VISUAL MODELS OF CHEMICAL ENTITIES AND REACTIONS: PERCEPTIONS HELD BY GRADE 11 LEARNERS

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Dissertation submitted in fulfilment of the requirements for the degree Magister Educationis in the School of Science, Mathematics and Technology Education at the North-West University, Potchefstroom Campus.

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POTCHEFSTROOM
2006

ACKNOWLEDGEMENT

I would like to formally acknowledge with sincere thanks, the following people and organizations for their contribution and support in carrying out this study:

- My family for their patience, consideration and support.
- Professor J. J.A. Smit for his prompt and meticulous supervision and his tolerance and understanding.
- Dr M.Lemmer for her valuable and generous contributions in guiding me through the study.
- Mrs Elsa Brand for proof reading and grammatical editing.
- Mrs M. Vosloo for her support and making it possible to have contact lessons with Prof. J.J.A. Smit.
- Mrs M. Wiggill for her assistance in a search for reading material in the Ferdinand Postma Library.

ABSTRACT

[Key words: models, atoms, ions, compounds, chemical reactions, alternative conceptions]

Learners of chemistry experience problems with the understanding of chemical reactions. One of the causes of this difficulty to understand chemical reactions seems to be that learners do not visualise them, or they do not know how to visualise them. The study aims at probing the learners' perceptions of visual models of sub-microscopic entities (atoms, ions, and molecules), to identify problems they encounter when trying to visualise and to understand chemical reactions.

The empirical survey was conducted amongst 100 physical science Grade 11 learners from four high schools in the Bojanala West region near Rustenburg in the North-West Province, South Africa.

The investigation was done by means of a questionnaire. The results of the questionnaire were used to identify alternative conceptions and problems that hampered learners' visualisation process. The results indicated that learners had problems with visualisation of the structure and the interaction of basic entities such as atoms, ions and molecules in chemical reactions. This had a negative effect on their understanding of chemical reactions and chemistry.

OPSOMMING

[Sleutelwoorde: modelle, atome, ione, verbindings, chemiese reaksies, alternatiewe persepsies]

Leerders van chemie ervaar probleme om chemiese reaksies te verstaan. Een van die redes vir hierdie probleem om chemiese reaksies te verstaan, is blykbaar dat leerders dit nie visualiseer nie, of nie weet hoe om dit te visualiseer nie. Hierdie studie stel dit ten doel om ondersoek in te stel na die leerders se persepsies van visuele modelle van subatomiese eenhede (atome, ione en molekule) ten einde die probleme wat hulle ondervind wanneer hulle probeer om chemiese reaksies te visualiseer of te verstaan, te identifiseer.

Die empiriese studie is onder 100 natuurwetenskap-leerders gedoen van vier hoërskole in die Bojanalawes-streek naby Rustenburg in die Noordwes-provinsie, Suid-Afrika..

Die ondersoek is deur middel van 'n vraelys gedoen. Die resultate van die vraelys is gebruik om alternatiewe persepsies en probleme wat leerders se visualiseringsproses verhinder, te identifiseer. Die resultate het aangedui dat leerders probleme ervaar met die visualisering van die struktuur en interaksie van basiese begrippe soos atome, ione en molekules in chemiese reaksies. Dit het 'n negatiewe uitwerking op hul begrip van chemiese reaksies en chemie.

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CHAPTER 1
ORIENTIVE INTRODUCTION

1.1 INTRODUCTION

Various studies, including one by Smit and Finegold (1995:621), have shown that models are important in the acquisition of scientific knowledge. Studies (see chapter 3) also indicate that learners are unable to use models to help them to understand physical science.

According to a literature survey done by Smit and Finegold (1995:622), a model is an invention of the human mind. Chapter 2 deals in depth with models. Models help one to describe and explain phenomena, or to make them easier to deal with and understand. It is thus important for educators to have a sound knowledge of the origin, nature and functions of scientific models. This will contribute to learners' understanding of the concepts in science by guiding correct visualisation, because educators are responsible to guide learners in the modelling process (Smit & Finegold, 1995:633).

One of the main reasons why learners do not understand chemical reactions is improper visualisation (Smit & Finegold, 1995:633). Visual models assist learners and educators to describe, predict and explain observations in order to promote the acquisition of knowledge and understanding of chemical reactions. If teachers do not consider learners' personal models, the aim of understanding science would not be achieved (Smit & Finegold, 1995:633).

Harré (1970) indicates that there are two carriers of scientific thinking, namely mental models (images) and words. Smit (2001:223) indicates that the basic rule in the construction of mental models involves that learners form scientifically acceptable mental images of physical entities and processes and associate these mental images with the corresponding verbal tags.

Smit and Finegold (1995:633) point out that models are a neglected topic in the teaching of science. This might be the reason why learners have conceptual problems and do not understand chemistry. According to Smit (2001:222), learners have alternative conceptions with regard to the nature and functions of scientific models. These alternative conceptions give rise to conceptual problems.

The existence of personal models that learners hold about chemical reactions is expected to contribute to a lack of understanding of chemistry. If educators were aware of these personal models, strategies aimed at the establishment of scientific models in learners' minds can be devised and implemented.

This study specifically focuses on learners' models of chemical reactions. In the context of this introductory discussion, the hypothesis to be tested in this dissertation can be formulated.

1.2 HYPOTHESIS

Problems that Grade 11 learners experience with the understanding of chemical reactions are caused by an inability to form visual models of the sub-microscopic entities and processes involved in chemical reactions.

1.3 MOTIVATION

Although studies have been conducted about the general views of scientific models, little attention has been paid to models at school level. No in-depth discussions of the different types of models and the nature and functions of models that are utilised in chemistry have been reported in literature. According to Smit (2001:223), the topic of models and their functions should receive more attention in teaching and learning. This would result in a better understanding of science.

Smit and Finegold (1995:621) came to the conclusion that student educators preparing to teach science are far from prepared to incorporate models properly in their teaching. This has a negative effect on learners' comprehension of chemistry. In educators' training programmes little attention is paid to the basic principles of scientific thinking and to the topic of scientific models in general.

It is an accepted fact that learners enter the science classroom with preconceptions (preconceptions are dealt with in Chapter 3). Knowledge about scientific models could help in discarding learners' conceptions that are not in line with generally accepted scientific thinking. Knowledge about scientific models is expected to help the educator in teaching scientific modeling and the modelling of chemical entities and processes.

1.4 OBJECTIVES OF THE STUDY

The study reported on in this dissertation focuses on (i) how learners visualise chemical reactions, and (ii) how their visualisation helps them with the comprehension of chemical reactions. The focus of this study is on visual models of chemical reactions on Grade 11 level. Specific objectives derived from the hypothesis are:

1.4.1 To conduct a literature study to identify and describe the models involved in the understanding of chemical reactions

The basic ideas and facts about models in chemistry recorded in literature will be identified and discussed in classifications, functions, the nature and the origin of models in science. Reference will be made to what models are as well as the different types of models. In educational context, alternative conceptions (learners' models) about different concepts in chemistry and about reactions will be discussed. A review of models in teaching and learning will receive attention.

1.4.2 To investigate how learners visualise atoms, compounds and ions in the context of chemical reactions

Models are frequently used to describe and explain scientific concepts; therefore it is important to investigate learners' mental models. An empirical survey will be conducted in order to get ideas of how learners visualise atoms, compounds and ions. The investigation will include the relation between the visualisation of these concepts and learners' understanding of the roles of these entities in chemical reactions.

1.4.3 To investigate how learners visualise simple chemical reactions

The visualisation of chemical reactions forms part of the empirical investigation. This investigation includes illustrations of reactants, processes and products by visual representation. This part of the study will add to the researcher's knowledge and comprehension of learners' views of the sub-microscopic entities and processes involved in chemical reactions.

The terms *models* and *alternative conceptions* as used in this study are described in section 1.5 below.

1.5 DESCRIPTION OF TERMS

1.5.1 Model

According to Harrison and Treagust (2000:355), a model can be taken as a way to do something as well as being a representation of a familiar or non-observable entity. If taken as a way to do something, a model could be steps for solving a problem or a procedure for preparing a standard solution. These types of models could be referred to as procedural models. Analogical models on the other hand, are restricted to the physical objects, pictures, equations and graphs that depict objects, theories and relationships. In chemistry, analogical models can be scale models, molecular models, symbolic models, such as chemical formulae, mathematical models like $PV = k$, theoretical models (reaction mechanisms) and concept-process models.

According to Vosniadou (as quoted by Harrison & Treagust, 2000:356), mental models are mental representations that individuals generate. They are descriptions of objects and ideas that are unique to the knower and arise through interaction with a target system. These kinds of models are highly personal. Highly abstract non-observable phenomena and processes are explained by using models. There are many different types of models. Their classifications are dealt with in Chapter 2. Chapter 2 also attends to definitions of what a model is.

In science, modelling is part of scientific thinking. Harrison and Treagust (1998:420) indicate that models could represent a concrete object or a process. Models are seen as scientists' attempts to represent difficult and abstract phenomena in everyday terms; terms that the scientist is familiar with. Models accompany most of the scientific explanations. They also facilitate learning and enhance memory. Models need to be useful and logical in order to be understood. The comprehension of a model depends on a learner's link between models and prior knowledge. Concept-building models represent aspects of scientific objects and processes.

Chemistry relies on models to describe and explain chemical processes and physical changes in matter. A distinction is often made between symbolic models in chemistry (equations and chemical formulae) and conceptual models dealing with concepts such as atoms, ions, molecules and chemical reactions. Chemistry cannot be taught without models (Harrison & Treagust, 1998:425). Van Driel and Verloop (1999:1142) state that models may be characterised as descriptive, explanatory or predictive. Models are always related to a target. They always differ in certain respects from the target and may change from time to time when new data on a topic is added.

1.5.2 Alternative conceptions

Wesi (1997:6) states that in the scientific community general agreement based on valid investigations and reliable reasoning determines what a particular concept should mean. Reasoning that does not fit into the accepted scientific arguments are considered scientifically incorrect and are referred to as alternative conceptions. According to Thijs and Van den Berg (1995:325), an alternative conception in science refers to a conception that is contradictory or inconsistent with concepts as intended by scientists (Wesi, 1997:6).

Alternative conceptions result when learners try to make sense of the world around them when they relate new knowledge to their personal experiences. These personal conceptions often indicate a lack of understanding of the underlying scientific concept. Curriculum material that learners encounter might have some influence on the formation of these conceptions (Coll & Taylor, 2001:171).

Through observations of the world around them, learners form their own understanding and ideas about what they see in their surroundings and what they learn in science (Wesi, 1997:6). These ideas are most of the time not in line with scientific thinking and cause problems with the learning of scientific concepts. They cannot be linked to other concepts or applied consistently in different situations.

Driver *et al.* (1985:2) indicate that the alternative conceptions are personal, very stable and resistant to scientific explanation and observation. Educators and learners may have alternative conceptions. Alternative conceptions may thus arise as a result of teaching. Synonyms used for alternative conceptions are preconceptions, misconceptions, children's science and naïve ideas (Wesi, 1997:8). An extended discussion of alternative conceptions, models and chemical reactions is given in Chapter 3.

1.6 METHOD OF RESEARCH

1.6.1 Literature study

Literature on models in science, chemical entities and reactions, the teaching and learning of chemical reactions and learners' perceptions of chemical reactions was obtained by means of electronic searches (ERIC, RSAT & EBSCOHOST) of recent publications on the topics, books and in scientific and educational publications.

A thorough literature study was conducted to gain an in-depth understanding of the role that models play in the conceptualisation in chemistry. The objectives stated above were partially addressed in the literature survey.

1.6.2 Empirical research

The method to acquire data was as follows: -

Based on the literature study, a questionnaire was compiled in order to probe into the issues stated in the three objectives. The data was processed by hand and analysed statistically. The results were interpreted and recommendations were made with regard to the teaching of chemical reactions.

1.6.3 Population

The study was focused on a group of hundred (100) Grade 11 science learners from four high schools in Bojanala West region near Rustenburg in the North-West Province, South Africa.

1.7 OUTLINE OF CHAPTERS

This chapter has stated the introduction, hypothesis, and objectives and gave the motivation for the study. The key terms *model* and *alternative conceptions,* were introduced. The method of research was outlined.

Chapter 2 gives a literature review of the classifications, functions, nature and origin of models in science. Chapter 3 gives a literature review on visualisation and alternative conceptions about models in chemistry.

Chapter 4 deals with the literature review of the use of models in teaching, while Chapter 5 deals with the empirical study. Chapter 6 gives the results of the empirical survey and discussions of results, with the conclusion and recommendation following in Chapter 7.

CHAPTER 2

LITERATURE REVIEW: CLASSIFICATION, FUNCTIONS, NATURE AND ORIGIN OF MODELS IN SCIENCE

2.1 INTRODUCTION

An objective (Chapter 1, paragraph 1.4.1) of the study was to conduct a literature study to identify and describe the models involved in the understanding of chemical reactions. This chapter takes a closer look at this objective. It focuses on general aspects of scientific models and then discusses specific models relevant to chemical reactions.

Halloun (1998:239) states that studies have shown that learners sometimes pass science examinations with little understanding of what they are doing. According to Halloun (1998:239), this is as a result of the presentation of concepts and principles without showing how they relate to one another, how they can be used for description, explanation, prediction, controlling and designing of real-world systems and phenomena.

According to Halloun (1998:240), model-based instruction provides an alternative to traditional instruction. Scientific concepts and principles are developed coherently and related to one another within the context of conceptual models. Researchers found that learners reach a better understanding of science under model-based instruction than under traditional lecturing (Halloun, 1998:240)(Gilbert & Boulter, 1995).

This calls for a deeper look into scientific models. This chapter gives an overview of the different classifications, the functions, nature and origin of scientific models. If models were to be used, it is necessary to know more about these models so that they can be used effectively in science teaching. This is necessary because most science lessons require the use of models to convey aspects of the science content and the nature and development of science.

2.2 THE ORIGIN AND NATURE OF MODELS IN SCIENCE

Models are an important content type in science (Jordaan, 1984) and serve an essential function in the teaching of science as indicated in the previous paragraph.

Smit and Finegold (1995:622) describe models as creations of the human mind. A model brings knowledge together, for example atomic models link the phenomena of heat, chemical bonding, light emission, electricity and density. Smit and Finegold (1995:621) continue and remarked that models do not occur in nature, while the objects of modelling do. Models are not copies or real representations of modelled entities. Models do not need to look like the real thing. Van Oers (1988:128) is of the opinion that models could be representations of a real entity but it is not the real thing. A model is a token or symbol of the real thing.

Smit and Finegold (1995:630) point out that scientific models are temporary by nature, which means that new knowledge on a topic might reveal shortcomings in an existing model, which could make it necessary to change the model or to reject it. An example of the development of models is the series of atomic models (Kgwadi, 2001). All scientists carry more or less the same mental picture of an object or entity. The mental pictures may be abstract mathematical models with no spatial image associated, or a model that can be visualised, or it could be an image or an icon.

