sharing* and *type of chemical bond* (*viz* polar or non-polar covalent) are separated so that pupils can process them separately but still have to see the links between the three.

In addition, the intervention questions presented to pupils at certain stages during the teaching of the topic serve to compartmentalise the different sections of the topic making each more manageable.

The importance of the feedback must also be emphasized. Unless pupils can see where and why they have made mistakes there can be no learning from the questions. Pupils were initially given a mark for their answers but then I realised that there was little value in this and only gave pupils comments that told them what they did correctly, what they had left out, how they could correct their thinking. Copies of pupil answers with feedback are available in Appendix 6.

Feedback serves to build up pupil confidence during the initial process of mastery of concepts. In Science, considered to be a difficult subject, pupils are often unsure of their ability to actually master the subject. My experience has shown me that lack of confidence is one the biggest stumbling blocks to achievement in Science. By pointing out to pupils what they can do and indicating how close they

are to the correct answer, the feedback boosts confidence and gives pupils small interim goals to strive towards. Pupils can develop a realistic picture of their own abilities as well as come to understand the thinking skills demanded of them in learning this section of Science.

The feedback told the pupils they could do this and that they could not do that and gave them pointers as to what they should do to master the material. Through this pupils become aware of what is right and wrong with their thinking thus affecting their metacognition. According to Rickey (2000) “Metacognition is generally thought to be a key to deeper, more durable, and more transferable learning.” In the learning of chemistry it is important for the understanding of ideas and in problem solving. The thought process that moves from “knowing material” to “what are the implications of this knowledge” to “how do I use this knowledge” does not always develop easily and naturally. Metacognitive processes have to be consciously developed in 15 – 16 year old pupils. The intervention questions, along with the feedback, were used to achieve the metaconceptual development.

Answering questions in isolation is purposeless and so feedback must be given to the pupils. In order for feedback to be effective it should be given as soon as possible and it should point out to pupils what they have done that is correct and incorrect and then point them to ways in which they can improve their performance. Because teaching goes on day after day pupils should receive this feedback before the teacher moves on to the next bit of work. In this way the layers and layers of sub-topic or mini-concepts are built up with pupils understanding each layer, developing a whole picture with no gaps and so ending up with a solid mental model of the topic.

My experience has shown me that pupils do not like engaging with their mistakes and errors. Pupils need to confront their lack of understanding in order for conceptual change to occur. Studies have shown that “students will be able to learn science concepts and principles only if they are aware about the shift of their initial metaconceptual views towards the metaconceptual perspectives of science knowledge” (Duit & Treagust, 2010) Viewing the correct answers to the intervention questions along with their answers helps pupils shape and reshape their metaconceptual views so as to develop sound mental models and develop conceptually. It is therefore important that part of the intervention questioning process also involves a time where pupils are encouraged to actively engage with the questions, their answers and the teacher feedback. The review of the feedback is an

important part of the Intervention Questioning Process and the whole process can be improved by placing greater emphasis on this metaconceptual development aspect.

Very often pupils are unaware of how to approach learning Chemistry. They do not fully understand the outcomes expected of them. In chemistry the facts are to be learned and understood but have to be integrated and the information applied to situations, often unknown. Pupils have to learn the “rules” of bonding and then apply these in many different situations. The intervention questions are able to give pupils an idea of how to structure their thinking on the topic so as to be able to see the links, develop a whole picture of the topic and so be able to apply this knowledge.

It is also important that pupils realise the value of the questions and of the feedback and use the questions, along with the feedback that points to the correct answers, when learning for subsequent tests and exams. The questions serve a formative function when used in class with teacher feedback. The questions can also be used summatively by pupils when preparing for tests and examinations.

7.4 A COMPARISON OF THE INTERVENTION QUESTIONING AND FEEDBACK PROCESS TO TRADITIONAL TEACHING METHODS.

The results of the evaluation of this method show that there is a statistically significant improvement in pupils score on the Conceptual Test tool when they use the intervention questions during the teaching phase.

Three different teachers in the same school taught in the way they normally do but used the intervention questioning process as an additional teaching strategy. All three have different by teaching styles – one uses a chalk and talk approach, another a “discovery oriented and pupil centred guided by the teacher” approach and the third a “structured talk – consolidation questioning – talk combination”.

The results seem to indicate that the teaching style of the teacher does not determine the effectiveness of the method and that using the intervention questioning process still does promote conceptual development. The two classes making up the test group were considered as a group and the results do not indicate whether there was a difference between the two classes. and whether one

teacher. The statistically significant learning gain in the test group is too great to be attributed to the teaching of one of the teachers. It is therefore attributed to the method used. It must be noted that I was the teacher who gave all the feedback commenting on the answers given to the intervention questions. Feedback was comment on the correctness of the science. Similar comment would be given by any teacher.

The statistical analysis of score and learning gain using a pre-test and post-test scenario indicated that there is a statistically significant difference between the test and control groups with the test groups (those that received the Targeted Intervention Questioning process) scoring higher on the Conceptual Test tool. It must be noted that this study had the characteristics of a case study as a small sample was used but as with a case study, the complexities and subtleties of this particular situation are highlighted. Table 6.4 shows an analysis of the gain in score and learning gain between pre- and post-test for run 1 and run 2. There appear to be inconsistencies and anomalies in this data but, considering the individual characteristics of the learners in each group, the precise positioning of the teaching in the normal day to day activity of a school these point to the complexity of a study of the learning process taking place in school. Generalisations can still be made – overall the test group did perform better and did experience greater conceptual development, but note should be taken of the complexities of a classroom.

Conventional teaching methods rely on presenting pupils with information, assuming understanding and learning occur, consolidation of what has been taught, followed by summative testing. Teaching does not traditionally consider pupil prior knowledge, the development of mental models and the concept formation.

According to the literature “Thus, when rudimentary student ideas interact with teacher demonstrations; scientific language, laws, and theories; and the students’ own experiences, students will try to reconcile their mental models (often referred to as conceptions or mental models by many investigators) and ideas with the accepted scientific concepts. The outcome of this reconciliation can result in the science concept being distorted into an alternative conception”(Harrison & Treagust, 1996).

An article by Hennessey (1999) states: “Even in the best constructivist learning environment metacognition does not simply happen. It must be explicitly promoted.” Here the Targeted

Intervention Questioning process provides the conceptual models and experiences for pupils to measure their own thinking thus promoting metaconceptual thinking.

So, why is this method better?

It is better because it adds an extra dimension to classroom practice. A teacher can be comfortable teaching in the way that he/she is comfortable with and can use the Targeted Intervention Questioning process to enhance the learning experience in a way that has been proved to be sound and which also has its origin in theory. It has to be emphasised that the structuring of the questions is critical.

7.5 WHAT ARE THE IMPLICATIONS FOR TEACHING? ACTION RESEARCH

Construction of the concept map that outlines the concepts to be taught was the most valuable part of the process for me as a teacher. Before I started this project I felt that I had a good understanding of Chemistry and I knew and understood all the concepts that I was teaching. However, the construction of concept map, working out and sequencing all the interlinked concepts was invaluable in deepening my understanding of the topic and in allowing me to see what difficulties pupils could encounter as they constructed their own personalised view of chemical bonding. It allowed me to see better ways and sequences in which to present material.

I shared the concept map with colleagues who were to use the intervention questions in their classes as part of this study. Reading a concept map constructed by another person was not at all effective in changing teaching practice or in developing teacher understanding. The process of constructing the concept map is the valuable part of the exercise, not merely reading an already constructed map. Concept mapping is difficult, even for adults, but should be encouraged amongst teachers as this deepens insight into a topic and reveals the difficulties pupils will most likely experience.

Following on from my experience with concept mapping, I have attempted to use concept mapping as a tool in the classroom for pupils to consolidate their knowledge of a topic. Pupils resist engaging in concept mapping. It is a difficult process and many pupils do not understand hierarchical structures, organisation of information and the need to organise information. Teaching pupils to gain benefit from concept mapping is the difficult part. Once pupils realise the power of concept mapping as a learning method and tool they are willing to make use of the methodology.