Hodgson and Hapser (as quoted by Harrison & Treagust, 1998:420) explain that classroom modelling could be either a multi-step problem-solving process or it could be a specific model such as a graph or an equation.

According to Smit and Finegold (1995:630), models must fit into the structure of science, which means they must co-exist with other models. Science often uses concept-building analogical models, such as scale models, pedagogical analogical models, maps and diagrams, mathematical and theoretical models and simulations to represent objects, ideas and processes. Models can be seen as scientists' and educators' attempts to represent difficult and abstract phenomena in everyday terms for the benefit of research and teaching. Models are thinking tools and can be purposefully manipulated by the modeller to suit epistemological needs (Harrison & Treagust, 1998:421).

Hesse (1966) indicated that models might be characterised as descriptive, explanatory or predictive. According to Van Driel and Verloop (1999:1142), an example of a predictive model is one describing the orbits of the planets in our solar system. The concept of gravity derived from Newtonian theory may be used to design a model that explains the movement of the planets and also enables the formulation of predictions. For example, the existence of the eighth planet Uranus was predicted from models of the solar system and was indeed later identified by observation.

De Vos (1985) and Van Hoeve-Brouwer (1996) (as quoted by van Driel & Verloop, 1999:1142) gave common characteristics that apply to all scientific models:

- A model is always related to a target that it represents.
- It is a research tool used to obtain information about a target that cannot be observed or measured directly (e.g. an atom).
- It cannot interact directly with the target it represents.
- The model enables the researcher to derive a hypothesis that may be tested while studying the target.
- It always differs in certain respect from the target, i.e. it must be kept simple and includes features that are relevant to the object of study. Therefore most models have a simple structure.

Van Driel and Verloop (1999:1150) indicate that scientists might reach agreement to arrive at what they value as consensus models. Co-existence of various models of the same target demonstrates that a model does not necessarily bear as much positive correspondence to a target as it possibly could because there are limitations.

Giere (1994) quoted by Halloun (1998:242), state that basic conceptual models are at the foundations of scientific theories. According to Halloun (1998:243), a comprehensive presentation of a scientific model can be brought about in four dimensions: domain, composition, structure and organisation. The following paragraphs describe each of the dimensions.

- According to Halloun (1998:247), the domain of a model consists of physical systems that can be described and explained by the model. It consists of physical quantities of the real world that share a specific feature that are represented in some respect. In the models of Newtonian mechanics, the concept of force characterises the interaction between physical entities that is the object and agent. In classical mechanics, two types of interaction are distinguished, i.e. interaction at a distance and contact interaction.

- The structure of a model (Halloun, 1998:243) consists of relationships among the descriptors of different entities (descriptive and / or explanatory).

- The composition of a model (Halloun, 1998:243) consists of conceptual objects and properties or descriptors.

- Organisation refers to a model's relationship to other models in a given scientific theory. "In science, an isolated concept is practically meaningless and useless" (Halloun, 1998:247). A concept is always related to other concepts in a scientific theory through axioms, definitions and laws, the network of which makes up the structure of basic models of the concept. Rules are established to tell us how one model relates to another model in order to describe, explain and /or predict the behaviour of objects.

Bower and Marrow (as quoted by Halloun, 1998:241) state that mental models represent important aspects of our physical and social world that can be manipulated when trying to explain events of that world.

2.3 CLASSIFICATIONS OF MODELS IN SCIENCE

Different classifications or taxonomies of scientific models are described in the literature. All reveal important aspects of scientific models. A brief discussion of the different classifications is given in the following paragraphs.

Santema (1978) classified all models related to nature into two categories: subjective models and models of being or existence. Models of being were used to create the world and are godlike. Subjective models on the other hand, are human creations. Subjective models are further divided into knowledge models and make models. Knowledge models are models that help scientists to know the world, while make models are used by engineers. Figure 2.1 visually displays the relationship between the different model types.

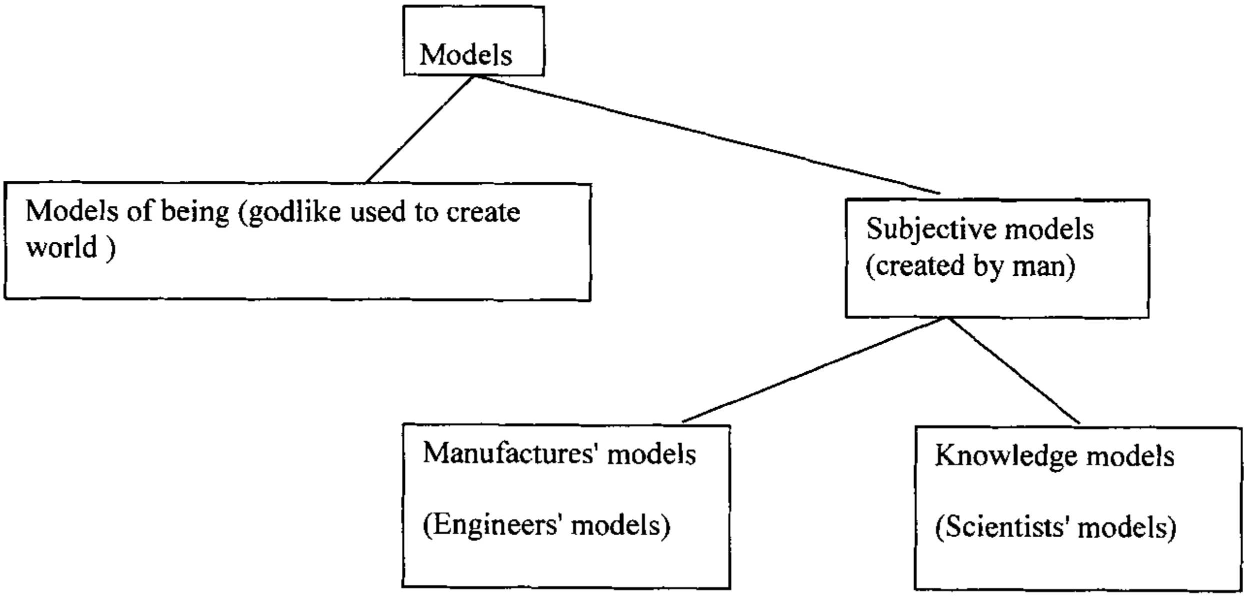


Figure 2.1: Relationship between models as described by Santema (1978)

Harré (1970) classified knowledge models into different types according to their relation to the source of the model (see Figure 2.2). The source of a model is the object or entity in nature that the model represents. Harré (1970) classified models as *homeomorphs* if the source were the object under modeling. If the source were not the object under modelling, the model falls in the class *paramorphs.*

Homeomorphs can be divided into *megamorphs* and *micromorphs*, *teleomorphs* and *metriomorphs* (Figure 2.2). At the basis of *megamorphs* and *micromorphs* is the process of scaling. *Micromorphs* deal with down-scaling of large entities, for example a model of the sun, a model of the universe, while *megamorphs* deal with up-scaling of very small entities, for example a model of the sodium chloride crystal and atoms (Smit, 2001:221).

The *teleomorph* is an improvement of the object under modelling. *Telemorphs* are further divided into *idealisations* and *abstractions,* as illustrated in Figure 2.2. An example of an *idealisation* is the ideal gas. *Abstract* models have fewer properties than the source of the object. Examples are the conventional current in DC electricity and electrically charged objects. *Paramorphs* are analogue models. Such models are usually referred to as *analogies*. Analogies relate the objects or process under modelling to something that scientists have more knowledge of or understand better (Smit, 2001:221).

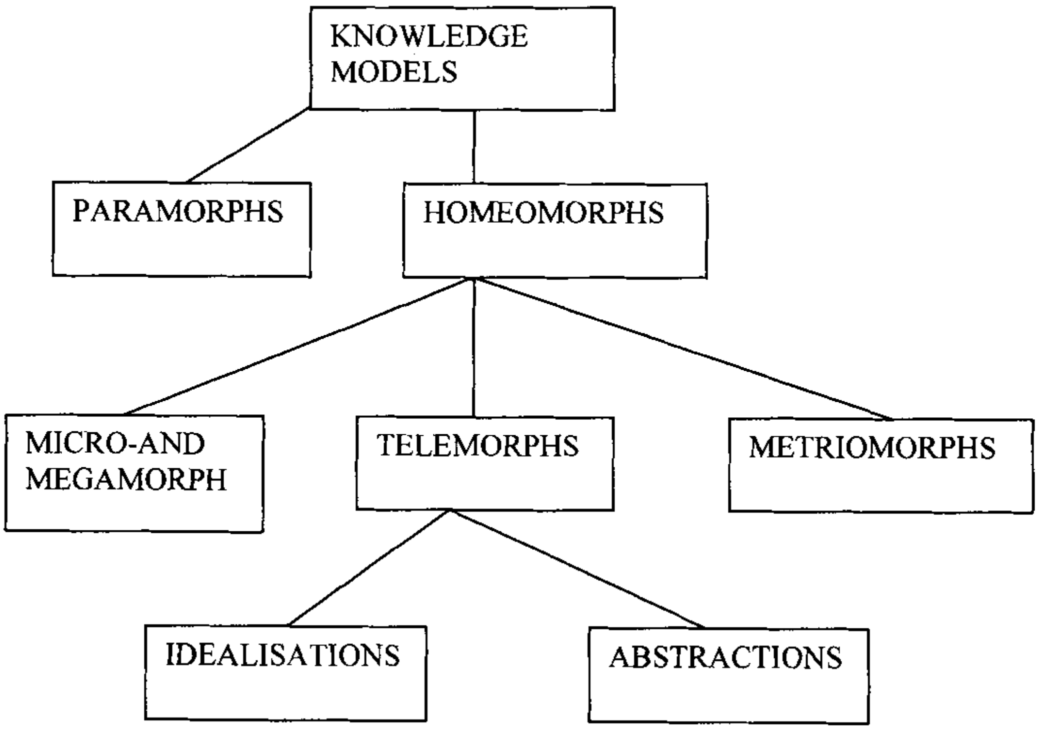


Figure 2.2: Harré's taxonomy of models (1970)

An example of an analogy is the planetary model of the atom. Scientists have a good idea of the solar system, where the sun is at a central position and the planets in orbits around it. In the planetary model of the atom an analogy is drawn. The nucleus is analogous to the sun and the electrons orbiting it to the planets.

Hesse (1966) illustrated that an analogy has positive, negative and neutral parts. The positive part relates the model and the object under modelling by their corresponding properties. The negative part gives the differences. The neutral part relates to the properties of the object and the model that we do not have sufficient knowledge of to classify them as positive or negative.

Harré (1970) presented another simpler classification of physics models. He distinguished between three types of models.

Type 1

Models of type 1 represent real existing entities. The existence of the entities has been proven experimentally. Examples of Type 1 models are models of atoms, gases, the earth and the planets. These entities are regarded as real and existing, since they were observed either by the naked eye or in experiments. An experiment is used to give proof of the existence of the entity.

Type 2

Harré (1970) stated that Type 2 models are models of hypothetical entities. The entity under modelling may or may not exist. No experiment has proven its existence, but there are indicators of its existence. If its existence could be proven experimentally, its status would change to that of Type 1. If its non-existence were proven, the model would shift into the history of physics. Type 2 models are related to time in history and developments in science. Take as examples the models of the neutron and of the eather. Both were Type 2 models. When experiments proved the existence of the neutron in 1932, the model of the neutron shifted to Type 1.

Type 3

Models that do not represent any real or hypothetical entities are classified by Harré (1970) as belonging to Type 3. These models are mostly functional and serve instrumental purposes, for example the conventional current model in electricity that enables the quantitative descriptions of energy transfer in electric circuits. Another example is the geocentric model of the universe that regards the stars as fixed with the earth at its center. This model still serves to guide fisherman at night on the oceans. Type 3 models have a utility value.

Another classification of models relevant to this study is made by Harrison and Treagust (1998:422), who classified analogical concept-building models into:

- Concrete/abstract models designed to represent reality;
- abstract models designed to communicate theory; and
- Models depicting multiple concepts and processes.

Concrete/abstract models designed to represent reality

According to Harrison and Treagust (1998:420), concrete / abstract models that are designed to represent reality, are further divided into scale models and pedagogical-analogical models. Scale models reflect external properties but rarely show internal structure or functions. They are not made of the same material as the target. Scale models look realistic but are different from the target. Pedagogical analogical models are concrete models that are used to depict abstract and non-observable entities, such as atoms and molecules. Some can be constructed by using balls and sticks.

Abstract models designed to communicate theory (Harrison & Treagust, 1998:422)

Abstract models are designed to communicate theory. These models are divided into iconic, symbolic, mathematical and theoretical models. Examples of iconic and symbolic models are, according to Harrison and Treagust (1998:420), chemical formulae, chemical equations and chemical reactions. They have explanatory and communicative functions. Physical properties, changes and processes can be represented as mathematical equations and graphs that elegantly depict conceptual relationships for example, Boyle's law, Newton's second law ($F = ma$) and exponential decays. It is important that learners construct qualitative explanations of these mathematical models. Theoretical models are human constructions describing well-grounded theoretical entities, for example the kinetic model of a gas uses the model of spheres for particles to relate the parameters volume, temperature and pressure.

Models depicting multiple concepts and processes

According to Harrison and Treagust (1998:422), models depicting multiple concepts and processes are further divided into three sectors, i.e. maps, diagrams and tables in the first section, concept-process models in the second and simulations in the third section.

Maps, diagrams and tables represent patterns, pathways and relationships that can easily be visualised by learners. For example, the periodic table and circuit diagrams. Concept-process models are models in which the science entities under modelling are *processes* rather than *objects*. Educators explain immaterial processes to learners by using concept-process models such as multiple models of acids and bases, oxidation-reduction and physical and chemical equilibrium. Simulations allow the researchers to develop skills without risking life and property. It includes virtual reality experiences, for example computer-based interactive multimedia. These usually employ stylised and real-life situations.

Harrison and Treagust (1998:424) also identifies and describes multiple explanatory models. Most science concepts depend on more than one model for their description and explanation. The more abstract and non-observable a phenomenon is, the more likely it is to require a model to be comprehended, for example atoms, molecules and chemical reactions. Each of the models explains a part of the target's attributes. Multiple simplified models also signal to learners that no individual model is absolute correct. Models have limitations because human inventions break down at some point.

2.4 FUNCTIONS OF MODELS IN SCIENCE

According to Smit (2001:222), the primary function of scientists' models is to supply knowledge of reality and thus to promote a better understanding of nature. Models can be used in the description, prediction and explanation of natural entities, processes and phenomena. They help to organise information in an attempt to understand nature and its workings. They play an important role in scientific communication.