Following on from the difficulties encountered in using concept mapping the use of the intervention questions to lead pupils through the structure and interrelatedness of the topic of chemical bonding is a valuable tool for developing understanding. The questions can be used as a structure that pupils can build their own concepts on.

During this study I was the teacher who reviewed and gave feedback on pupils' answers to the intervention questions for all teachers teaching a "test" class. The review of pupil answers led to discussions on what was taught and how it was taught. This became a valuable tool for teacher mentoring and transfer of methodology. It also allowed me to quickly ascertain any conceptual errors that were being taught. Teachers can sometimes pass on conceptual errors they themselves have but more commonly, I think, the way in which material is relayed to pupils leads to the formation of conceptual errors.

Overall, I think that the Intervention Questioning process along with the use of the Conceptual Test tool can be a valuable way in which Science teachers at school level can monitor each other and together improve their subject knowledge and understanding of concepts.

This Conceptual Test can be used in future as a summative test once teaching on chemical bonding has been completed. Test results will allow comparison of successive groups of pupils. This test can be used to measure pupil readiness when starting to teach the section on intermolecular forces in Grade 11 as knowledge of chemical bonding is a prerequisite. I also used the test (not under test conditions but as a discussion document) to help other teachers refine and consolidate their own understanding of the topic.

The Conceptual Test tool includes a number of questions that probe pupil understanding of the prior knowledge or concepts that underlie the concepts that make up chemical bonding. These questions can be used on their own to gauge pupil readiness for the teaching of chemical bonding before teaching begins. Now that I understand the process of conceptual development better I realize that the most important aspect of teaching Chemistry is to ensure that the precepts pupils have are sound and based on good scientific understanding.

A problem encountered in schools currently is that pupils attend endless extra lessons in order to achieve well in Science. The need for extra lessons points to the fact that pupils are not reaching the

required level of understanding or learning during class time. Many times teachers will get to the end of a section only to find that somewhere during the teaching process they have “lost” the pupils. Class time is limited, pupils are pressured, there is an emphasis on results and not on sound understanding, pupils expect instant gratification of needs. All these factors mean that a very different way of teaching is required for current pupils. An alternative to the traditional “teacher talk, pupil homework, summative test” approach is needed. This Targeted Intervention Questioning process, along with the feedback could help solve this problem.

An analysis of results has repeatedly shown that pupils take longer than expected to master new terminology. Teaching methodologies should be altered to take this in to account. By putting in the effort to ensure that solid foundations, linked to prior knowledge, are built, pupils will have a better chance of being able to write descriptive answers and apply their knowledge. This is the mental modelling described in the literature (Harrison & Treagust, 1996) and is necessary for concept development to occur.

Pupil inability to link the submicroscopic properties of matter to the macroscopic, two aspects of the Chemistry Triplet as reported (Hilton & Nichols, 2011) has been highlighted in this study. Teachers should take this into account and ensure that a great deal of focus is put on methods that link these two aspects of the property of matter.

The implications for teaching outlined above mirror what is reported in the literature regarding what is needed in order to teach for conceptual change:

- “- know the phenomena, the methods, and the concepts, principles, and theories that constitute the science they are teaching;
- know what conceptions their students hold about the units to be taught, and the extent to which they are scientifically acceptable;
- be aware of the role played by students’ existing knowledge in understanding new material;
- be convinced of the need to use conceptual change teaching strategies particularly when students’ existing conceptions conflict with those being taught; and

- be able to plan and perform teaching actions that give effect to these strategies.” (Hewson, 1992) (p 12)

7.6 RESEARCH LIMITATIONS

This study was carried out in the setting of the school where I teach – a private, boys only, relatively small school. Consequently, it can be argued that the result of the study cannot be generalised to the South African population as a whole.

The study has, however, shown that the method developed and tested is effective in fostering good concept development which is what every science teacher strives for. What was tested was a method, a framework that can be developed and further improved depending on circumstance. For this reason it is more suited for generalisation than it appears to be.

As this study involved action research the criticism aimed at action research in general – namely the robustness of the methods (Bodner et al 2001) can be applied here. I have tried to eliminate this by developing a stringent testing tool (the Conceptual Test tool) and by collecting quantitative data as well as qualitative data.

Personal bias can always be considered a problem in action research. However, as this was an evaluation of a method of teaching the topic is not an opinion laden subject of study and the effect of personal bias will be minimized.

The small sample gave this study some of the characteristics of a case study and as such the results can be considered to not be generalizable unless others see the applicability of the results (Cohen et al 2007). The study evaluated a method that should be of interest to other science teachers as the method serves to improve science teaching at a time when this is much needed in our country.

7.7 AREAS FOR FUTURE RESEARCH

Arising from this study a number of questions that require further research can be asked.

- How can more effective linking to prior knowledge be achieved?
- How can teaching be modified to improve prior knowledge during teaching of new content and to prevent muddling of prior knowledge even further?

- How can teachers of the chemistry improve pupil understanding of the links between the macroscopic, sub-microscopic and representational aspects of chemistry?

7.8 CONCLUSION

I began this study as I wanted to evaluate a different method of teaching the section on Chemical bonding to Grade 10 pupils. Over the years teaching this section has led me to realize that it is a difficult section for pupils but up until now I have not really found a way of making the material accessible to pupils so that the majority of them come out with a well-developed mental model of the concepts. Well-developed mental models mean that there has been sound concept formation. If the concepts developed are sound then pupils will retain this knowledge and will be able to apply their knowledge in other situations. To me as a teacher the ultimate goal in teaching is to have pupils remember their work so well that it is “part of them” and so be able to use this knowledge to solve problems.

Discussions with pupils have led me to realize that there are “gaps” in pupils’ understanding of the topic. The teacher paints the picture of the concept while teaching but somewhere during this process pupils miss parts of the whole picture. After teaching on a topic is completed and pupils ask for extra help to master the topic they will say things like “I did not know that” or “Where did that come from” or “I must have been absent when you taught that”. Despite being in the classroom, concentrating and applying themselves to learning pupils miss things. As a result the big picture is lacking in detail and pupil understanding does not develop fully.

As I was investigating teaching as it was happening and as the project was designed with improvement of teaching in mind action research was used as a research methodology. This methodological approach was chosen as it suits my situation, in a school, researching my teaching methods. I have made use of the aspects of action research listed in McNiff and Whitehead (2010). Action research differs from other types of research by being based in practice, especially teaching practice, in this instance. I strove to enhance understanding of teaching practise and the effectiveness of this practice. This study has not been just about teaching practice but rather about the thorough research of teaching practice so as to revise and refine it with the aim of improving our understanding of how pupils learn and in so doing also improve pupil learning.

The statistical results and the analysis have pointed to a teaching method that promotes conceptual development and add value to traditional methods of teaching. Reasons cited in the literature for improved concept learning and teaching have been addressed and encapsulated in the Intervention Questioning process resulting in a method that can be used by any teacher to improve concept development.

Over and over the complex nature of the learning process has been made evident in this study. For me as a teacher this has been the most exciting finding. It has helped me understand why pupils sometimes (very often?) do not understand chemistry. It gives me reason to keep on striving to improve the teaching of this subject. It is not the inability of pupils to understand chemistry that is the problem, it is rather the teachers' inability to understand how learning is happening that hampers their progress.

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APPENDIX 1

INTERVENTION QUESTIONS

RUN 1

QUESTION 1:

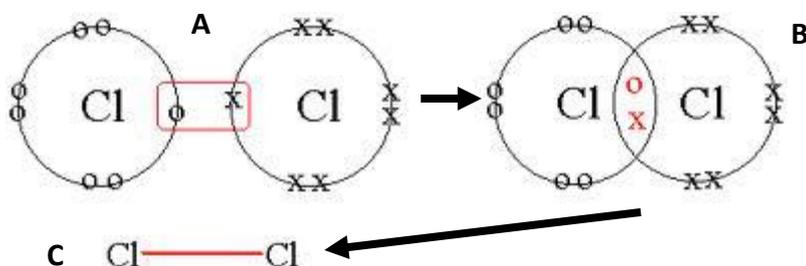
- 1.1 Use an Aufbau diagram to explain why a hydrogen atom is not stable.
- 1.2 Explain, by referring to the electron configuration, why a neon atom never forms a Ne_2 molecule.