Gilbert and Boulter (1995) describe the function of teaching models as to preserve the conceptual structure of a consensus model, demonstrate constant interplay of thoughts and actions in science and deal with previous knowledge of learners by providing ways to build on their personal understanding of science.

Halloun (1998:242) points out that models comprise the core content of scientific knowledge, and modelling is a major process for constructing and employing this knowledge.

Harrison and Treagust (2000:352) indicate that analogical models are used to explain some aspects of scientific content, such as food chains, magnetic fields or molecular models, in order to make abstract content more accessible to the learners in familiar, visual and often tactile ways. They further indicate that models provide the means for exploring, describing and explaining scientific and mathematical ideas. Models make science relevant and interesting.

Harrison and Treagust (1998:420) state that analogical models stimulate learners' curiosity and imagination and enhance their creative thinking. With the aid of models learners can learn to think in more sophisticated ways than was previously considered possible. Models offer a way to do something as well as being a representation of a familiar or a non-observable entity. Mental models are intrinsic descriptors of objects and of ideas that are unique to the knower and arise through interaction with the target system.

Teachers use models to explain immaterial processes, such as electrons flowing in a wire. Models can act as aids to memory, explanatory tools and learning devises if they were understood and remembered by learners (Harrison & Treagust, 1998:421).

Van Driel and Verloop (1999:1143) indicate that models play an important role in communication between scientists. They are used to make predictions or are perceived as tools for obtaining information about a target that is inaccessible for direct observation, for example an atom. A model of a target enables the researcher to derive a hypothesis that may be tested. Testing the hypothesis produces new information about the target.

Halloun (1998:242) reveals that models are considered as unifying themes in recently published science education standards. Meaningful understanding of individual scientific concepts is best achieved within the context of schematic and especially basic models. Conceptual models can be used to build a general theoretical framework or to develop individual concepts.

2.5 MODELS IN CHEMICAL REACTIONS

According to Smit (2001:221), visualisation of chemical reactions makes the reactions to be subjective because visualisation is a human creation. An example is the visualisation of a chemical reaction as particles colliding to form a new substance. Models of chemical reactions can be classified as knowledge models (Harré,1970) because they help one to understand and know the nature of chemical reactions.

Smit (2001:221) further indicates that chemical reactions are paramorphs, because the source of the model is not the object under modelling. Paramorphs are "parallel" to the real thing, and are therefore analogue models. They are related to the process under modelling by something scientists have knowledge of or understand better. An example is the representation of chemical reactions by particles colliding and combining to form new substances. Through everyday experiences the scientist is acquainted with particles and collisions between particles.

An attempt to explain the physical behaviour of substances leads to the evolution of the **kinetic molecular theory**. This theory has at its core a model. This underlying theory is described below.

According Horn *et al.* (1992:183), a given sample of ***matter is composed of a huge number of small particles*** (molecules, atoms, and/or ions). The kinetic molecular model assumes large spaces between gas particles, particles colliding and exerting very small forces if any and no forces on each other when not colliding. When particles collide, forces are exerted on each other. In solids, particles are tightly packed in fixed positions and only vibrate around the fixed positions. The amplitudes of the vibrations increase with a rise in temperature. In liquids, the particles are tightly packed and able to move, but are not as free to move as in gases. Particles in a liquid glide over one another.

There are forces of attraction and repulsion between particles. Horn *et al.* (1992:183) state that gas particles exert forces on one another during collisions. They always fill the container in which they are placed. They have no fixed positions and slide over one another. In liquids, the forces keeping the particles together give liquids their fluid properties. This explains why liquids take up the shape of the container. In solids the particles are held together by strong forces of attraction. The particles have fixed positions in a solid. This explains their specific shapes and sizes.

Particles of matter are in a state of constant motion. According to Horn *et al.* (1992:183), a container filled with a gas contains a large number of particles. Particles are in constant random motion, colliding with each other and with the walls of the container. In a short period of time a particle undergoes many collisions. This explains why gases fill the container and why they undergo diffusion. The particles of liquids are able to move from one place to the other but they cannot move as fast and free as in gases because they are much closer together. Particles of solids vibrate around fixed positions; they cannot move from one position to another without addition of energy.

Due to continuous motion, particles collide. Horn *et al.* (1992:184) state that in gases, pressure on the sides of a container is explained in terms of collisions of gas molecules with the sides of the container. This pressure is dependent on the number of collisions per unit area and on the force of each collision. Liquids also exert pressure on the sides of the container due to collisions.

All collisions between gas particles are perfectly elastic. Horn *et al.* (1992:184) state that this means that the kinetic energy of a particle before collision is the same as that after collision.

Speeds of particles (atoms or molecules) are continuously changing due to collisions with others. A distribution of kinetic energies is associated with the distribution of molecular speeds. The average kinetic energy of a group of particles in a container or in the atmosphere at a given temperature remains constant and is a useful concept in physics and chemistry. As the temperature of a gas increases, the average kinetic energy of the gas molecules also increases.

2.6 SUMMARY

In this chapter objective 1.4.1 of this study (Chapter 1), that was to conduct a literature study to identify and describe the models involved in the understanding of chemical reactions, was attended to.

The next chapter (Chapter 3) deals with objectives 1.4.2 and 1.4.3 (Chapter 1), that was to investigate in a literature study how learners visualise atoms, compounds, ions and chemical reactions.

CHAPTER 3

LITERATURE REVIEW: VISUALISATION AND ALTERNATIVE CONCEPTIONS ABOUT MODELS IN CHEMISTRY

3.1 INTRODUCTION

In this chapter the focus is on objectives 1.4.2 and 1.4.3 of this dissertation (Chapter 1). Alternative conceptions about models in chemistry and about chemical reactions identified in a literature study are reported. Models involved in the understanding of chemical reactions are identified and described. Different types of alternative conceptions are discussed. The literature reveals that popular synonyms used for alternative conceptions are *preconceptions, misconceptions, children's science and naïve ideas* (Wesi, 1997:8). In this dissertation the term *alternative conception* will be used.

3.2 ALTERNATIVE CONCEPTIONS

First, a general view about what alternative conceptions are and how they are formed is given. Thereafter the different types of alternative conceptions will be discussed.

3.2.1 Nature and formation of alternative conceptions

Coll and Taylor (2001:176) describe alternative conceptions as those conceptions in which the view is in disagreement with the scientific view. Alternative conceptions result from reasoning based on common sense that people unconsciously follow and apply. They are results from quick explanations of natural phenomena without much reflection, based on broad generalisations (Vicente, 2002:47).

Gilbert and Watts (1983:66) state that the process of acquisition of knowledge can be broken down into elementary steps, while the progress in knowledge acquisition depends on whether the previous step has been mastered. The problem of not mastering the previous step could give rise to misconceptions, which cause a flaw in the cognitive structure of the learner. Gilbert and Watts (1983:66) further state that conceptions are reflections of an individual of how the person thinks the world really is. He/she describes alternative frameworks as a brief summary of descriptions that attempt to capture both the explicit responses made and the construed intentions behind them. They are interpretations of data, stylised by the responses made by learners (Gilbert & Watts, 1983:69).

According to Smit and Nel (1997:202), insufficient development of the basic concepts could lead to the development of alternative conceptions. Harrison and Treagust (2000:353) state that unfamiliarity with scientific modelling and the limitations of analogical and metaphoric representations lead to the formation of alternative conceptions. Alternative conceptions depend on how learners interpret models, as well as their prior experience, knowledge, language skills and thinking strategies. They state that mental models of learners' (alternative conceptions) are unstable and difficult to access.

Taber (1998:597) states that some alternative conceptions would be due to different authors using the same terms in distinct ways. Emphasis on alternative conceptions is related to the uniqueness of each person's construction of a perception of the world. The constructed systems will each evolve and continue to evolve in order to import and give meaning to new experiences. "Everyday conceptions are supported and reinforced through everyday conversations, reading books or consumption of mass media" (Nieswandt, 2001:159.).

Clement (2000:1042) states that a learners' framework for learning includes the preconceptions and natural reasoning skills that are present before instruction. Preconceptions should include both alternative conceptions that are in conflict with the target model, and useful conceptions that are compatible with the current scientific models that can be used as building blocks for developing the target model. According to

Gilbert and Watts (1983:66) the interplay between the macroscopic and microscopic worlds is a source of difficulty for many chemistry learners.

3.2.2 Types of alternative conceptions

The Committee on Undergraduate Science Education (1997:28) has identified five types of alternative conceptions. These are preconceived notions, non-scientific beliefs, conceptual misunderstandings, vernacular misconceptions and factual misconceptions.

Preconceived notions are popular conceptions rooted in everyday experiences, for example many people believe that water flowing underground must flow in streams because the water they see at the earth's surface flows in streams (Committee on Undergraduate Science Education, 1997:28).

Non-scientific beliefs include views learnt by learners from sources other than scientific education, such as religion or mythical teachings. For example, some learners have learnt through religious instruction about an abbreviated history of the earth and its life forms. These religious and mythical teachings have in comparison with scientific evidence led to controversy in science teaching (Committee on Undergraduate Science Education, 1997:28).

Conceptual misunderstandings arise when learners are taught scientific information in a way that does not provoke them to confront paradoxes and conflicts resulting from their own preconceived notions and non-scientific beliefs. To deal with their confusion, learners construct faulty models that usually are so weak that learners themselves are unsure about the concepts (Committee on Undergraduate Science Education, 1997:28).

Vernacular misconceptions arise from the use of words that mean one thing in everyday life and another in a scientific context, for example "work and power" (Committee on Undergraduate Science Education, 1997:28).

Factual misconceptions are falsities often learnt at an early stage and retained unchallenged into adulthood. For example, the idea that lightning never strikes twice at the same place is untrue (Committee on Undergraduate Science Education, 1997:28).

3.3 VISUALISATION AND MENTAL MODELS

According to Harré (1970), the two carriers of scientific thinking are mental models (images) and words. Visual models play an important role in one's mental models. Nouns and verbs associated with mental pictures, for example a molecule is associated with a mental picture that can be drawn on paper. According to Smit (2001:223), conceptualisation involves the formation of scientifically acceptable mental images of entities and processes associated with the corresponding verbal tags by the learners. The presence of alternative conceptions gives rise to conceptual problems rooted in scientifically unacceptable mental images.

Harrison and Treagust (2000:356) describe mental models as models that refer to a special kind of mental representation that individuals generate during cognitive functioning. Drawings of models increase the reasoning chain and may increase the likelihood of a learner's confusion.

Driver *et al.* (1985:147) probed into the minds of learners from a New Zealand school about what they imagine what is happening when a solid changes to a liquid, a liquid to a gas and vice versa. The majority of learners gave an account of the changes referring only to observable macroscopic changes. Among those who used molecular ideas, the notion that molecules speed up during heating was used frequently. They also used the idea that particles tend to move apart during heating. This study of Driver *et al.* (1985:147) also revealed that learner's drawings showing shape, arrangement and spacing of molecules in the three states of matter showed particles in the liquid and gaseous states as smaller than those in the solid state (Driver *et al*, 1985:147).

3.4 ALTERNATIVE CONCEPTIONS AND MODELS IN CHEMISTRY

3.4.1 Chemical bonding

Coll and Taylor (2001:173) state that from the use of ball and stick models to model ionic lattices arose the alternative conception that continuous covalent or ionic lattices contain molecular species because learners mistake sticks for individual chemical bonds. They reported that some learners believe that a chemical bond is a physical entity. This arises from a world view that building a structure requires energy input, whereas destruction involves the release of energy. Therefore, learners believe that bond-breaking releases energy and bond-making requires energy input.

Coll and Taylor (2001:173) further indicate that the concept of electronegativity resulted in a number of alternative conceptions, such as the inability to establish the correct polarity of polar covalent bonds, the view that the number of valence electrons, the presence of lone pairs of electrons or ionic charge determine molecular polarity. The other alternative conception was that eletronegativity comprises the attraction for a sole electron.

Learners find it difficult to grasp the electrostatic nature of chemical bonding. They confuse it with acid-base as parallel, because the attraction between two oppositely charged species was thought to result in neutralisation rather than bond formation (Coll & Taylor, 2001:173). According to studies by Coll and Taylor (2001:173), some learners believe that the number of valence electrons and the number of covalent bonds are one and the same thing.

3.4.2 The mole concept

Johnstone *et al.* (as quoted by Gilbert & Watts, 1983:81), point out difficulties in teaching the mole concept. They state that learners have the misconception that one mole of a compound will always react with one mole of another, regardless of the stoichiometry of the reaction.

3.4.3 Alternative conceptions about particles

According to Gilbert and Watts (1983:81), learners' conceptions indicate age-dependence. Thirteen to fourteen year-olds find it difficult to interpret the constant motion of particles as intrinsic and are led to the view that there must be an agent responsible for the movement of the particles. They commonly indicate air as the "mover of particles". Driver (1983), (as quoted by Gilbert & Watts, 1983:81), reported that when learners were asked to use the kinetic theory to explain the expansion of mercury in a thermometer during temperature rise, they responded by using the notions of particles being embedded in a substance (like raisins in a cake), while the particles themselves were regarded to expand.

3.4.4 Alternative conceptions about ions

According to Taber (1998:601), learners see ions as altered atoms, for example as "an atom which has lost or gained electrons", rather than being viewed as entities in their own right. They see an atom as the basic unit of matter. In Coll and Taylor's (2001:179) research, the sodium ion was viewed as being larger than the chloride in a sodium chloride molecule because it has more protons and electrons in the same shell and protons attract them closer, therefore making it smaller than chlorine. This was revealed while learners were in possession of a periodic table, thereby confusing ionic size with the trend in atomic size. Research done by Coll and Taylor (2001:179) further indicates the alternative idea that metals and ionic compounds possess intermolecular bonds and this was used to explain why these structures are held together.

3.4.5 Alternative conceptions about molecules

Taber's research (1998:602) indicates that with regard to covalent bonding, learners explained that the two electrons that held molecules together were shared by two atoms. They believe in ionic molecules. According to Coll and Taylor (2001:179), learners used the term molecules to describe particles in metals and ionic substances and believed that lattices were molecular in nature. For example, when describing the conductivity of metallic copper, they stated that the copper molecule is flowing from positive to negative so that the electrons can flow along. Vicente (2002:48) reveals that learners think most properties or changes in a system depend on a single independent variable; they focus on a variable whose change is most evident. An example is the idea that the polarity of a molecule only depends on the polarity of its bonds.

3.4.6 Alternative conceptions about chemical reactions

According to de Vos and Verdonk (1987) (as quoted by Nieswandt, 2001:159), learners believe that properties of substances can change without the substance itself undergoing any drastic change. For example, when copper is heated in air, a black layer forms. Learners often describe these phenomena as "copper has become black". They think that copper has been given a new characteristic, which is a black colour.

Andersson (1986), (as quoted by Nieswandt, 2001:160), pointed out that an alternative conception results from thinking that the phenomena during chemical reactions are interpreted as being a result of mixing and separating mixtures. For example, learners believe that carbon (black solid) can be extracted from an invisible gas such as carbon dioxide (CO_2). Driver *et al.* (1985) reported that learners also think that in a reaction of the combustion of paper, the wood is irretrievably destroyed into ashes.

Vicente (2002:48) indicates that learners' reasoning is guided by what they observe and not by qualities that are not necessarily perceivable. For example, they think that mass is not conserved during a chemical reaction or that the chemical identity of substances changes during a change of state or phase (e.g., when water changes from solid to liquid to gas).

3.4.7 Other alternative conceptions in chemistry

Vicente (2002:48) states that learners think that an active agent is always directly responsible for changes observed in a system. For example, the more electrons an atom have, the larger it is, while the atomic size only depends on the number of electrons in the system. They think that the characteristics of the microscopic models of matter are very similar to the observable properties of the macroscopic systems under study. They use reality to explain the model and do not use the model to explain reality. For example, molecules expand when heated or water vapour molecules weigh less than ice molecules.

Vicente (2002:48) further states that learners pay more attention to structural features, such as the distribution of atoms in space than features such as particle speeds and interaction when using the particle model of matter to explain chemical phenomena. For example, electrons in a chemical bond are fixed in space, or atoms in a solid do not move, or that chemical transformation cease at chemical equilibrium. Learners also think that images, analogies or symbols used in the classroom to represent abstract concepts correspond to concrete reality. For example, atoms are like small solar systems, or chemical bonds are concrete physical entities made of matter. Learners do not recognise the conditions in which scientific laws or principles can be applied to a system or process, regardless of the conditions under which the process occurs. For example, they think that all compounds are made of molecules or that chemical changes are always irreversible (Vicente, 2002:48).

Harrison and Treagust (1998:421) states that learners and some educators think about scientific models in mechanical terms and believe that models are true pictures of non-observable phenomena and ideas. His research indicated that language common to both biology and chemistry, for example "nucleus and shells", is a major source of confusion for some learners. Harrison and Treagust (1998:421) states that several learners concluded that atomic nuclei divide and those atoms could reproduce and grow. Electron shells were visualised as shells that enclosed and protected atoms, while electron clouds were structures in which electrons were embedded.

According to Vicente (2002:47), many learners think the size and mass of an atom change during a phase transformation. They perceive heat as a fluid; they think heat is always needed to start a chemical reaction; they believe that gases do not have any mass; and that ionic compounds are composed of molecules. They also think that condensed water on the outside of a glass is liquid that has filtered through the walls (Vicente, 2002:47).

3.5 SUMMARY OF ALTERNATIVE CONCEPTIONS

Table 3.1 below summarises the alternative conceptions that learners have on the topics of chemical bonding, the mole concept, particles, ions, molecules, chemical reactions and in other topics in chemistry.

Table 3.1: Summary of alternative conceptions

Topic related to	Description of alternative conceptions	Reference
Chemical bonding	Ball and stick model leads to alternative conception that bond-breaking releases energy and bond-making requires energy.	Coll & Taylor (2001:173)
	Electronegativity comprises the attraction for a sole electron.	Coll & Taylor (2001:173)
	Number of valence electrons and the number of covalent bonds are one and the same.	Coll & Taylor (2001:173)
The mole concept	One mole of a compound will always react with one mole of another, regardless of the	Gilbert & Watts (1983:81)

	stoichiometry of the reaction	
Particles	Constant motion of particles is due to air as the mover of particles.	Gilbert & Watts(1983:81)
Ions	Ions are altered atoms that have gained or lost electrons. Confusion of ionic size with the trend in atomic size. Metals and ionic compounds possess intermolecular bonds	Taber(1998:601) Coll & Taylor (2001:179) Coll & Taylor (2001:179)
Molecules	Molecules are particles in metals and molecules are ionic, and lattices are molecular in nature. Explain conductivity of copper by saying that copper molecules are flowing from positive to negative so that electrons can flow along. Polarity of molecules only depends on the polarity of its bonds.	Coll & Taylor (2001:179) Coll & Taylor (2001:179) Vicente (2002:48)
Chemical reactions	Properties of substances can change without the substance itself undergoing any drastic change. Mass is not conserved during a chemical reaction. Chemical identity of substances changes during a change of state or phase.	Vicente (2002:48) Vicente (2002:48) Vicente (2002:48)

Chemistry	An active agent is always directly responsible for changes observed in a system.	Vicente (2002:48)
	Characteristics of the microscopic models of matter are similar to the observable properties of the macroscopic systems under study.	Vicente (2002:48)
	Chemical transformation cease at equilibrium, while chemical changes are always irreversible.	Vicente (2002:48)
	Analogies or symbols used in the classroom to represent abstract concepts correspond to concrete reality.	Vicente (2002:48)
	Heat is always needed to start a chemical reaction, and it is a fluid.	Vicente (2002:47)
	The size and mass of an atom change during a phase transformation.	Vicente (2002:47)
	Gases do not have mass.	Vicente (2002:47)

3.6 SUMMARY

In this chapter, objective 1.4.1 (Chapter 1), namely a literature investigation of alternative conceptions of models in chemistry was partly dealt with. The next chapter (Chapter 4), deals with the last part of objective 1.4.1, which is the literature study of the use of models in teaching and learning. Objectives 1.4.2 and 1.4.3 were addressed in so far as the literature was concerned. A general view about alternative conceptions described by different authors and examples of some alternative conceptions in chemistry was discussed.

CHAPTER 4

LITERATURE REVIEW: THE USE OF MODELS IN TEACHING

4.1 INTRODUCTION

This chapter deals with the concepts of teaching and learning of science. Objectives 1.4.1 and 1.4.3 (Chapter 1) that deal with the use of models in teaching and learning will be discussed. Teaching and learning are considered interrelated and inseparable, although they are two totally different processes. First, a description of what learning is and what teaching is, is given. Thereafter teaching that involves models and constructivism will be dealt with.

4.2 CONSTRUCTIVISM

In the past, science teaching was dominated by the transmissive approach. Learning of science was passive and knowledge was transferred from the educator's head to what was considered to be the "empty vessel" of the learner's head. Learners' alternative conceptions were given little if any attention and were considered to be easily extinguished or replaced by the educator through persuasive arguments. Emphasis is at present placed upon the learner as an active individual reaching out to make sense of events and constructing knowledge through social interaction and experiences with the physical environment. This view acknowledges that learners bring to school science ideas, expectations and beliefs concerning natural phenomena that they have developed to make sense of their own experiences. These ideas could differ from the currently accepted scientific view and from the intended learning outcome and could be extremely resistant to change (Coll & Taylor, 2001:171).

Following from this view, the constructivist paradigm developed. According to Novodvorsky (1997:242), constructivism is a learning theory that is based on the following assumptions:

The first assumption of this theory is that knowledge is constructed in the mind of the learner. This view takes into account individual differences of learners and the uniqueness of each one's perceptions and capabilities. These perceptions of the world resulted from observations made from surroundings and personal experience. "The constructivist view recognizes that it is impracticable to expect learners to achieve success at the same rate, and that individuals' attitudes influence their learning" (Wesi, 1997:58).

Attitudes are determined by beliefs, values and prior knowledge that individuals possess. According to Driver *et al.* (1985:8), knowledge is not transmitted from the educator to the learner; the learner constructs it. The educator is viewed as a facilitator that creates opportunities for learning.

The second assumption of the constructivist theory is that learners bring to class prior knowledge about science. This prior knowledge has a direct impact on learning according to the constructivist view. Learners' minds are nowadays not regarded as empty vessels that have to be filled.

According to the constructivist theory, learning is not a purely receptive process. It is viewed as a process of construction of knowledge. The constructed knowledge is matched with prior knowledge before it is to be accepted by the learner. If it is found to be inconsistent with existing structures, it may be rejected because it does not make sense. When it does not make sense, it leads to memorisation and indicates that learning has not taken place. Learning is said to have taken place when prior knowledge has been modified in order to match incoming knowledge. If incoming knowledge matches existing knowledge, the new knowledge is internalised and form part of the individual's mental structures.

According to Driver *et al.* (1985:9), the constructivist theory views learning as a lifelong process that is continuous. Learning takes place anywhere inside or outside the classroom and can be formal or informal.

4.3 LEARNING OF SCIENCE

According to Scott *et al.* (1992:20), Kelly (2000:758) and Hewson and Hewson (1983:732), learning is seen in terms of conceptual development or change, which involves interaction of new and existing knowledge rather than simply the addition of new information. Hewson and Hewson (1983:732) further state that new knowledge (concepts) must meet three conditions before learning could take place. They are as follows:

1. ***Intelligible***. One should know what a concept means and be able to construct a representation (model) of it.
2. ***Plausible***. One should believe it to be true and reconcilable with other existing conceptions.
3. ***Fruitful***. It should provide explanatory and predictive power that includes that it must serve to solve problems and suggest new approaches.

Mathewson (1999:36) describes learning as "the conscious and unconscious construction of coherent mental frames or schemas that serve as expanding and modifiable frameworks for assimilating new information and as the locus for accommodating discrepant or entirely novel experience through a restructuring of schemas." According to Hammer (1991), the learning of science might be considered to be learning the ways and models of science.

Nieswandt (2001:161) views learning as a process of active construction that is shaped, helped or hindered by learners' prior knowledge and conceptions.

4.3.1 A model of learning

White (1988:116) states that a model explains what happens when someone learns to use sources such as information processing and constructivist theories. Learning science highlights special characteristics that make some issues more prominent than others. Of the utmost importance is the manner of presentation of information by educators and texts, and the way that information is filtered through learners' beliefs from observations of the world, which could lead to rejection and the amendment of the information, or to changing beliefs.

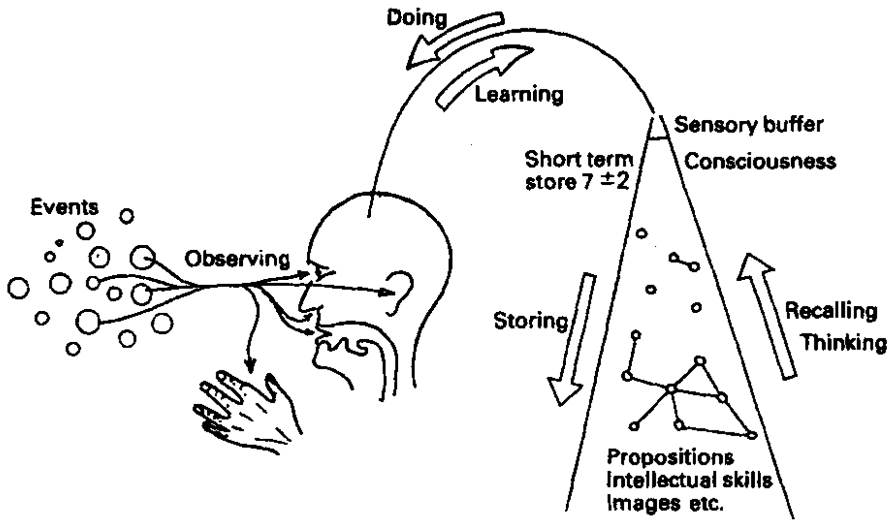


Figure 4.1: Model of learning according to White (1988:117)

According to White (1988:116), the above model of learning (Figure 4.1), is a representation of information processing whereby a learner selects stimuli from many surrounding events. This physical stimulus is then translated into a meaningful mental form that allows construction of meaning so that there is integration with older knowledge. White (1988:117) defines the model in Figure 4.1 as only a shadow of reality that indicates how learning may be fostered.

4.3.2 Selection and translation of events

White (1988:117) states that at the beginning of information processing in the model of learning (Figure 4.1), the learner is surrounded by events. The learner's body has receptors or senses that are sensitive to physical consequences of events. These senses are sight, touch, taste, smell and hearing. These stimuli have to be above a certain threshold intensity before the nervous system is triggered and a sensation is experienced. White (1988:118) remarks that before one could differentiate between any two stimuli, there has to be a certain size difference in intensity or quality. For example, the brightness of two lights must differ by a considerable degree to indicate their difference. The most important fact is that we are not conscious of all the stimuli that are above their thresholds because they are filtered from the consciousness and ignored. This indicates that attention can be directed to a more important message (stimuli) at a particular time. This contributes a lot to determination of what is learnt.

There are various stimuli in the classroom. The educator has to help learners "tune in" to events that will help them to focus on what is to be learnt. Learners can only focus on one event at a time therefore a selection of events for attention is important for learning.

4.3.2.1 Attributes of events

According to White (1988:119), properties of events are attributes that tend to make them noticed, and they can be determined more or less objectively. The motion, absolute intensity of stimulus, the relative strength of a stimulus compared with the rest of the field affects what is noticed. A part of the field that is at low intensity is noticeable if the rest of the field were at a uniform level of high intensity. For example: "Astronomers are aware that little or no light comes to us from dark gas clouds such as the Coalsack nebula, yet they stand out against a background of bright illumination from the Milky Way" (White, 1988:120). Contrast is an attribute that matters; it can be in an instantaneous field or in a sequence of events. Educators use contrast when talking at a steady tone or loudness. They may raise or lower the intensity or the pitch of the sound in order to emphasise a point.

4.3.2.2 Attributes of the observer

Attributes of the observer, such as the level of alertness, affects the selection of events. Alertness may include sleeping or a wakeful state. They have variations that may result from physical causes, such as tiredness or illness, or from the effect of a stimulant or a depressive drug. Variations may also have an emotional or cognitive cause (White, 1988:120). The level of alertness is controllable. This means that within the limits of our physical state we can decide to be alert or not.

Ornstein (as quoted by White, 1988:120), described practical techniques for enhancing perception through the psychology of consciousness, such as yoga practices. There is a need to filter out most of what happens around us in order to function without exhaustion. In order to maintain alertness in schools and tertiary institutions, educators need to alter activities to suit their learners' states. For example, one can hold off to begin a difficult topic when learners are not alert and instead, routine work to round off the previous topic is given to learners (White, 1988:121). White (1988:121) remarks that another attribute - cognitive strategies available to the observer - affects selection.

4.3.2.3 Interaction between events and observer

People focus on the aspects of the surroundings that are relevant to their current purposes. For example, a learner working in a laboratory can be so engaged in an activity that he/she does not hear an instruction from the educator. Events can be judged and discarded unconsciously by scanning the environment. The selection of events is also affected when the observer finds the event unusual, interesting or understandable. An event has to be interpreted; meaning has to be constructed from stimuli received through past experiences before it can be classified as unusual, interesting or understandable. For example, an organism that was subjected from birth to a continuous random and non-recurring sequence of visual experiences would not learn to see. Construction of patterns is such an important characteristic that we tend to forget that these patterns are learnt (White, 1988:121).