QUESTION 2:

2.1 A hydrogen molecule forms when:

- the unpaired electrons in 2 hydrogen atoms form a bond.
- the s orbital in one hydrogen atom overlaps with the s orbital in a second hydrogen atom, the electrons are shared and form a covalent bond.
- the electrons in the two hydrogen atoms join to form a chemical bond.

2.2 This diagram shows the formation of a chlorine molecule:



- Explain what is happening in each step (A – C) of the sequence shown here.

QUESTION 3

- 3.1 Hydrogen atoms have an electronegativity value of 2,1. Chlorine atoms have an electronegativity value of 3,5. Explain how these values affect the type of chemical bond that forms between a hydrogen atom and a chlorine atom. You will have to explain what “electronegativity” means. Please use diagrams in your answer.

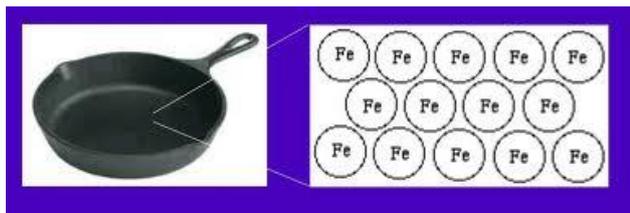
QUESTION 4

- 4.1 An ionic bond forms between a sodium atom and a fluorine atom. This is because:
- sodium is a metal and fluorine a non-metal;
 - sodium atoms do not share electrons;
 - fluorine atoms have a much higher electronegativity than sodium atoms and so attract the bonding electrons into the fluorine atom, resulting in the transfer of an electron from the sodium to the fluorine atom.
- 4.2 Draw 2 diagrams that show that you understand and can distinguish between the process of forming a covalent bond and of forming an ionic bond. Supply a key and additional explanations if necessary.

QUESTION 5

Name

Diagram of iron particles



- 5.1 For each of the following statements decide whether it is correct or not. For each incorrect statement, please explain **what is incorrect** about the statement.
- Iron has the type of bonding called metallic bonding, holding the particles together.
 - In iron metal each iron atom is bonded to each of the other atoms surrounding it.
 - Iron conducts electricity because some of the atoms can slip past others and move through the metal.
 - Chemical bonds are not needed to hold the iron atoms together because the atoms are identical.
 - Iron expands when heated and this is because the atoms get bigger when heated.

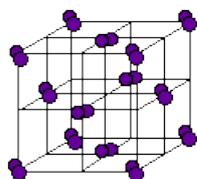
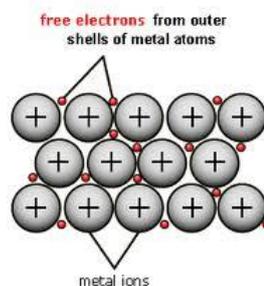
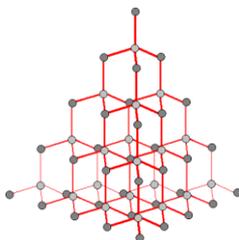
QUESTION 6

Name:

Look at the diagrams below showing different types of solids.

Link each of the substances given below to one of the diagrams. Give a reason for your answer.

- Silver
- Potassium fluoride
- Iodine (I_2)
- Diamond



APPENDIX 2

INTERVENTION QUESTIONS

RUN 2

QUESTION 1:

The element hydrogen contains hydrogen molecules (H_2) because hydrogen atoms do not exist as individual atoms.

Atoms combine with other atoms because individually they are not STABLE. This means that they have too much energy.

1.1 Use an Aufbau diagram to explain why a hydrogen atom is not stable.

Draw the diagram:

Explain in words:

ELECTRON CONFIGURATION refers to the arrangement of electrons in an atom.

SHELL DIAGRAMS and **AUFBAU DIAGRAMS** are used to represent electron configuration.

1.2 Explain, by referring to the electron configuration, why a neon atom never forms a Ne_2 molecule.

QUESTION 2:

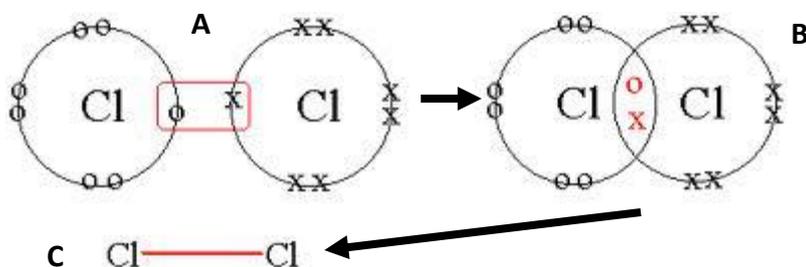
Write down definitions for the following terms:

- Unpaired electron:
- Orbital:

2.1 A hydrogen molecule forms when:

- the unpaired electrons in 2 hydrogen atoms form a bond.
- the s orbital in one hydrogen atom overlaps with the s orbital in a second hydrogen atom, the electrons are shared and form a covalent bond.
- the electrons in the two hydrogen atoms join to form a chemical bond.

2.2 This diagram shows the formation of a chlorine molecule:



Explain what is happening in each step (A – C) of the sequence shown here.

QUESTION 3

Hydrogen atoms have an electronegativity value of 2.1. Chlorine atoms have an electronegativity value of 3,5.

- 3.1 What is meant by the term **electronegativity**?
- 3.2 How do electronegativity values affect the sharing of electrons in a bond?
- 3.3 Explain how the electronegativity values of hydrogen and chlorine affect **the type** of chemical bond that forms between a hydrogen atom and a chlorine atom.

Please use diagrams in your answer.

QUESTION 4

- 4.1 An ionic bond forms between a sodium atom and a fluorine atom. This is because:
 - A. sodium is a metal and fluorine a non-metal;
 - B. sodium atoms do not share electrons;
 - C. fluorine atoms have a much higher electronegativity than sodium atoms and so attract the bonding electrons into the fluorine atom, resulting in the transfer of an electron from the sodium to the fluorine atom.
- 4.2 Draw 2 diagrams that show that you understand and can distinguish between the **process** of forming a covalent bond (as in F_2) and of forming an ionic bond (as in NaF).

Supply a key and additional explanations if necessary.

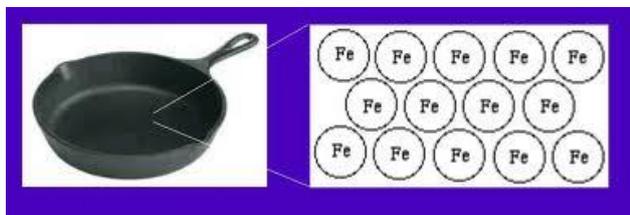
COVALENT BOND:

IONIC BOND:

QUESTION 5

Name

Diagram of iron particles



- 5.1 For each of the following statements decide whether it is correct or not. For each incorrect statement, please explain **what is incorrect** about the statement.
- A. Iron has the type of bonding called metallic bonding, holding the particles together.
 - B. In iron metal each iron atom is bonded to each of the other atoms surrounding it.
 - C. Iron conducts electricity because some of the atoms can slip past others and move through the metal.
 - D. Chemical bonds are not needed to hold the iron atoms together because the atoms are identical.
 - E. Iron expands when heated and this is because the atoms get bigger when heated.