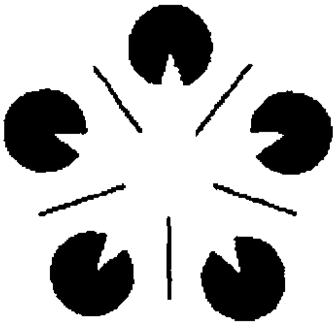


Figure 4.2 a

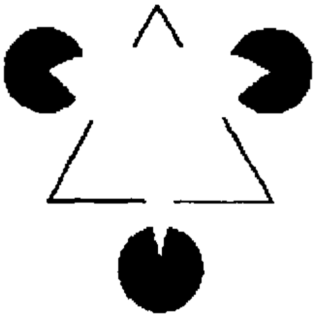


Figure 4.2 b

Figure 4.2a and 4.2b: Illusory contrast: the black shapes influence observers to construct white shapes between them (White:1988:123)

Figure 4.3: Drawing that an observer can construct as either an old or a young woman (White:1988:123)

Referring to figures 4.2a and b, White (1988:122) indicates that although the figures do not contain a shape with three curved sides or a five-pointed star, most people construct them. In other instances, alternative patterns may be constructed so that the world is seen in a quite different way. An example is given in Figure 4.3, which could represent either a young woman or an old one.

The learning of patterns occurs early in life. In learning science, it matters a lot whether particular patterns have been acquired or not. Seeing and the use of the other senses involve the process of imposing meaning.

White (1988:126) states that knowledge affects sensation so that the educator and the learner may recognise the stimuli they receive in different ways. Therefore, they may experience different sensations even when in the same surroundings. For example, a learner may see an undifferentiated field of grass while a botanist sees a number of highly contrasted areas sharply defined. The selection is affected by knowledge, attitudes and abilities. For example, when one has a strategy of reflective thinking one may pick out items from the scene that others might pass over as of no importance. Most of the time educators are rarely prepared to tolerate a lack of concentration on the events they want their learners to select. Experienced educators have skills to maintain learners' attention.

4.3.3 Short-term memory

The short-term memory stores events that have been selected and translated. The elements in the short-term memory can also be recalled from long-term memory through a link with an element already present. For example, an image of atoms can be triggered by propositions about the development of the atomic models. One of the properties of the short-term memory store is that it has a limited capacity and that the items can be held in it for only a brief duration unless they are rehearsed. For example, if someone reads to you a sequence of numbers you can repeat them if there are seven digits or less, but longer sequences can rarely be repeated without error. Another example is imagining and making mental manipulations of a sphere, a cube, and a pyramid side by side and placing one above the other. Now add a rod. This makes it harder to visualise all four objects than it was to visualise three. They cannot all be kept in the picture at the same time (White, 1988:127).

White (1988:128) remarks that a short-term store is useful in learning because it makes us think about what we mean by things stored in it. One aspect of learning is to see the world in fewer, larger chunks. The size and number of chunks one can perceive in a situation bring about the difference between a knowledgeable person like an educator and an ignorant one like the learner. An expert inhabits a simpler world than a beginner, because the expert breaks it into a smaller number of meaningful units. Chunking or grouping together of facts helps the short-term memory and is important in communication and learning. White (1988:131) states that the educator's role is to help learners to form larger and fewer chunks in order for information to be accommodated in the short-term memory. For example, when an educator shows learners apparatus used in schools for gas generation, the learner may see the equipment as a small number of units shown by the marked off areas in Figure 4.4a, while learners are having to cope with more as in Figure 4.4b

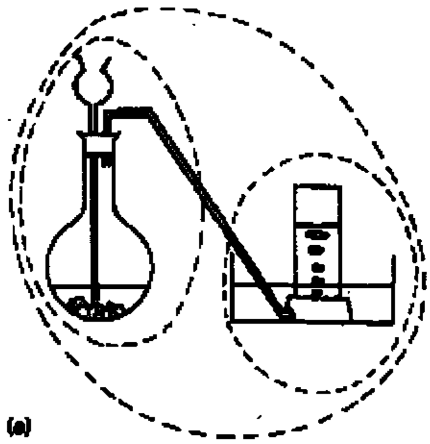


Figure 4.4a: Hypohetical chunking of gas generation apparatus by an educator (White, 1988:130)

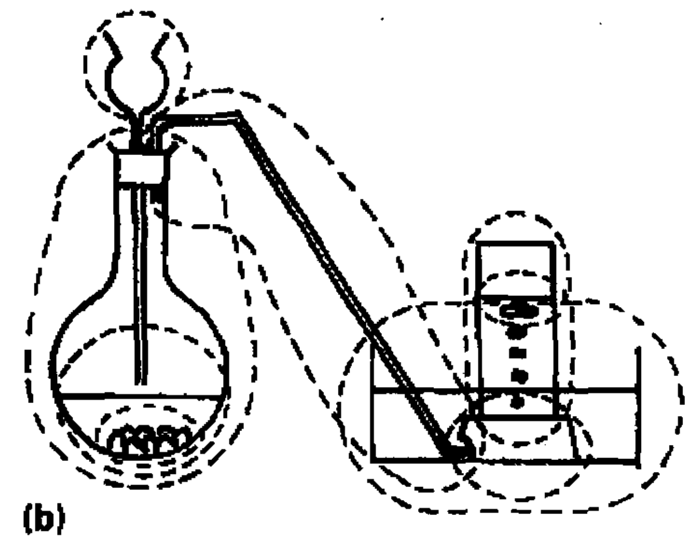


Figure 4.4b: Hypothetical chunking of gas generation apparatus by a learner (White,1988:130)

The more one learns, the more integrated and yet more differentiated the world becomes. A disadvantage when acquiring bigger chunks is that one tends to see what one expects to see. Some fine details may then be missed by the expert but seen by the beginner. For example, in the gas generation drawings the thistle funnel in the second drawings 4.4b does not reach the surface of the liquid, so the apparatus is incorrectly arranged and most experts would miss this (White, 1988:131). The duration of short-term memory can also affect learning. The only way to maintain an item in short-term memory is to rehearse it. Rehearsal is a mental repetition (White, 1988:133).

4.3.4 Consciousness and attention

According to White (1988:134), the brain exhibits unconscious control over voluntary as well as involuntary acts. For example, the flexing and relaxing of opposed muscles when someone decides to bend an elbow. Unconscious control can be illustrated by calling attention, first to a common experience, secondly to a remarkable research finding. A common experience is walking. Once a decision has been taken to start walking, the act continues without much attention. A person can stroll while thinking of other things as long as there are no hazardous obstacles, giving little thought to the walking. Therefore, all of the short-term capacity will be free for thinking.

4.3.5 Deep processing

White (1988:135) indicates that deep processing is affected by what has happened before and what is anticipated to follow. The issues that are central to processing are choice, capability and time.

4.3.5.1 Choice

White (1988:136) says learning is voluntary and conscious and is undertaken only when it fits in with the learner's goals. Learners' goals that lead them to learn science arise from social needs, such as the need for achievement, acquisition or affiliation. Therefore learning is a social act. According to White (1988:137), people differ in how clearly formulated their goals are and how conscious they are of them. The balance between their long- and short-term goals determines their actions.

White (1988:137) indicates that educators and curriculum designers might want to transmit to learners the long-term goal of understanding science to a higher degree. For this goal to be achieved, advanced learning strategies of reflection and interlinking of knowledge are required. Scientific laws and potentially meaningful facts are learnt as strings or propositions unrelated to experience, while intellectual skills are practised so that they can be applied automatically to a limited number of standard exercises (White, 1988:138).

According to White (1988:138), scientific knowledge is retrieved and demonstrated in classroom context in order to meet the short-term goal, but this knowledge can be allowed to peel off. To conquer alternative conceptions of scientific principles and phenomena is to bring the short-term goals into accord with the long-term ones. A sense of psychological well being, self-respect and pride in achievement are the rewards for self-developed goals. The externally imposed goals' rewards include a pass in a test, signs of approval, or the withholding of punishment. These goals are short-term. It is most important to have a balance between short-term and long-term goals. A shift in the balance towards fostering long-term goals and reliance on internal rewards should be encouraged (White, 1988:138).

White (1988:139) remarks that learners will not become self-sufficient as long as learning is undertaken to meet externally imposed goals alone. There will be no acquisition of permanent commitment to learning and no development of cognitive strategies and reflection on their learning in this case. The other factor in choosing to do something is the judgments of the likelihood of success and weighing those judgments against the rewards and penalties involved. For example, when a course in science with an exam at the end is taken, a decision has to be made whether or not to sit for the examination. The reward may be judged high and the risk moderate, so the choice will be to sit for the examination.

According to White (1988:139), episodes are crucial in deciding whether to act or not. In familiar situations as well as new ones, it is the learner's perception of the context. The rewards and penalties that are present influence the judgments that interact with needs to determine the performance that follows. The quality of learning can be improved by making judgments more conscious and realistic and by making learner's perceptions of context more sensitive and supportive. Judgment is a recurring process involving not only the initial decision to act, but also of monitoring the progress to make decisions about whether to keep going and whether to change the way things are done. One of the principles of metacognition training that is aimed at improving learning is to make learners' judgments of their progress frequent and deliberate (White, 1988:139).

White (1988:140) states that perception of context matters in the choice because it influences judgments about the rewards of learning. For example, learners complain that what they learn in the science classroom is not transferred to life outside school and therefore they see no point in the science they learn, because they feel there is no need to. Metacognition training may help by requiring learners to reflect on the meaning of the propositions and skills they are taught and to consider how they relate to other knowledge and to non-school life. Choice is determined by goals, needs, rewards, penalties, judgments and perceptions of context.

4.3.5.2 Capability

According to White (1988:140), the other factor that determines the quality of learning is capability. This can be in the form of permanent disabilities in the learning of handicapped learners in schools, and cannot be changed through training. For example, there are learners that can read aloud fluently but are unable to carry out semantic processing. There are also learners that are innately capable but not skilled in processing because they lack good cognitive strategies and have no physical cause. According to Baird (quoted by White, 1988:140), the proportion of these learners can be reduced by appropriate training.

4.3.5.3 Time

White (1988:141) states that it takes time to give meaning to communication. In reading, the rate of flow is under the control of the recipient of the information, but in oral communication, it is usually not. In conversations one can ask the other person to wait a moment, but in group situations such as lectures and in classrooms it is more difficult. In lectures one has to choose between thinking about the implications of one sentence and keeping up with what is being said without really processing it. In primary and secondary schools the educators adjust the pace of presentation to suit their judgments of the learners' grasp of information and use questions to promote processing. At university level, educators rely on the learners to put in effort outside the lecture to understand the topic, and they give little opportunity for processing during the presentation (White, 1988:141).

4.3.6 Processing of propositions

The meaning of constituent parts, illustrative linking, explanations, evaluation and resolution of conflicting beliefs are some of the ways of processing of propositions that will be discussed.

4.3.6.1 Meaning of constituent parts

White (1988:142) remarks that processing could be done by separating a sentence into blocks that are imaged (pictured) or related to known objects or phenomena. For example, a sentence like "black things radiate heat better than white or silver ones'' may be processed for example in three steps: step 1, the learner may picture an object with black or silver colours. In step 2, the recall of an episode such as receiving heat from a radiator may help to process "radiate heat better". In step 3, an image of an electric radiator with many arrows pointing out from it may be formed. Black is thus given a meaning through translation of the word to an image of something known or to an episode. Formation of images may not always be essential.

4.3.6.2 Illustrative linking

According to White (1988:142), processing could involve more linking of an illustrative kind. Each new element added changes the learners' understanding of its original concept. Elements can include episodes, propositions and images that can be suggested by the learner or the educator in order to help with firm establishment in the memory. Learners should be encouraged and trained to elaborate their knowledge by coming up with the relevant images, episodes and propositions. Reflection and elaboration are important cognitive strategies that should be fostered and they may also be employed in inventing knowledge.

4.3.6.3 Explanations

White (1988:143) states that processing might involve explanation of statements. A scientific phenomenon requires and involves explanations that are either a logical deduction from directly experienced propositions or analogies. Research by Symington and White (1983) (quoted by White, 1988:143) found that children explained the fact that trees have bark most often through analogy with skin, followed by a conclusion that it protects the inside. Other explanations may be beyond children's understanding of the phenomenon, but do not mean that they do not understand the statement. It should be borne in mind that explanation is not an essential part of processing, nor is it a prerequisite for another act of processing.

4.3.6.4 Evaluation

According to White (1988:143), evaluation determines the learner's acceptance and degree of commitment to the proposition. The manner of evaluation can provide a new depth of processing. At the shallow level, the statement can be accepted because of reliance on authority, for example educators, books, parents, and it is coupled with acceding to truth in some context only. For example, the learner in the classroom may go along with the educator's presentation of the world, but will activate the beliefs received in the classroom only in that context. Another example is that if the educator classifies spiders as animals, the learner will co-operate to the extent of answering in tests that way, while believing outside the classroom that spiders are not animals.

White (1988:143) indicates that a deeper level of education involves checking the new information against old information (knowledge). If it conforms to it by explaining something that has been a puzzle, commitment to the new knowledge should be high. If there is an objection, faith in the proposition is withheld. Evaluation may be through direct experience, such as practical experiments or demonstrations in the classroom. Evaluation can lead to rejection of knowledge. Rejection could occur either because the new statement runs counter to present beliefs, or because of feeling threatened by it. An example is that learners did not want to accept scientists' classification of people as animals because of opinions about the behaviour of animals.

4.3.6.5 Resolution of conflicting beliefs

White (1988:144) states that relating new information to old information and explanation of statements as well as phenomena are some of the stressed current practices, but there is a need to evaluate the commitment to believe it. Overcoming beliefs that are rooted in experience turns out to be very difficult and educators can never be certain that they have succeeded completely. According to Posner *et al.* (quoted by White, 1988:145), the conditions that are necessary before an old belief is exchanged for a new one is that the learner must be dissatisfied with the first belief and find the new one intelligible, plausible and fruitful. This can be done by a demonstration to prove that the old belief is inconsistent with the phenomena that the new one fits. This is very difficult, because most of the time learners' observations are influenced by what they believe should have happened, or by a belief that principles are specific to context and therefore what is true for a scientific apparatus does not apply to real things (White, 1988:144).

4.3.7 Processing of strings

White (1988:146) states that strings in science might remain in memory as strings but take on meaning as they are linked to propositions.

4.3.8 Processing of intellectual skills

White (1988:147) says intellectual skills are common in science curricula. Learners are pleased by achievement in acquiring a new intellectual skill; an example is being able to solve high-order problems. Part of processing of a skill is acquiring an explanation for why each operation is performed. Intellectual skills include skills of balancing molecular equations in chemistry, analysing, interpreting, and problem-solving.