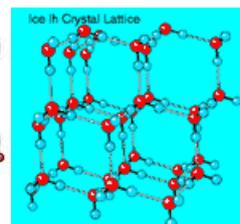
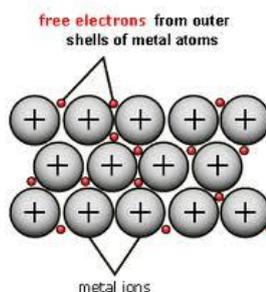
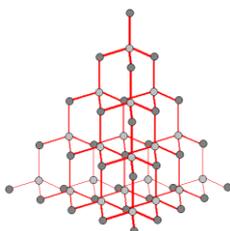
QUESTION 6

Name:

Look at the diagrams below showing different types of solids.

1. Link each of the substances given below to one of the diagrams.
2. Draw a line from the name to the diagram.
3. Give a reason for your answer.

- A. Silver B. Potassium fluoride C. Ice D. Diamond



APPENDIX 3

SEQUENCE OF INTERVENTION QUESTIONS

GUIDELINES FOR TEACHERS

INTERVENTION QUESTION 1:

Give pupils this question after you have covered the reasons for bonding – ie full outer levels are stable....

The intervention question makes pupils reflect on: **What electron configurations are stable, unstable?**

INTERVENTION QUESTION 2

Give pupils this question after you have covered the idea that orbital overlap results in electron sharing and covalent bond – as examples H_2 , F_2 , HCl

The intervention question makes pupils reflect on: **sharing of a pair of electrons can result in a full outer energy level part of the time which is a more stable situation than atoms with unpaired electrons in non-full energy levels. Sequence of orbital overlap – electron sharing – covalent bond is emphasised.**

INTERVENTION QUESTION 3

Give pupils this question after you have covered electronegativity and equal/nonequal sharing of bonding electrons.

The intervention question makes pupils reflect on : **Electronegativity and sharing of electrons – equal and unequal. Definition of polar and non-polar covalent bonds.**

INTERVENTION QUESTION 4

Give pupils this question after you have covered Ionic bonding – description and process of formation of ionic bonds on— electrons are transferred from metal to non-metal and resulting ions attract and form the bond.

The intervention question makes pupils reflect on the difference between ionic and covalent bonds.

NB USE QUESTION 4 BEFORE 2 AND 3 IF YOU DO IONIC BONDING FIRST.

INTERVENTION QUESTION 5

Give pupils this question after you have covered Metallic bonding.

This question makes pupils reflect on: Metallic bonds, general sharing of valence electrons and relate this to properties of a metal.

INTERVENTION QUESTION 6

Give pupils this question after you have covered the nature of bonds and relation to structure – molecular compounds, ionic lattices, giant covalent/atomic structures (as in diamonds and graphite) metals.

This question makes pupils reflect on: **the substances and how the microscopic properties affect the macroscopic properties**

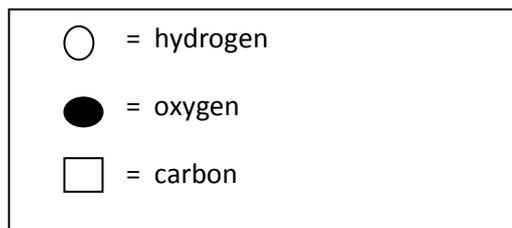
APPENDIX 4

CONCEPTUAL TEST TOOL

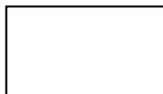
PILOT TEST

6. Draw particle diagrams to represent the following molecules.

Use the following key:



a. One molecule of hydrogen (H_2)



b. One molecule of carbon dioxide (CO_2)



c. $3H_2O$



7. Draw an Aufbau diagram for an atom of aluminium- below.

8. Aluminium is a metal in Group 3 of the Periodic Table. It has:

- A. 13 valence electrons.
- B. 3 valence electrons.
- C. 1 valence electron.

9. Valence electrons are

10. Core electrons are

11. Hydrogen is a very reactive element and combines chemically with many other elements. Helium, also in Period 1, is a noble Gas which means that it is completely unreactive. By referring to the electron configuration, explain why the two elements have such different reactivity.

12. When chlorine reacts with hydrogen a gas, hydrogen chloride, is formed. When chlorine reacts with sodium, solid sodium chloride forms.

- a. Write down the formula for each of these compounds.

b. Describe the chemical bond formed in each of these substances.

c. Draw a diagram (just a sketch) to represent each of these two compounds.

d. Explain **why** the bond between H and Cl differs from the bond between Na and Cl.

13. The bond between H and F is a polar covalent bond.

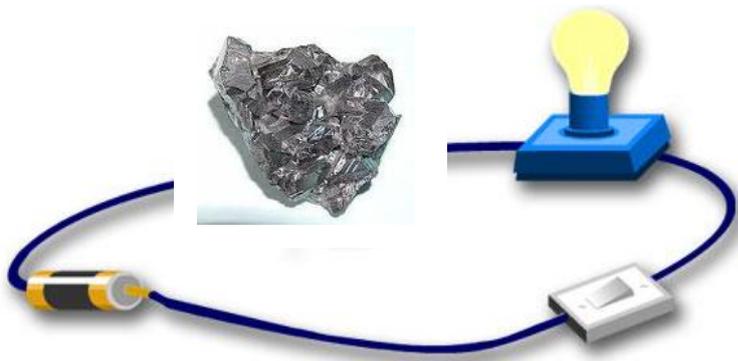
The bond between F and F is a non-polar covalent bond.

13.1 Describe the difference between these two types of bonds.

13.2 What property of an atom of H and that of an atom of fluorine causes the different bonds to form.

13.3 Explain the effect of this property.

14. A piece of zinc is connected to a cell and a light bulb.



14.1 Do you expect the light bulb to light up?

14.2 Name the charged particles moving through the zinc.

14.3 Describe the chemical bonds in the zinc that allow for this behavior.

APPENDIX 5
CONCEPTUAL TEST TOOL
RUN A

CONCEPT DEVELOPMENT TEST

Candidate number

V1 1

Please answer all the questions by marking an appropriate number in a shaded box or by writing your answer into the shaded space provided

1. What is your name?

2. Which one of the following are you being assessed for?

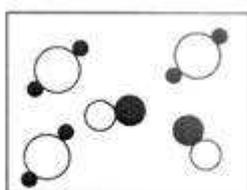
Pre-Test Form 3	1
Post-Test Form 3	2
Pre-Test Form 4	3
Post-Test Form 4	4

V2 5

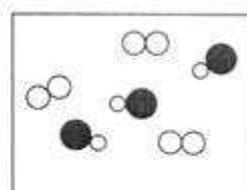
3. Which particle diagram **correctly** represents a mixture of a compound and an element?



A



B



C

V3 7

4. Carbon dioxide is a **compound**. Explain why it is considered to be a compound.

V4 9

5. Choose terms from:

**DECOMPOSITION
EVAPORATION**

MELTING

**COMBUSTION
SUBLIMATION**

to replace the symbols **A, B & C** in the sequence below:



Write your answers below:

A.
B.
C.

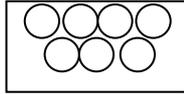
V5 12

V6 14

V7 16

Question 6 follows on the next page ...

6. The diagram represents the metal **iron**.



Mark the statement which best explains why iron is considered to be an element:

A. The atoms are all packed in an ordered arrangement.	1
B. The atoms are identical.	2
C. Iron is a metal.	3

V8 18

7. Explain your answer to Question 6

V9 20

8. Sugar is dissolved in water and a solution of sugar in water is formed.

Circle the number/s corresponding to the correct statement/statements listed below

A. This is a physical process because the substances sugar and water are still present and can be separated again by means of a physical process.	1
B. This is a chemical process because the sugar is no longer visible.	2
C. This is a chemical process because a new substance is formed.	3
D. This is a physical process because no new substances are formed.	4

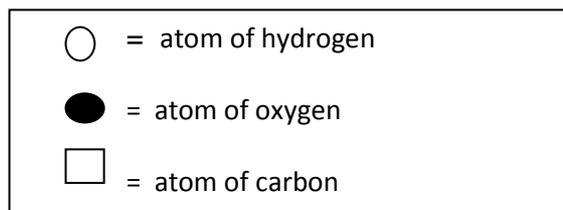
V10 23

V11 25

V12 27

V13 29

9. The following key is used to represent different atoms:



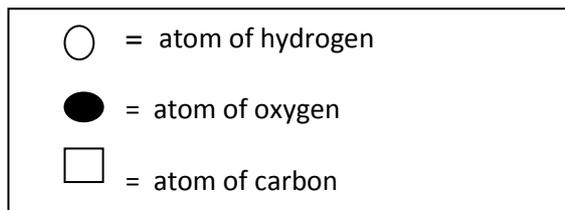
Draw particle diagrams to represent the following molecule:

a. One molecule of hydrogen gas (H₂)

V14 31

Question 9 continues on the next page ...

9. (cont.) The following key is used to represent different atoms:



Draw particle diagrams to represent the following molecules:

b. One molecule of carbon dioxide gas (CO₂)

V15

--	--	--

 35

c. 3H₂O (l)

V16

--	--	--

 39

10. Draw an Aufbau diagram for an atom of aluminium, below.

V17

--	--

 43

11. The diagram above indicates that aluminium has:

A. 13 valence electrons.	1
B. 3 valence electrons.	2
C. 1 valence electron.	3

V18

--

 46

12. Where are the valence electrons?

V19

--

 48

13. Where are the core electrons?

V20

--

 50

Question 14 follows on the next page ...

14. Hydrogen is a very reactive element and combines chemically with many other elements. Helium, also in Period 1, is a noble Gas which means that it is completely unreactive. By referring to the electron configuration, **explain why** the two elements have such different reactivity.

Please write your answer in the box below:

V21

--	--	--

 52

15. When chlorine reacts with hydrogen a gas, hydrogen chloride, is formed. When chlorine reacts with sodium, solid sodium chloride forms.

Write down the formula for each of these compounds **in the box below:**

V22

--	--

 56

16. **Describe** the chemical bond formed between hydrogen and chlorine.

Write your answer in the box below:

V23

--	--

 59

17. **Describe** the chemical bond formed between sodium and chlorine.

V24

--	--

 62

18. **Draw a diagram** (just a sketch) to indicate the difference between these two substances.

Draw your diagram in the box below:

V25

--	--

 65

Question 19 follows on the next page ...

19. **Explain why** the bond between an atom of H and an atom of Cl differs from the bond between an atom of Na and an atom of Cl.

Write your explanation in the box below:

V26 68

20. The bond between a F atom and another F atom is a non-polar covalent bond. The bond between a F atom and a H atom is a polar covalent bond.

Describe the difference between these two types of bond **in the box below:**

V27 71

21. What property of the atoms determines this difference between the chemical bonds in the molecules mentioned in question 20?

V28 74

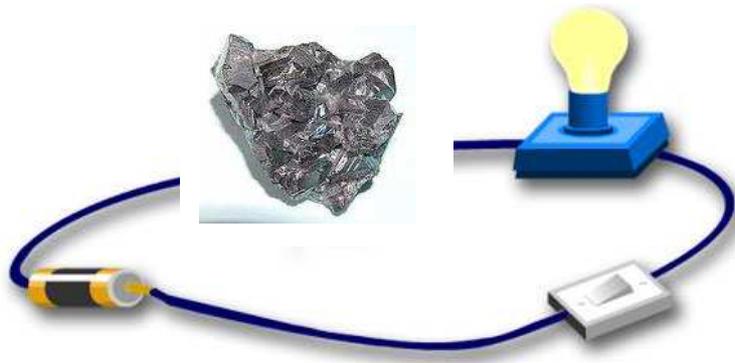
22. **Explain** the effect of this property **in the box below:**

V29 76

Question 23 follows on the next page ...

A cell is connected to a piece of zinc and a light bulb, the switch is closed:

Use this diagram to answer Questions 23 to 25 below.



23. Do you expect the light bulb to light up?

A. Yes	1
B. No	2

V30 79

24. Name the charged particles moving through the zinc.

V31 81

25. **Describe** the chemical bonds in the zinc that are responsible for this behaviour.

Use the box below for your answer:

V32 83

APPENDIX 6
CONCEPTUAL TEST TOOL
RUN 2

CONCEPT DEVELOPMENT TEST

Candidate number

V1 1

Please answer all the questions by marking an appropriate number in a shaded box or by writing your answer in the shaded space provided

1. What is your name?

2. Which one of the following are you being assessed for?

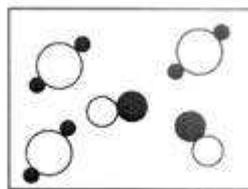
Pre-Test Form 3	1
Post-Test Form 3	2
Pre-Test Form 4	3
Post-Test Form 4	4

V2 5

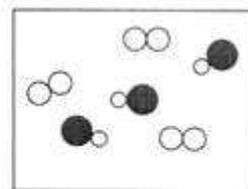
3. Which particle diagram **correctly** represents a mixture of a compound and an element?



A



B



C

V3 7

4. Carbon dioxide is a **compound**. Explain why it is considered to be a compound.

V4 9
V5 11

5. Consider the following 3 changes that the substance water can undergo:



Which of these changes is a **chemical change**?

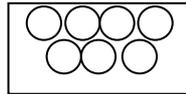
V6 13

Explain the difference between a **phase change** and a **chemical change**

V7 15
V8 17

Question 6 follows on the next page ...

6. The diagram represents the metal **iron**.



Mark the statement which best explains why iron is considered to be an element:

A. The atoms are packed in an ordered arrangement.	1
B. There is only one type of particle meaning the substance is made up of atoms.	2
C. The spaces between the particles are very small.	3
D. There is only one type of particle meaning this is not a mixture.	

V9 19

7. Explain your answer in 6

Write your answer in the box below:

V10 21
 V11 23

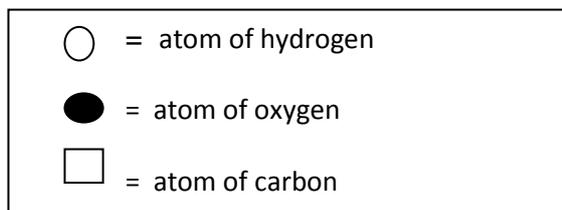
8. Sugar is dissolved in water and a solution of sugar in water is formed.

Mark the correct statement listed below

A. This is a physical process because the substances sugar and water are still present and can be separated again by means of a physical process.	1
B. This is a chemical process because the sugar is no longer visible.	2
C. This is a chemical process because a new substance is formed.	3
D. This is a physical process because the new substances formed can be changed back into sugar.	4

V12 25

9. The following key is used to represent different atoms:



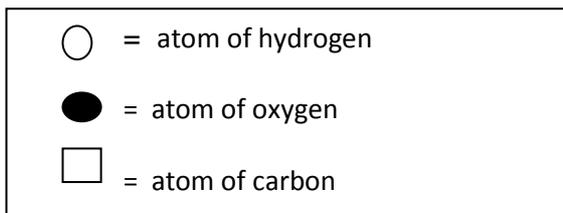
Using the key above draw particle diagrams to represent the following molecules:

a. $3\text{H}_{2(g)}$

V13 27
 V14 29
 V15 31

Question 9 *continues on the next page ...*

9. (cont.) The following key is used to represent different atoms:



Using the key above draw particle diagrams to represent the following molecules:

b. Five molecules of carbon dioxide gas (CO₂)

V16		33
V17		35
V18		37

c. 5H₂O_(l)

V19		39
V20		41
V21		43

10. Valence electrons are ...

V22		45
-----	--	----

11. Core electrons are ...

V123		47
------	--	----

12. Draw an Aufbau diagram representing an atom of aluminium, clearly marking the core and valence electrons.

V24		49
V25		51
V26		53
V27		55

Question 13 follows on the next page ...

13. Hydrogen is a very reactive element and combines chemically with many other elements. Helium, also in Period 1, is a noble Gas which means that it is completely unreactive. By referring to the electron configuration, **explain why** the two elements have such different reactivity.