4.3.9 Processing of motor skills

According to White (1988:148), intellectual skills are often linked to motor skills because they are associated with it and are also part of its processing and are essential in its transference to a new situation. The motor skills that are acquired in science can be learnt for specific tasks or for transfer. Examples of motor skills acquired in science are using thermometers, micrometers, ammeters, protractors, burettes, pouring liquids and handling chemicals. These skills teach the learner precision and care. Practice and correction of performance are needed to build up a high degree of skill.

4.3.10 Processing of episodes

According to White (1988:149), what matters in storage and recall of an episode is how discriminable it is from other events. As many things happen around us, we cannot process them all to the same extent. Processing of an episode can lead to destruction of its details and to submergence in a generalised episode if it is similar to other experiences. Processing of episodes involves attaching it to other episodes, propositions, skills and images. White (1988:150) indicates that processing of verbal knowledge and intellectual skills requires chunking and selection that are important in processing episodes. Each time episodes are recalled and contemplated, details may be changed so that a new form of the episode is restored. Sometimes we observe accurately but gradually amend the episode so that it becomes consistent with beliefs. This poses a problem when trying to get learners to abandon inappropriate conceptions. Learners' episodes from a demonstration or experiment have to be similar for common learning to occur (White, 1988:150).

4.3.11 Processing of images

White (1988:152) states that processing of images involves linking and also requires an image to have a label. Visual images can be linked with other images and this makes it easier to recall. We have labels for most of the things that we can see and hear, but few for scents. Scents tend to be linked with specific episodes. To make learning easier, we build up representation of unobservables such as atoms, and processes such as burning and dissolving. Complex images require a great deal of processing to be stored accurately and permanently.

4.3.12 The learning of cognitive strategies

White (1988:153) says strategies take time to be learnt. They are agents of processing and also the result of it. According to Baird and White (as quoted by White, 1988:153), investigations on the learning of cognitive strategies involve direct attempts to train learners in strategies such as determining the purpose of learning, assessing the degree of understanding attained and reflecting on the relation of the topic under study to others.

4.3.13 Levels of attending

According to White (1988:153), with the lowest level of attendance, the learner does not select the event for attention and it does not get into the short-term memory. For example, being distracted when listening has the consequence that later one does not know what was said, even though one was are aware that someone was talking to you. In the second level, the words are selected and translated into meaningful forms and get into the short-term memory, but are not processed further. An example is, being aware that the educator is speaking without being able to recall more than the most immediate words.

White (1988:154) indicates that the third level involves some processing, like imagining terms without linking it to other propositions and episodes. This involves searching for meanings of terms without the applications of the terms or evaluating it. The fourth level refers to deep processing where there is linking, explanation and evaluation. The fifth level is when the learner is in full conscious control of the processing act and can extend or complete it at will. It involves the determination of purpose of learning.

The capabilities of operating at these levels vary from person to person and are amenable to training. At schools the aim is to help learners to operate at the fourth level (White, 1988:154).

4.4 TEACHING OF SCIENCE

According to White (1988:160), teaching involves the responsibility of the educator to put appropriate information in the way of the learner and arrange it in the form that maximises the learner's chance of understanding it and promotes the learner's ability to construct meaning. To explain this further, discussions on content, selection of information within a topic, care over language, sequence and pace of presentation, questioning, use of the laboratory and teaching style are discussed in the next paragraphs.

4.4.1 Content: what is to be learnt?

White (1988:160) indicates that content varies with circumstance and consideration is given to principles that apply generally. Society's needs guide the selection of content. For example, the society needs specialists to keep a technological civilization operating to advance scientific knowledge. Society also needs an informed population that understands the function of science and has a balanced cultural development. Future specialists in chemistry must understand how the structure of atoms gives elements their properties and how elements combine to form compounds. White (1988:161) states that this can be done by preparing future specialists through experience with materials and practical techniques and studies that contain a greater practical component. Learners need practice in reflecting on observations, which is the ability to apply the scientific method (White, 1988:161).

According to White (1988:163), the focus should be on analysing, synthesising, purifying, studying structures, searching out properties and controlling reactions. A syllabus such as that would involve much and has to do with learners learning chemistry through exercises such as making and repairing with fiber glass, choosing among detergents, stemming corrosion and developing films. The unifying principles that are introduced should be presented only in as much detail as their relation to everyday application of chemistry warrants.

White (1988:164) states that in biology and earth sciences, attention should be paid to observation, description, looking for parallel structures in different species and landforms. Practical experience is better than no experience. This form of teaching will encourage the development of the different cognitive strategies.

4.4.2 Selection: what to say?

White (1988:165) indicates that what the educator says will determine learning, and this is a much more complex process. "The educator has to decide which propositions in his head are best to communicate next, has to frame them into words and utter them, and each learner has to process the words and construct a meaning for them" (White, 1988:165). For construction of deep meaning, the educator has to give learners the content and bring to their attention the relevance of things they know already that are related to this new knowledge. The heart of good teaching involves the art of selecting strings, propositions, skills, images and episodes that will assist learners' comprehension of content. This is acquired through experience. Learners should not be given too much or too little knowledge (White, 1988:165).

4.4.3 Communication: how to say it?

According to White (1988:166), his model of learning emphasises that the meaning of what is said depends on the person's existing knowledge, and different people can construct different meanings from the same message. The educator can do many things in framing sentences to help or hinder learners' construction of meaning, such as sentence construction, economy of words, and establishing meanings of nouns and verbs.

4.4.3.1 Sentence construction

White (1988:166) indicates that sentences needs to be finished, although failure to complete sentences is less of a problem when participants are well acquainted with each other and with the topic. An educator needs to finish his or her sentences because leaving sentences incomplete makes communication poor, which hinders learning. Long sentences with complicated or incorrect grammar make construction of meaning impossible and complicated for learners. Educators should refrain from the use of unfinished and confusing utterances by checking their performance occasionally and by recording a lesson and scoring its clarity (White, 1988:169).

4.4.3.2 Economy of words

White (1988:170) remarks that misunderstanding in communication is also created by the need for economy in speech or writing that could lead to saying things that are not strictly what we believe. Economy of words creates a difficulty for educators because to forever emphasise exceptions may obscure a set of principles learners should acquire. Receivers of information are usually not familiar enough with the topic to know about exceptions and therefore can build up incorrect deductions from principles; for example, birds fly and we have flightless birds like the ostriches and penguins. People want simple answers. Exceptions are important because they transmit a message that is often missed in school. A balance should be struck, and while principles are emphasised, the exceptions must be noted (White, 1988:170).

4.4.3.3 Qualifiers and connectives

White (1988:171) states that most learners do not understand the implications of qualifying words like "most", "generally", "often", "many", "nearly", "usually", "some" and "frequently". For example, "most chlorides are soluble in water", could stimulate a different construction than it would without the "most". An alert learner would think that with "most" included in the sentence it means that there are some chlorides that are not soluble in water.

White (1988:171) further remarks that conjunctions such as "and", "consequently" and "nevertheless", matter in science education and represent subtle, complex relations and therefore their meanings are acquired more slowly. Unfamiliarity with logical connectives inhibits and distorts processing. Either the learners spend so much time working out what the educator means by saying "on the other hand", that the next few sentences are missed, or more often, the learners miss the point of the connective and so construct a meaning different from the one that the educator intended to convey. Accurate and quick interpretations of connectives are needed for a learner to construct propositions that have similar meanings to those of the educator (White, 1988:171).

According to White (1988:173), educators have to use connectives and qualifiers and figure out some procedure to be followed to help learners to understand them. For example, learners could explain the difference between "Calcium carbonate is soluble in water" and "Calcium carbonate is barely soluble at all in water". As well as training learners in the use and interpretation of qualifiers and logical connectives, educators need to be sensitive to their importance in conveying meaning and should check whether the learners comprehend their implication and should probe whether the constructions that the learners have made are reasonable (White, 1988:173).

4.4.3.4 Nouns and verbs

White (1988:174) says nouns and verbs need careful use in science teaching. They are labels given to concepts. Communication problems occur when people associate different cases with a label or when interpreting the meaning in different contexts. The verb "put" has connotations of transfer and "has" of possession of some substance. Examples are: "Now I put a force on this ball" or "The ball has a force on it" when an educator demonstrates a principle of mechanics. Such connotations may lead learners to construct meanings for statements that are not what the educator intended. Meanings of nouns and verbs build up from things that people are told and from their own observations.

According to White (1988:175), confusion can be brought about by the use of the word "animal", which is mostly restricted to large four-legged mammals. Learners end up not classifying whales, spiders, fish and birds as animals. Common usage encourages them to construct meaning for the word that is different from scientific usage. Communication can fail even when two people have identical meaning for words if they use and interpret them in different contexts. Context is important in science teaching because many words have different common and scientific usages, for example, animal, force, energy and weight. Physics teaching is more troubled by this than any other subject because it is an abstraction that maps concepts on to the real world, while leaving out many of the details. When an educator says: "An object will stay in its state of rest or uniform motion in a straight line unless acted on by external force", this is meant to be interpreted in scientific context (White, 1988:175).

White (1988:175) indicates that in everyday context people accept that things stay still unless pushed, but resist the notion that they will keep on going forever. Explaining how context affects the meaning of the word could save learners from confusion and misunderstanding in order to bridge the gap between the world of science and the world that learners experience outside the classroom.

4.4.4 Sequence of presentation

According to White (1988:176), in addition to what was mentioned above, educators have to arrange sentences in a sequence that helps the learners to construct sensible meanings. Anderson (as quoted by White, 1988:177) proposed that the two features of a communication that affect its comprehensibility are the degree of linking between successive sentences and the rate of introduction of new major ideas. Relaxed sentences should have an advantage over disjointed ones, for example, suppose the educator says: "Vectors have magnitude and direction and sense. Money is a scalar." Without additional knowledge, the sentences are unrelated for the hearers, yet they will try to make sense of them because people are used to the notion that one sentence leads to the next and illuminates it in some way. Learners know that the stream of information is to be interpreted as a whole, not as separate items (White, 1988:176).

Anderson *et al.* (as quoted by White, 1988:177) found that new ideas need to be spaced into their introduction. They can be separated by elaboration of each through examples, explanations and applications. These elaborations help learners to construct meanings for the new notions. Constructions of meaning from elaboration may vary. Analysing, linking of sentences and the rate of introduction of new ideas as well as the use of connectives and qualifiers in lessons will reveal whether educators make it easy or difficult for their learners to construct meaning from what they hear (White, 1988:177).

4.4.5 Pace of presentation

White (1988:178) states that pace depends on the educator's estimates of the state of his/her class. From the answers to questions and non-verbal signs the educator forms an interpretation of the class's understanding of the topic. Lundgren (as quoted by White, 1988:178), found that educators tend to base their decisions on when to move to new matters in reactions to a small number of learners that are neither the most nor the least able but that are regarded as being about four fifths of the way down the ability scale. The success of lessons depends on the accuracy of the educator's judgment of comprehension of marker learners. Decisions on when to proceed should be based on more deliberate and more powerful probes of understanding than are common in current practice (White, 1988:179).

4.4.6 Questioning

According to White (1988:180), an educator's questions serve the purposes of control of behaviour, learning and pace of a lesson. Questions control behaviour because they focus attention and learners concentrate on what the educator does because they may be called on to answer. Low-level comprehension questions maintain attention and the educator's response rewards or punishes the learners for their levels of attention. A question directs learners to the events that the educator wants them to focus on and encourages them to process information. One of the functions of questioning is that it promotes deeper processing that is at the fourth level of attention (White, 1988:180).

White (1988:180) states that deep processing occurs when questions force learners to link recently acquired information with episodes or older propositions, or when they require them to apply their new knowledge to a problem, for example, "Have you noticed the gaps between railway lines? What happens to them in hot weather?" The educator tries to encourage learners to link the propositions that metal expands when heated with an episode of railway lines. When a quick survey of informal signals such as a slight nod or appropriate facial expression suggests that the linking makes sense to most learners, the educator moves on to the next question. The model of learning implies that linking is too important to be left to such "soft" assessment and a useful change in teaching style would see more reliable testing of whether the link has been made. For example, after presenting the proposition about expansion, the educator could ask learners to write about an example (White, 1988:181).

White (1988:182) remarks that answering deep processing questions provokes thought, images are formed, propositions are seen to be related, and episodes are recalled. The questions encourage linking of images, propositions and episodes, and so promote extensive patterns of connections in the learners' cognitive structures. Higher cognitive questions should encourage processing that will be evident in better recall after a long period and greater capability to apply the knowledge to new problems. Very difficult questions may provoke little processing because learners may know nothing that would help them to answer. Higher cognitive questions must be pitched at a level that may encourage processing. In questioning the educator needs the skills of selecting questions, encouraging learners to attempt the questions, and discussing how to think about them (White, 1988:183).

According to White (1988:183), time is required to think about answers thoroughly and to permit better learning. The interval should not be too long because learners' attention could wonder away to other things. This encourages learners to take more responsibility for the direction of the lesson and for their own learning. Having learners ask questions encourages processing and helps the educator to gain insight into the learners' understanding. One of the advantages of learners asking questions is that it trains the cognitive strategy of reflective thinking. The other form of training is to watch other learners' attempts in framing questions (White, 1988:184).

4.4.7 The laboratory

White (1988:186) remarks that the laboratory provides educators and learners with liveliness and fun. Many learners are attracted to science because of the colour, mystery and oddness of the equipment and materials that are present in the laboratory. White (1988:186) says the laboratory provides training in motor skills, cognitive strategies of problem solving and learning. The laboratory could be a source of episodes and images that give meaning to propositions that learners have already learnt or that they will acquire. It can be used to communicate understanding of as well as the skills associated with the scientific method. According to Kreitler and Kreitler (1974) (as quoted by White, 1988:186), laboratory experiences help learners to establish the accuracy of beliefs, promotes reflection on knowledge, resolution of conflicting principles, and provides direct experience with concepts in order to give meaning to them (White, 1988: 186).

White (1988:188) says the laboratory is a source of episodes - unique ones that remain in the memory and that as unforgettable events can be pillars to which propositions and intellectual skills are anchored while the common ones merge into scripts that make concepts understandable. Educators have to promote the linking of episodes obtained from the laboratory to other information. Everyday experiments enable learners to form scripts and images that give meaning to propositions and skills. According to White (1988:190), repeated experiences with chemicals give meaning to words such as "reaction", "precipitate", and "solution" so that sentences like "magnesium reacts with hydrochloric acid to evolve hydrogen" and "ferric oxide is precipitated when sodium hydroxide is added to a solution of a ferric salt" are readily processed.

White (1988:190) indicates that one weakness of laboratory episodes is their lack of relation to the materials and experiences that learners encounter out of school. He says that school-acquired knowledge remains apart from everyday matters, so that it is difficult to meet the aim for science to illuminate people's lives. The episode formed during experiments with common materials would link science propositions and intellectual skills to the learners' broader knowledge. The laboratory sessions have to fit into a weekly schedule and a certain amount of material has to be presented (White, 1988:190).