Please write your answer in the box below:

V28 57
V29 59
V30 61

14. When chlorine reacts with hydrogen, a gas, hydrogen chloride, is formed. When chlorine reacts with sodium, solid sodium chloride forms.

Write down the formula for each of these compounds **in the box below:**

V31 63
V32 65

15. **Describe** the chemical bond formed between hydrogen and chlorine.

Write your answer in the box below:

V33 67
V34 69

16. **Describe** the chemical bond formed between sodium and chlorine.

V35 71
V36 73

17. **Draw a diagram** (just a sketch) to indicate the difference between these two substances.

Draw your diagram in the box below:

V37 75
V38 77

Question 18 follows on the next page ...

18. Explain why the bond between an atom of H and an atom of Cl differs from the bond between an atom of Na and an atom of Cl.

Write your explanation in the box below:

V39		79
V40		81

19. The bond between a F atom and another F atom is a non-polar covalent bond. The bond between a F atom and a H atom is a polar covalent bond.

Describe the difference between these two types of bond in the box below:

V41		83
V42		85

20. What property of the atoms determines this difference between the chemical bonds in the molecules mentioned in 19?

V43		87
-----	--	----

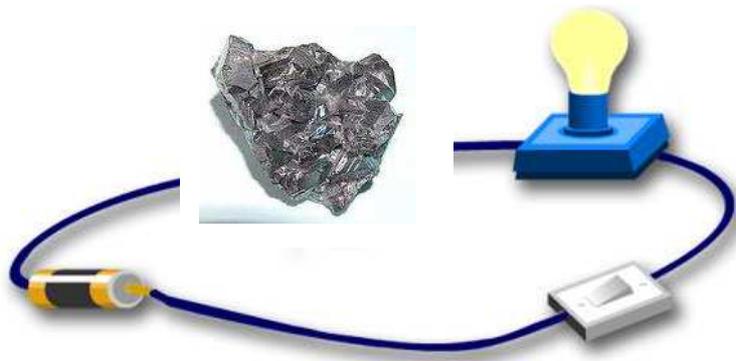
21. Explain the effect of this property in the box below:

V44		89
V45		91

Question 22 follows on the next page ...

A cell is connected to a piece of zinc and a light bulb.

Use this diagram to answer Questions 22 to 24 below.



22. Why does the light bulb light up when the switch is closed?

V46		93
V47		95
V48		97

23. Name the charged particles moving through the zinc.

V49		99
-----	--	----

24. **Describe** the chemical bonds in the zinc that are responsible for this behaviour.

Use the box below for your answer:

V50		101
V51		103

APPENDIX 7
EXAMPLES
of
CONCEPTUAL QUESTION ANSWERS
and
FEEDBACK

Examples of pupil answers with feedback:

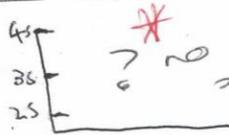
*you must learn the terminology - the words I have underlined

QUESTION 1:

Name: Murray Furness

1.1 Use an Aufbau diagram to explain why a hydrogen atom is not stable.

0/8



It does not have enough valence electrons

* which are the valence e⁻s

1.2 Explain, by referring to the electron configuration, why a neon atom never forms a Ne₂ molecule.

It is not balanced enough to form Ne₂

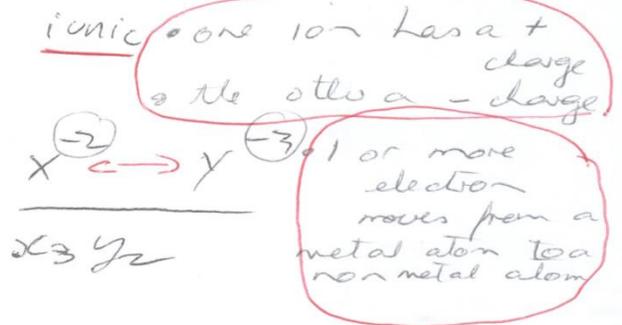
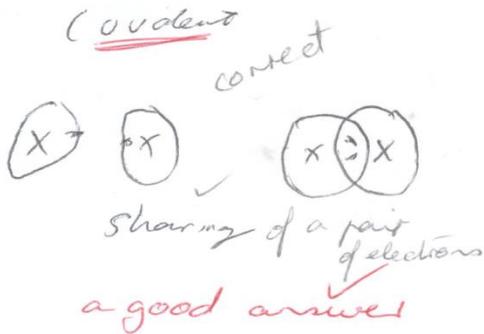
* the question asks you to refer to the electron configuration - show an aufbau diagram in your answer & explain why that electron arrangement is stable.

4.1 An ionic bond forms between a sodium atom and a fluorine atom. This is because:

- A. sodium is a metal and fluorine a non-metal;
- B. sodium atoms do not share electrons;

(C) fluorine atoms have a much higher electronegativity than sodium atoms and so attract the bonding electrons into the fluorine atom, resulting in the transfer of an electron from the sodium to the fluorine atom. *correct ✓ This is because*

4.2 Draw 2 diagrams that show that you understand and can distinguish between the process of forming a covalent bond and of forming an ionic bond. Supply a key and additional explanations if necessary.



NB - In an ionic bond the metal ion is (+) and the non-metal ion is (-). The oppositely charged ions form the bond.

APPENDIX 8

DATA FOR SUMMARY OF T-TEST RESULTS - SCORE

FORM 3 RUN 1 – SUMMARY A

Mrs A Roché - Research Project - T11058 11:48 Tuesday, December 20, 2011 1
 (A01-R5.1) : PROC TTEST on PAIRED varbs from data sets CONTPOS and CONTPRE

The TTEST Procedure

Difference: CPOSCORE - CPRSCORE

N	Mean	Std Dev	Std Err	Minimum	Maximum
32	5.3438	5.0648	0.8953	-4.0000	17.0000
	Mean	95% CL Mean	Std Dev	95% CL	Std Dev
	5.3438	3.5177 7.1698	5.0648	4.0605	6.7336
	DF	t Value	Pr > t		
	31	5.97	<.0001		

PAIRED t-test

CONTROL GROUP

POST-SCORE – PRE-SCORE

Mrs A Roché - Research Project - T11058 11:48 Tuesday, December 20, 2011 3
 (A01-R5.2) : PROC TTEST on PAIRED varbs from data sets TESTPOS and TESTPRE

The TTEST Procedure

Difference: TPOSCORE - TPRSCORE

N	Mean	Std Dev	Std Err	Minimum	Maximum
33	10.9394	6.2547	1.0888	-2.0000	28.0000
	Mean	95% CL Mean	Std Dev	95% CL	Std Dev
	10.9394	8.7216 13.1572	6.2547	5.0300	8.2730
	DF	t Value	Pr > t		
	32	10.05	<.0001		

PAIRED t-test

TEST GROUP

POST-SCORE – PRE-SCORE

Mrs A Roché - Research Project - T11058 11:48 Tuesday, December 20, 2011 5
 (A01-R9a) : PROC TTEST with CLASS varb of V33 of varbs from data set TCPR

The TTEST Procedure

Variable: SCORE

V33	N	Mean	Std Dev	Std Err	Minimum	Maximum
TestPRE	33	16.0606	5.1596	0.8982	8.0000	27.0000
ContPRE	32	20.2500	5.0673	0.8958	12.0000	29.0000
Diff (1-2)		-4.1894	5.1144	1.2689		

V33	Method	Mean	95% CL Mean		Std Dev	95% CL Std Dev	
TestPRE		16.0606	14.2311	17.8901	5.1596	4.1493	6.8245
ContPRE		20.2500	18.4230	22.0770	5.0673	4.0625	6.7369
Diff (1-2)	Pooled	-4.1894	-6.7250	-1.6538	5.1144	4.3564	6.1941
Diff (1-2)	Satterthwaite	-4.1894	-6.7243	-1.6545			

Method	Variances	DF	t Value	Pr > t
Pooled	Equal	63	-3.30	0.0016
Satterthwaite	Unequal	62.989	-3.30	0.0016

Equality of Variances

Method	Num DF	Den DF	F Value	Pr > F
Folded F	32	31	1.04	0.9215

UNPAIRED t-test

DIFFERENCE
between

CONTROL

and

TEST GROUPS

PRE-TEST

Mrs A Roché - Research Project - T11058 11:48 Tuesday, December 20, 2011 8
(A01-R9b) : PROC TTEST with CLASS varb of V33 of varbs from data set TCPO

The TTEST Procedure

Variable: SCORE

V33	N	Mean	Std Dev	Std Err	Minimum	Maximum
TestPOST	33	27.0000	7.6811	1.3371	9.0000	42.0000
ContPOST	32	25.5938	5.8578	1.0355	13.0000	37.0000
Diff (1-2)		1.4063	6.8449	1.6982		

V33	Method	Mean	95% CL Mean	Std Dev	95% CL Std Dev
TestPOST		27.0000	24.2764 29.7236	7.6811	6.1771 10.1598
ContPOST		25.5938	23.4818 27.7057	5.8578	4.6962 7.7878
Diff (1-2)	Pooled	1.4063	-1.9874 4.7999	6.8449	5.8305 8.2900
Diff (1-2)	Satterthwaite	1.4063	-1.9770 4.7895		

Method	Variances	DF	t Value	Pr > t
Pooled	Equal	63	0.83	0.4108
Satterthwaite	Unequal	59.72	0.83	0.4090

Equality of Variances

Method	Num DF	Den DF	F Value	Pr > F
Folded F	32	31	1.72	0.1347

UNPAIRED t-test

DIFFERENCE
between

CONTROL

and

TEST GROUPS

POST-TEST

FORM 3 RUN 2 – SUMMARY B

Mrs A Roché - Research Project - T11058 13:51 Monday, July 2, 2012 57
(A03-R5.1) : PROC TTEST on PAIRED varbs from data sets CONTPOS and CONTPRE

The TTEST Procedure

Difference: CPOSCORE - CPRSCORE

N	Mean	Std Dev	Std Err	Minimum	Maximum
40	14.2250	6.2613	0.9900	2.0000	29.0000
Mean	95% CL Mean	Std Dev	95% CL Std Dev		
14.2250	12.2225 16.2275	6.2613	5.1291 8.0398		
DF	t Value	Pr > t			
39	14.37	<.0001			

Difference: PCPOSCORE - PCPRSCORE

N	Mean	Std Dev	Std Err	Minimum	Maximum
40	29.0306	12.7783	2.0204	4.0816	59.1837
Mean	95% CL Mean	Std Dev	95% CL Std Dev		
29.0306	24.9439 33.1173	12.7783	10.4675 16.4077		
DF	t Value	Pr > t			
39	14.37	<.0001			

PAIRED t-test
CONTROL GROUP
POST-SCORE – PRE-SCORE

Mrs A Roché - Research Project - T11058 13:51 Monday, July 2, 2012 59
(A03-R5.2) : PROC TTEST on PAIRED varbs from data sets TESTPOS and TESTPRE

The TTEST Procedure

PAIRED t-test
TEST GROUP
POST-SCORE – PRE-SCORE

Difference: TPOSCORE - TPRSCORE

N	Mean	Std Dev	Std Err	Minimum	Maximum
41	17.5610	4.9852	0.7786	2.0000	28.0000
	Mean	95% CL Mean	Std Dev	95% CL	Std Dev
	17.5610	15.9874 19.1345	4.9852	4.0929	6.3786
	DF	t Value	Pr > t		
	40	22.56	<.0001		

Difference: PTPOSCORE - PTPRSCORE

N	Mean	Std Dev	Std Err	Minimum	Maximum
41	35.8387	10.1739	1.5889	4.0816	57.1429
	Mean	95% CL Mean	Std Dev	95% CL	Std Dev
	35.8387	32.6274 39.0500	10.1739	8.3529	13.0176
	DF	t Value	Pr > t		
	40	22.56	<.0001		

UNPAIRED t-test
**DIFFERENCE
between**
CONTROL
and
TEST GROUPS
PRE-TEST
The TTEST Procedure

Variable: SCORE

V52	N	Mean	Std Dev	Std Err	Minimum	Maximum
TestPRE	41	18.8049	5.9255	0.9254	6.0000	29.0000
ContPRE	40	13.7750	5.6455	0.8926	3.0000	23.0000
Diff (1-2)		5.0299	5.7889	1.2865		

V52	Method	Mean	95% CL Mean	Std Dev	95% CL Std Dev
TestPRE		18.8049	16.9346 20.6752	5.9255	4.8649 7.5816
ContPRE		13.7750	11.9695 15.5805	5.6455	4.6245 7.2490
Diff (1-2)	Pooled	5.0299	2.4691 7.5906	5.7889	5.0100 6.8568
Diff (1-2)	Satterthwaite	5.0299	2.4706 7.5891		

Method	Variances	DF	t Value	Pr > t
Pooled	Equal	79	3.91	0.0002
Satterthwaite	Unequal	78.957	3.91	0.0002

Equality of Variances

Method	Num DF	Den DF	F Value	Pr > F
Folded F	40	39	1.10	0.7636

Mrs A Roché - Research Project - T11058 13:51 Monday, July 2, 2012 61
 (A03-R9b) : PROC TTEST with CLASS varb of V52 of varbs from data set TCPO

The TTEST Procedure

Variable: SCORE

V52	N	Mean	Std Dev	Std Err	Minimum	Maximum
TestPOST	41	36.3659	7.1616	1.1184	15.0000	46.0000
ContPOST	40	28.0000	7.8610	1.2429	11.0000	44.0000
Diff (1-2)		8.3659	7.5150	1.6701		

V52	Method	Mean	95% CL Mean	Std Dev	95% CL Std Dev
TestPOST		36.3659	34.1054 38.6263	7.1616	5.8797 9.1632
ContPOST		28.0000	25.4859 30.5141	7.8610	6.4394 10.0938
Diff (1-2)	Pooled	8.3659	5.0416 11.6901	7.5150	6.5039 8.9013
Diff (1-2)	Satterthwaite	8.3659	5.0370 11.6947		

Method	Variances	DF	t Value	Pr > t
Pooled	Equal	79	5.01	<.0001
Satterthwaite	Unequal	77.919	5.00	<.0001

Equality of Variances

Method	Num DF	Den DF	F Value	Pr > F
Folded F	39	40	1.20	0.5598

UNPAIRED t-test

 DIFFERENCE
 between

 CONTROL

 and

 TEST GROUPS

 POST-TEST

APPENDIX 9

GRADE 10

**Summary of unpaired t-Test (between group) and paired t-Test (within group)
results using score**

	PRE-TEST		POST-TEST
TEST		<p>33</p> <p>DIFF = 10.9</p> <p>(8.7 – 13.2)</p> <p>T 10.05 p < 0.0001</p>	
	<p>33</p> <p>DIFF = -4.19</p> <p>(-6.72 to -1.65)</p> <p>T -3.3 p < 0.0016</p>	<p>←</p> <p>→</p>	<p>33</p> <p>DIFF = 1.4</p> <p>(-1.98 to 4.79)</p> <p>T 0.83 p = 0.41</p>
CONTROL		<p>32</p> <p>DIFF 5.3</p> <p>(3.5 – 7.2)</p> <p>T 5.97 p < 0.0001</p>	
		<p>←</p> <p>→</p>	

Run 2

Summary of unpaired t-Test (between group) and paired t-Test (within group) results using score:

	PRE-TEST	POST-TEST
TEST	<div style="border: 1px solid black; padding: 5px; width: fit-content; margin: auto;"> 40 DIFF = 5.03 (2.47 ; 7.59) T = 3.91 p = 0.0002 </div>	<div style="border: 1px solid black; padding: 5px; width: fit-content; margin: auto;"> 41 DIFF 17.56 (15.99; 19.13) T 22.56 p < 0.0001 </div>
CONTROL	<div style="border: 1px solid black; padding: 5px; width: fit-content; margin: auto;"> 40 DIFF 14.23 (12.22; 16.23) T 14.37 p < 0.0001 </div>	<div style="border: 1px solid black; padding: 5px; width: fit-content; margin: auto;"> 40 DIFF 8.37 (5.04; 11.69) T = 5,01 p < 0.0001 </div>