4.4.8 Style, and three principles of teaching

This discussion will focus on the form of mechanisms that the educator uses to control the learning of the class, because it leads to processing of information and the construction of meaning.

According to Galton and Eggleson (as quoted by White, 1988:191), educators' styles include the following: informers, problem-solvers or inquirers. Informer-style educators require learners to process sentences and are expected to develop strategies for doing so. The outcome of learning from an informing educator will depend on the pace of presentation. Rapid delivery of information inhibits processing and slower delivery allows learners to contemplate the meaning of each sentence and its relation to others. The informing style will not encourage formation of strategies that are an important part of finding out knowledge for oneself (White, 1988:192). Learners taught by an informer-educator will not develop strategies of deciding whether further learning is required; consider the purpose of learning and reflect on the significance of information to one's own life (White, 1988:192).

White (1988:192) states that problem-solvers and inquirers also build patterns of cognitive strategies that learners gain. There is no one style that should be encouraged and trained to follow. The information above provides a background for stating the three principles of teaching:

- Principle of maximum opportunity for processing;
- principle of matching teaching style with learning style and both with content; and
- principle of balance.

The principles are discussed in the next paragraphs.

4.4.8.1 Principle of maximum opportunity

White (1988:193) indicates that variations in the pace of presentation would affect the amount of processing or construction of meaning that occurs. At a too rapid pace, learners are swamped with information and little information will get past the short-term store. Presentation of less information or one intellectual skill can involve little processing. The rate of pace will depend on factors such as the newness of the information to the learners, their abilities, their physical state, interest in the topic and the style of the educator.

According to White (1988:194), learners in a class differ in the pace at which they can process the information and a means must be adopted to allow each learner to reach a personal maximum. Educators may make use of the marker learners. An implication of the principle of maximum opportunity for educators includes a need for excellent command of subject matter because their judgments of pace involves knowing how much interlinking of knowledge of the topic is possible and useful. Educators in training should have opportunities to become familiar with the thinking of learners. Another implication is that class teaching where all must keep to the same rate of learning is less efficient than procedures in which each learner can work at a personal optimum rate (White, 1988:194).

4.4.8.2 Principle of matching

According to White (1988:196), the teaching method and learners' learning strategies must be a match in the immediate processing of new information. The type of outcome is another consideration in matching. The nature of what is to be learnt has to be fitted to teaching and learning styles. When strings are being acquired, didactic teaching combines well with learners' ability to concentrate on the task. Outcomes such as relating propositions to each other are then attainable.

4.4.8.3 Principle of balance

White (1988:197) states that it is not good to use a single teaching style, because learners then develop only a restricted set of cognitive strategies and may never acquire strategies that are essential in other situations. Rapid alternation of teaching styles inhibits acquisition of strategies because learners may never have sufficient experience with any one. There should be a balance between the educators' control of learning and the learners' control of learning to avoid learners becoming indifferent to the information given to them. The principle of balance asserts that excess in any direction in the arrangement of conditions of learning is bound to bring penalties. The problem for the educator is to recognise what constitutes excess. Until everyone has the same values and perceptions there will always be a need for balance (White, 1988:197).

Kelly (2000:758) states that the constructivist approach promotes conceptual understanding rather than rote memorisation of science and that construction of knowledge is an active process. According to Saunders (1992) (quoted by Kelly, 2000:759), strategies to promote constructivist teaching and learning include hands-on activity, discussion, group work and problem-solving forms of assessment. Teaching science calls for minds-on explorations that engage learners in thoughtful, reflective investigations, fostering a genuine interest and curiosity in science. The educator's role becomes one of being a facilitator that initiates discussions, determining learners' understanding and utilising that information to restructure learners' existing concepts.

The educator needs to create a learning environment that provides the opportunity for discussions and that will be supportive of conceptual change learning. A learning environment refers to any setting that provides opportunity for interaction and exploration (Scott *et al.*, 1992:20). In some situations, a teacher is required to take on a neutral or consultative role.

Teaching strategies according to Hewson and Hewson (1983:732) are the following:

- **Integration**: it is a dominant teaching strategy in science whereby new conceptions are integrated with existing conceptions.
- **Differentiation**: existing conceptions are differentiated into more clearly defined separated but closely related conceptions. The learner needs to see that what was plausible in one situation is no longer plausible in a different or more complex one.
- **Exchange**: the aim is to exchange an existing conception for a new plausible one. It becomes necessary to create dissatisfaction with the existing conception as well as showing that the new conception has more explanatory and predictive power than the old one.
- **Conceptual bridging**: the aim is to establish an appropriate context in which important abstract concepts can be linked with meaningful common experiences.

Sensitivity towards learners' evolving conceptions helps teachers to understand their learners better and will maximise their learners' learning. The constructivist theory of learning makes the studying of models attractive (Harrison & Treagust, 2000:378). According to Barnes (1976) as quoted by Gilbert and Watt (1983:85), the educator's task is to form linkages between old and new knowledge to help form cognitive bridges.

Harrison and Treagust (2000:377) recommend that analogical models comprise the methods, products, the teaching and learning tools of science. Educators should regularly check learners' visualisation of the model that is found in learners' textbooks. Learners cannot be expected to reliably interpret models that they have not designed or experienced previously, therefore models should be negotiated with learners. Models are designed for specific purposes and learners need to understand that.

According to Harrison and Treagust (2000:377), educators should remain aware of the differences between expert modellers and naïve modelers (their learners). It should be kept in mind that learning to become a skilled modeller is like learning to write creatively, that is it is only achieved through much practice over a lengthy period. Hardwickle (1995) (as quoted by Harrison & Treagust, 2000:378), said that educators should allow learners to make, play with and explore different models through projects and the use of model-making sets.

Nussbaum and Novick (1981) (as quoted by Gilbert & Watts, 1983:85), stated that learners are expected to restructure their frameworks in order to accommodate results that present discrepancies when compared to predictions and explanations derived from their own ideas. This sequence is:

1. The educator creates a situation that requires learners to invoke their frameworks in order to interpret it.
2. The educator encourages learners to verbalise and use pictures to describe their ideas.
3. The teacher assists them, non-evaluatively, to state their ideas clearly and concisely.
4. Learners debate the pros and cons of the different explanations that have been put forward. This will create cognitive conflict within many of those participating.
5. The educator supports the search for the most highly generalisable solution and encourages signs of forthcoming accommodation in learners.

4.5 MODELS IN THE TEACHING AND LEARNING OF SCIENCE

Science lessons involve the use of models to explain aspects of science content, for example the magnetic field and molecular models. Teachers use analogical models to make concepts more accessible to the learners. The models are more than communication tools; they provide means for exploring, describing and explaining scientific and mathematical ideas; they help to make science relevant and interesting and worth learning. Models should be used with care in teaching and learning because they may expose learners to interpretations that often lead to unexpected alternative conceptions. Educators are expected to teach modelling skills and take time to discuss and criticise the models used in class (Harrison & Treagust, 2000:353).

Glynn (as quoted by Harrison & Treagust, 2000:354) highlighted the need for educators to help learners identify the positive and negative aspects of an analogy. They do not comment on a third and also important aspect of an analogy: the neutral aspect. Hesse (1966) stated that the neutral aspects of an analogy are neither obviously correct nor clearly wrong. These neutral aspects can stimulate new ideas and provide topics for research.

Educators' explanations and learners' mental models interact. How learners interpret these models, depends on the learners' prior experience, knowledge, language skills and thinking strategies (Harrison & Treagust, 2000:355). These authors pointed out that experienced educators recognise, value and encourage these interactions.

According to Harrison and Treagust (1998:422), models can only act as aids to memory, explanatory tools and learning devices. Harrison and Treagust (1998:422) also states that educators need to plan the use of models in their lessons. The focus involves pre-lesson planning in which the educator focuses on the concept's difficulty, learners' prior knowledge and ability and the model's familiarity.

Drawings are models of mental models and this lengthening of the reasoning chain may increase the likelihood of learner confusion. This gives rise to questions such as: "what influence does the representational form of models have on the effectiveness of model-based learning?" "How can educators decrease their reliance on pictures of models in ways that enhance the learners' thinking and modelling skills?" (Harrison & Treagust, 2000: 376). It is likely that effective analogical models will be developed by educators and writers that appreciate the variableness of learners' models and that are experienced with learners' models during learning (Harrison & Treagust, 2000:354).

4.6 SUMMARY

This chapter has dealt with aspects of the learning and teaching of science. Views on what learning and teaching is, were discussed. Strategies of teaching science and models of teaching and learning were discussed. The importance of the constructivist teaching and learning approach was highlighted.

The empirical study in the next chapter (Chapter 5) aims at establishing how learners visualise atoms, compounds and ions in terms of chemical reactions. In or words, the chapter will focus on learners' models of atoms, compounds, ions and chemical reactions.

CHAPTER 5
EMPIRICAL STUDY

5.1 INTRODUCTION

This chapter gives an overview of the empirical study that formed part of the research reported on in this dissertation. It deals with the institutions at which the research instruments were administered, the population, the development of the questionnaires and the method used in processing the questionnaires.

5.2 EMPIRICAL RESEARCH

The survey was conducted with 100 Grade 11 learners from four high schools in Rustenburg, in the North West Province, South Africa.

5.2.1 Population

The learners involved in the survey were all in Grade 11 and enrolled for Physical Science. Physical Science includes both physics and chemistry in South African schools. One hundred (N=100) learners from four different schools were involved in the survey. From every school 25 learners were selected according to their science marks for the first semester. Equal numbers of high, medium and low performers were selected per school. The schools were situated in the Rustenburg region in the North-West Province in South Africa. Approximately seventy per cent (70%) of the learners were from rural areas.

5.2.2 Questionnaire for learners

The questionnaire consisted of 24 items. These items were a combination of open and close-ended questions (Appendix A). The items in the questionnaire focused on descriptions, definitions and pictorial interpretations or representations of verbal information. All learners completed the questionnaire in class under the supervision of their educators. There was no time limit for completing the questionnaires. Learners were allowed sufficient time to write until they had finished.

The items involved addressed the different concepts from different point of views. The basic concepts in chemistry such as atoms, chemical reactions, the elements and compounds are part of the content in the Grade 10 syllabus. The assumption was made that they had already studied these concepts in Grade 10. The questionnaire covered the following concepts in chemistry: atoms, molecules, ions and chemical reactions. Learners were expected to be familiar with these concepts. Problems experienced by learners in the learning of these concepts were identified in the questionnaires.

A questionnaire was developed and administered to probe into learners' knowledge, skills and abilities with regard to visualisation and understanding of atoms, molecules, ions and chemical reactions. Three physical science Grade 12 learners who did not form part of the target population helped the researcher to edit the questionnaires. This assured that the items in the questionnaire were at the level of Grade 11 learners' comprehension. Two experts on physics and physics education and two grade 11 science educators checked the questionnaire for validity and reliability

5.2.3 Processing of questionnaires

All the learners that were present on the day that the questionnaire was administered completed it. The analysis was done by the researcher. Analysis of the learners' responses in the questionnaire was done according to a procedure described by Gilbert (1991). According to this procedure, the questionnaires were firstly read to get the ideas and opinions held by learners about the pictorial and verbal descriptions of concepts, to identify alternative conceptions and problems they experience when trying to form pictures of concepts. The second reading involved the collection of data. The basic concepts in chemistry such as atoms, chemical reactions, the elements and compounds are part of the content in the Grade 10 syllabus. The assumption was made that they had already studied these concepts in Grade 10

5.3 SUMMARY

This chapter dealt with the empirical part of the study. The empirical part of this research was based on a standard scientific research method. The method of data collection (a questionnaire), analysis of data and the population involved in the study were outlined. The analysis of the data was done by the researcher. The results from the study and the discussion of the results are presented in the next chapter, Chapter 6.

CHAPTER 6

RESULTS OF THE EMPIRICAL SURVEY AND DISCUSSIONS OF RESULTS

6.1 INTRODUCTION

This chapter presents and discusses the results of the learners' questionnaire (Appendix A). Table 6.1 summarises the results. Tables 6.2 to 6.5 present alternative conceptions gathered from learners' responses, while tables 6.6 to 6.9 present common problems learners had with the visualisation of atoms, molecules, ions and chemical reactions.

The tables represent the learners' responses to the items in the questionnaire (Appendix A). The number and percentages of learners linked to a specific response are given in the tables, with discussions of each item presented below the tables.

6.2 LEARNERS' RESPONSES

Table 6.1 gives a summary of learners' responses for main items and sub-items in the questionnaire (Appendix A). Responses are classified under gender: male / female; acceptable: yes / agree / true /always; unacceptable: no / disagree / false / sometimes, never /unsure, and no attempt.