APPENDIX 10

LEARNING GAIN FORM 3 RUN 1 2011

APPENDIX 10

LEARNING GAIN FORM 3 RUN 1 2011

Mrs A Roché - Research Project - T11058 14:51 Thursday, September 20, 2012 3
 (A01-R15) : PROC TTEST with CLASS varb of GROUP of varb GAIN from data set GRFC

The TTEST Procedure

Variable: GAIN

GROUP	N	Mean	Std Dev	Std Err	Minimum	Maximum
Control	32	0.1965	0.1813	0.0321	-0.1379	0.5833
Test	33	0.3609	0.1972	0.0343	-0.0645	0.8485
Diff (1-2)		-0.1644	0.1895	0.0470		

GROUP	Method	Mean	95% CL Mean		Std Dev	95% CL Std Dev	
Control		0.1965	0.1311	0.2619	0.1813	0.1454	0.2411
Test		0.3609	0.2910	0.4308	0.1972	0.1585	0.2608
Diff (1-2)	Pooled	-0.1644	-0.2584	-0.0704	0.1895	0.1614	0.2295
Diff (1-2)	Satterthwaite	-0.1644	-0.2583	-0.0706			

Method	Variances	DF	t Value	Pr > t
Pooled	Equal	63	-3.50	0.0009
Satterthwaite	Unequal	62.828	-3.50	0.0009

Equality of Variances

Method	Num DF	Den DF	F Value	Pr > F
Folded F	32	31	1.18	0.6429

LEARNING GAIN FORM 3 RUN 2 2011

Mrs A Roché - Research Project - T11058 14:15 Friday, July 6, 2012 1
 (A03-R16) : PROC TTEST with CLASS varb of SGRP of varb LG from data set COMBOB

The TTEST Procedure

Variable: LG

SGRP	N	Mean	Std Dev	Std Err	Minimum	Maximum
Control	40	0.4109	0.1856	0.0294	0.0625	0.8387
Test	41	0.5979	0.1692	0.0264	0.0571	0.8621
Diff (1-2)		-0.1871	0.1775	0.0394		

SGRP	Method	Mean	95% CL Mean		Std Dev	95% CL Std Dev	
Control		0.4109	0.3515	0.4703	0.1856	0.1521	0.2384
Test		0.5979	0.5445	0.6513	0.1692	0.1389	0.2165
Diff (1-2)	Pooled	-0.1871	-0.2656	-0.1085	0.1775	0.1536	0.2102
Diff (1-2)	Satterthwaite	-0.1871	-0.2657	-0.1084			

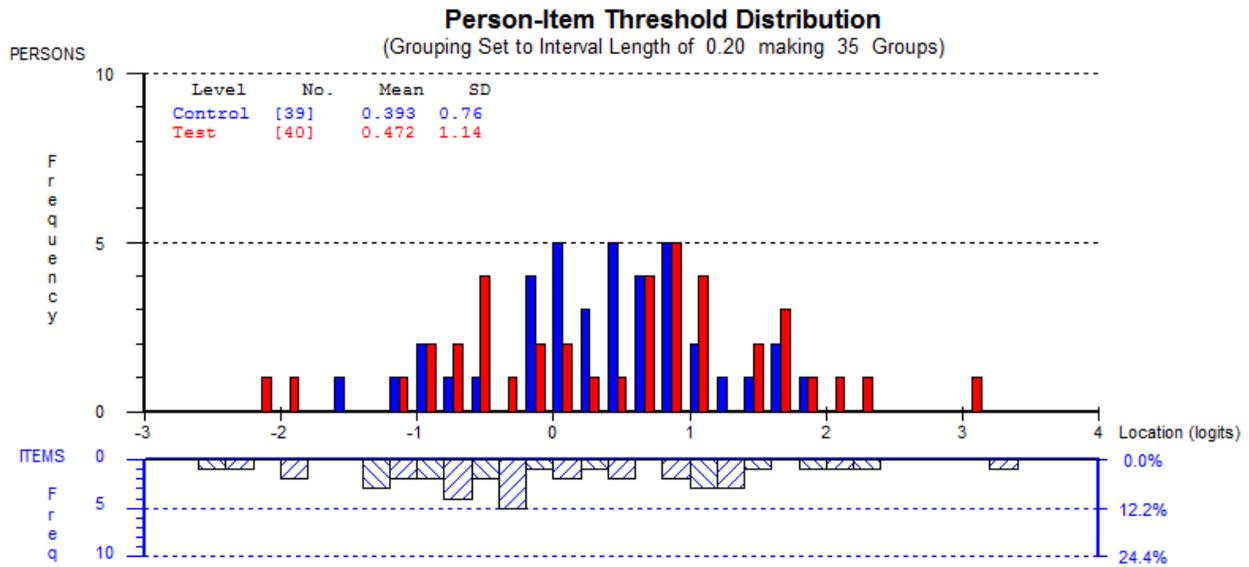
Method	Variances	DF	t Value	Pr > t
Pooled	Equal	79	-4.74	<.0001
Satterthwaite	Unequal	77.924	-4.74	<.0001

Equality of Variances

Method	Num DF	Den DF	F Value	Pr > F
Folded F	39	40	1.20	0.5612

APPENDIX 11

RASCH ANALYSIS DOCUMENTATION



WRIGHT MAP

APPENDIX 12

CONSENT FORMS

4th May 2011

Dear Parents

As part of my MSc in Science Education I am carrying out a study of the effectiveness of certain teaching strategies in fostering concept development. In particular, I will be targeting Form 3 pupils while they are studying the section on Chemical Bonding. Pupils will write a test before being taught and then again after the teaching is completed. This study is aimed solely at the improvement of teaching Physical Science.

During this study:

- **Your son is assured anonymity – no names will be mentioned in reports;**
- Test results from the study will not affect term marks;
- The normal curriculum will be followed, only the teaching method will be different.

Please will you give permission for your son to be part of this study by completing the tear off slip below and returning to me.

If you do not wish your son to take part in the study, he will in no way be discriminated against. He will be part of the class that receives the alternative teaching strategy, but will not take part in the testing process.

Yours sincerely

Mrs Angela Roche

I parent of

give permission for my son to participate in the study outlined above.

Signed:

Date:

June 2011

REQUEST FOR PERMISSION TO USE ST ALBAN'S COLLEGE PUPILS FOR A RESESARCH PROJECT

I wish to use Form 3 and Form 4 classes in a study of the effectiveness of a new teaching method to teach a section of their syllabus that deals with Chemical Bonding and Intermolecular Forces.

This research project forms the basis of an MSc: Chemical Education that I began in January 2010 and hope to complete by December 2012.

Pupils will be tested before teaching on the relevant section begins and then once the teaching on that section is completed. The test group (2 classes of each year group) will receive intervention questions along with feedback on their answers to promote concept formation. The control group (the other 2 classes) will be taught in the conventional way. Any marks scored in these tests and questioning will not affect term marks. Parental permission was obtained for the pupils in the test group to take part in the study.

In order to document the permission granted by the school please will you complete the following:

I

give permission for Angela Roche to make use of the facilities available at St Alban's College for her research project that forms part of a MSc degree. In addition, the school gives her permission to involve the relevant pupils in her study.

Signed:

Date:



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

ETHICS COMMITTEE

Faculty of Natural and Agricultural Sciences

05 December 2011

Ms A Roche

Box 11058

Hatfield

0028

Dear Ms Roche

Re: EC111031-075 An alternative method of teaching chemical bonding to high school pupils

The project conforms to the requirements of the Ethics Committee.

Kind regards

A handwritten signature in blue ink, appearing to read 'NH Casey', written over a horizontal line.

Prof NH Casey
Chairman: Ethics Committee