TABLE 6.1 RESULTS OF LEARNERS' QUESTIONNAIRE (N=100)

Item	Gender	Acceptable/Yes/ Agree/ True/ Always	%	Unacceptable/No/ Disagree/ False/ Sometimes	%	Never/ Unsure	%	No attempt	%
1.1 Can you form a picture of an atom in your mind?	M	45	45	10	10				
	F	31	31	14	14				
	Total	76	76	24	24				
1.2 If yes, draw the picture as it appears in your mind.	M	20	20	26	26			9	9
	F	19	19	14	14			12	12
	Total	39	39	40	40			21	21
1.3 Describe in your own words what an atom is.	M	19	19	35	35			1	1
	F	22	22	23	23			0	0
	Total	41	41	58	58			1	1
1.4 Give an example of an atom.	M	26	26	19	19			10	10
	F	20	20	16	16			9	9
	Total	46	46	35	35			19	19
1.5 All material objects (books, humans, animals, plants, the earth, air…) are made of atoms.	M	29	29	12	12	14	14		
	F	17	17	16	16	12	12		
	Total	46	46	28	28	26	26		
2.1 Can you form a picture of a molecule in your mind?	M	46	46	9	9				
	F	36	36	9	9				
	Total	82	82	18	18				
2.2 Give an example of a molecule and draw this molecule as it appears in your mind.	M	35	35	15	15			5	5
	F	26	26	13	13			6	6
	Total	61	61	28	28			11	11

2.3 Describe in your own words what a molecule is.	M	19	19	31	31			5	5
	F	20	20	25	25			0	0
	Total	39	39	56	56			5	5
2.4 How are molecules formed?	M	24	24	26	26			5	5
	F	26	26	18	18			1	1
	Total	50	50	44	44			6	6
3.1What is an ion?	M	6	6	29	29			20	20
	F	12	12	28	28			5	5
	Total	18	18	57	57			25	25
3.2 How are ions formed?	M	11	11	26	26			18	18
	F	11	11	23	23			11	11
	Total	22	22	49	49			29	29
3.3 What is a cation?	M	14	14	13	13			28	28
	F	6	6	22	22			17	17
	Total	20	20	35	35			45	45
3.4 Give an example of a cation and draw its picture.	M	5	5	14	14			36	36
	F	8	8	14	14			23	23
	Total	13	13	28	28			59	59
3.5 What is an anion?	M	15	15	12	12			28	28
	F	6	6	22	22			17	17
	Total	21	21	34	34			45	45
3.6 Give an example of an anion and draw its picture.	M	6	6	13	13			36	36
	F	6	6	18	18			21	21
	Total	12	12	31	31			57	57
4.1 What is a chemical reaction?	M	25	25	26	26			4	4
	F	21	21	20	20			4	4
	Total	46	46	46	46			8	8
4.2 A chemical reaction is only possible if the atoms participating in	M	40	40	9	9			6	6
	F	26	26	12	12			7	7
	Total	66	66	21	21			13	13

the reaction are moving.									
4.3.1 How do you picture the chemical reaction $H_2 + O_2 \rightarrow H_2O$?	M F Total	29 26 55	29 26 55	20 16 36	20 16 36			6 3 9	6 3 9
4.3.2 How would you balance this chemical equation?	M F Total	33 27 60	33 27 60	16 9 25	16 9 25			6 0 6	6 0 6
4.4 Write down an example of a chemical reaction.	M F Total	19 19 38	19 19 38	29 24 53	29 24 53			7 2 9	7 2 9
4.5 Do you find the formation of pictures important for understanding chemical reactions?	M F Total	44 33 77	44 33 77	6 9 15	6 9 15			5 3 8	5 3 8
4.6 Do you try to make pictures of chemical reactions in your studies?	M F Total	2 1 3	2 1 3	40 32 72	40 32 72	6 7 13	6 7 13	7 5 12	7 5 12
4.7 Does formation of pictures simplify chemical reactions?	M F Total	38 27 65	38 27 65	9 10 19	9 10 19			8 8 16	8 8 16

6.3 DISCUSSION OF LEARNERS' RESPONSES

In this section an item by item discussion of learners' responses to the item in the questionnaire (Appendix A) is given. The discussion is based on the results summarised in tables 6.1 to 6.9.

6.3.1 Atoms

ITEM 1.1: Can you form a picture of an atom in your mind?

All learners attempted this item. Some 76% of the learners responded by saying that they could form a picture of an atom in their minds. Of these, 45% were males and 31% were females. Only 24% responded negatively. Both Grade 10 and Grade 11 syllabi emphasise the atomic structure. Models are used to represent atoms. This had a positive influence on learners' responses to this item. This proves that it is easier for learners to form mental pictures of things they have seen even if it might not make sense to them.

ITEM 1.2: If the answer to item 1.1 is "yes", draw the picture as it appears in your mind.

Some 76% said yes in item 1.1. It is clear from the drawings of an atom that learners had different ideas of how an atom looks like. From a scientist's point of view thirty-nine per cent (39%) of the responses were acceptable, 40% gave unacceptable responses and 21% of the learners did not attempt to respond to this item. There were basically three types of visual responses. The first one was that of a sphere having a central nucleus. The second one was that of a positive nucleus surrounded by electrons in their orbits (Bohr's model of the atom). The third one was that of a sphere consisting of positive and negatively charged particles evenly distributed (Thomson's model of the atom).

In most of the responses the basic ideas were an atom pictured as a sphere with only a nucleus or with the nucleus and negatively charged particles or with positive and negatively charged particles. In grades 10 and 11 textbooks Bohr's model of the atom consists of concentric spheres with the positive particles at the center and negative charges distributed around it. The textbooks also include Thomson's model of the atom and the use of the Lewis and Couper structures to show the formation of ions and molecules. Most of the learners did not use them to draw a picture of an atom. The conclusion is that learners experience difficulties in representing atoms visually.

ITEM 1.3: Describe in your own words what an atom is.

The aim of this item was to establish what learners think an atom is. Almost all learners responded to this item. Some 41% of the responses were acceptable and most of them were definitions from the textbooks they were using. A number of problems with regard to the definition of an atom were brought to surface by the responses to this item. One of these problems was that an atom is the smallest particle that can take part in a chemical reaction. Other responses included the view that atoms have a positive nucleus and electrons surrounding it. The atom is regarded as very small. Only 1% of the learners did not respond to this item.

Some 58% of the responses to this item were unacceptable. Some of the unacceptable ideas are that an atom is described to be a molecule or a combination of molecules, and that an atom is a number of neutrons or protons. This indicates that these learners have a distorted idea of what an atom is. Consequently, they would not have acceptable pictures of atoms in their minds and therefore are unable to draw atoms correctly. In conclusion, learners' responses indicate that there is a serious problem with regard to the concept of atoms and the problem is related to their inability to visualise.

ITEM 1.4: Give an example of an atom.

This item was included to establish learners' ability to relate atoms to the real world. Some 46% of the responses to this item were acceptable. The correct responses included writing of the correct formula and for some atoms the names were given. This item was not specific regarding the type of response needed (chemicals symbols or the names of a specific atom, therefore both were accepted). A percentage of 35 of the responses were unacceptable. Some of the learners indicated that they had no idea of examples of atoms through the kind of responses they gave such as water on atomic mass. Most learners gave examples of compounds. Only 19% did not attempt this item.

ITEM 1.5: All material objects (books, humans, animals, plants, the earth, air) are made of atoms.

This item was also used to establish learners' ability to relate atoms to everyday life. Learners were expected to state where they agree, disagree or are unsure about the statement above. Some 46% agreed with the statement, while 28% disagreed. Some 26% were unsure. This indicated that learners know little about atoms and its occurrence in their living worlds. Learners find it difficult to relate atoms to everyday life situations.

6.3.2 Molecules

ITEM 2.1: Can you form a picture of a molecule in your mind?

All learners responded to this item. The majority of learners (more learners than in 1.1) responded positively that they could form a picture of a molecule in their minds. Only 18% indicated that they found it difficult to form pictures of molecules in their minds.

ITEM 2.2: Give an example of a molecule and draw this molecule as it appears in your mind.

This item probed into learners' understanding and the ability to give examples and to form pictures of molecules. Some of the learners gave the correct examples with unacceptable drawings, or wrong examples and acceptable drawings. Others gave the examples without drawings of molecules. Some 61% of the responses were acceptable, while 28% were unacceptable. In most of the acceptable responses, water was given as an example and a water molecule was represented by one big circle for oxygen to which two small circles were attached.

From the unacceptable responses it was clear that learners who gave those responses had no idea of how to draw pictures of molecules. Some confused ionic compounds with molecules. Only 11% of the learners simply did not respond to this item. This led to a conclusion that these learners did not have an idea of what a molecule is.

ITEM 2.3: Describe in your own words what a molecule is.

This item tested learners' understanding of molecules. Most learners (56%) found it difficult to describe a molecule. Their common descriptions of molecules include the following: small gas particles, an element in the form of liquid and small droplets of water. Some 39% gave acceptable descriptions. Only 5% were unable to respond to the item. This indicates that emphasis in tuition about molecules is mostly on giving examples such as water and other substances such as gases and not on definitions or general descriptions of molecules.

ITEM 2.4: How are molecules formed?

This item probed further into learners' knowledge of molecules. Half of the group (50%) of learners could explain how molecules are formed. Some of the explanations were very simple, for example, learners consider molecules to be formed when *two* atoms combine. This could be as a result of the examples that they were given in class. Examples of molecules such as oxygen gas (O_2), Nitrogen gas (N_2) and hydrogen gas (H_2) were given in class.

Other definitions were very broad and vague. These definitions did not give a clear picture of the learners' understanding or learners' thoughts on how molecules are formed. They stated for example, that molecules are formed by chemical reactions. This response could not be considered totally incorrect, especially when thinking about the reaction between carbon and oxygen gas to yield carbon dioxide as a product, which is classified as a molecule.

A considerable number of learners (44%) responded with unacceptable answers. Some associated the formation of molecules with boiling water. They were of the opinion that when water or any liquid boils, molecules are formed. This explanation indicated that these learners do not have any idea of how molecules are formed. No response was given by 6% of the respondents.

6.3.3 Ions

ITEM 3.1: What is an ion?

This item brought to the surface a variety of responses. From the 75% of learners who attempted it, 57% could not define or describe ions correctly. Only 11% defined an ion as a hard metal such as steel, as an element, or as a solid particle. This group indicated confusion between ions and iron (Fe) metal and the occurrence of iron, like iron in the body. Some indicated that they had no idea of what ions were, and defined them as stable molecules. A significant number of learners (25%) did not attempt to respond to this item. Only 18% gave acceptable descriptions, such as an ion is formed when an atom loses or gains electrons. A few learners explained the kind of ions formed when there is a loss or a gain of electrons, namely cations and anions.

ITEM 3.2: How are ions formed?

The responses to this item revealed that learners experience serious problems with the concept of ions. A relatively high percentage of learners (29%) did not respond to this item. Failure of learners to respond to this item can be attributed to the following: The textbooks used in their schools do not give sufficient information on ions. Some 57% of the responses were unacceptable, for example 6% gave the explanation that ions are formed by joining pieces of metals or by molecules joined together. Some 7% stated that ions are formed when small particles bond together. These explanations are not in line with the scientific explanation and reveal that learners do not understand the concept of an ion.

ITEM 3.3: What is a cation?

The response to this item was very low, because 45% of learners did not attempt to answer it. This could be expected because of their poor performance in item 3.1 (What is a cation?) In item 3.1, learners revealed that they knew little about ions. From those who responded to item 3.3, 35% gave unacceptable responses. The unacceptable responses included statements such as: a cation is a negatively charged element or that cations are positive charges. Some learners stated that *cation* was supposed to be *caution* and said that it's a warning sign. Only 20% of the respondents gave acceptable responses, which indicated that they really understood what cations are and even gave explanations of how they are formed. For example, they said cations are positive ions and are formed when atoms lose or donate electrons.

ITEM 3.4: Give an example of a cation and draw its picture

This item produced the lowest percentage of responses of all items in the questionnaire with 59% of learners not responding. The lack of responses indicates that there are serious problems with regard to the concept of ions in general. A low 13% of respondents were able to give acceptable drawings and correct examples. The sodium ion was given as an example by a moderate number of learners and Bohr's model of the atom was used for a diagram. It was pictured as having electrons distributed in shells around the positive nucleus but did not have an equal number of electrons and protons.

More than a quarter of the population (28%) gave unacceptable responses, including those who gave correct examples, but unacceptable diagrams. Some learners could not give examples of cations and had just drawn a sphere with scattered plus signs. They did not indicate whether they understood that cations may have negative particles even if it may be less than the number of positive particles.

ITEM 3.5: What is an anion?

In this item, 21% of the responses were acceptable. About a third (34%) of the learners gave unacceptable responses. Some said that anions are chemicals that contain iron molecules. Some of the definitions indicate that learners have an idea but get confused or have a problem to phrase their responses. An example is the definition that anions are negative charges. Since cations were pictured as a sphere with scattered positive charges, learners seem to be confusing charges with ions. Almost half (45%) of the learners did not know what anions are and did not attempt this item.

ITEM 3.6: Give an example of an anion and draw its picture.

From the definition of anions (item 3.5), it was clear that learners did not know what anions are, and therefore it was not surprising to find that 57% of the group under survey did not respond to this item at all. Even learners who gave acceptable responses in item 3.5 found it difficult to draw pictures of anions. Others gave correct examples but unacceptable drawings. Some 31% of the learners gave unacceptable responses, while only 12% gave acceptable responses.

6.3.4 Chemical reactions

ITEM 4.1: What is a chemical reaction?

No less than 98% of learners responded to this item, although only 46% gave a correct description of a chemical reaction. The most common description was that of a combination of two or more atoms or compounds, or a reaction between two or more substances to form products. Learners indicated awareness that chemical reactions have reactants and products. Others referred to a chemical reaction as a combination of chemicals. Unacceptable responses were given by 46% of the learners. Only 11% had a common alternative conception that in a chemical reaction only *two* elements combine. Some learners confused a chemical reaction with a mixture and defined a chemical reaction as a mixture of elements. They did not give information on products and an indication of whether they were aware of the fact that the product's physical and chemical properties were completely different.

ITEM 4.2: A chemical reaction is only possible if the atoms participating in the reactions were moving.

The purpose of this item was to test the level of thinking about chemical reactions. The responses were reasonable, because 66% agreed with the above statement, 21% disagreed, while 13% failed to attempt to answer this item. The responses indicated that the majority of learners think and do not see further than the chemical formulae used to describe chemical reactions. Horn et al (1992:183) stated that in the kinetic theory of matter particles of matter are in a state of constant motion. This statement seems to have a positive influence on learners' response to this item (see paragraph 2.5).

ITEM 4.3.1: How do you picture the chemical reaction $H_2 + O_2 \rightarrow H_2O$?

The aim of this item was to determine how learners visualise chemical reactions. This item gave learners the liberty of using any form of response they were comfortable with, for example, explanations, descriptions or drawings. Most of the learners had a problem to describe how they picture the chemical reaction above. A surprising percentage of 55 gave acceptable responses, even though their description of pictures did not indicate creativity and an advanced level of thinking. They did not use Bohr's or Lewis' structures of the atom. They did not use pictures but described the chemical reaction above. Most of them described the chemical reaction above simply as hydrogen gas reacting with oxygen gas to give water. They did not even try to draw pictures of the reactants and the products and as many as 36% of the responses were unacceptable. This item and responses supports White's(1988:142) statement from the literature study that learners should be encouraged to and trained to elaborate their knowledge by coming up with the relevant images, episodes and proporsitions (refer to chapter 4:46).

Examples included the explanation that it is a reaction formed by two molecules, hydrogen oxide reacting with two atoms of oxygen. This is an alternative conception already revealed in item 4.1. Some stated that it is a reaction taking place in the atmosphere. One learner stated that gases are reacting together, giving water in liquid form as the product. No responses to this item came from 9%.

ITEM 4.3.2: How would you balance this chemical equation?

A high percentage (60%) of the learners managed to give an acceptable response. This group balanced the equation given in 4.3.1 correctly. Most of them found it difficult to put on paper the steps taken to balance the equation. Unacceptable responses came from 25%. In almost all of the unacceptable responses learners tried to balance the chemical equations but were unable to do it correctly. The deduction was that they did not know how to balance the chemical equation in 4.3.1. The 6% that did not respond to this item were all males. The lack of response indicates that they had a problem with balancing equations.

ITEM 4.4: Write down an example of a chemical reaction.

The responses to this item indicated that learners had problems when it came to the writing of the correct chemical formulae of compounds, and the products formed. The following are examples of unacceptable equations: $K + OH \rightarrow KOH$, and $K_2 + O_2 \rightarrow K_2O$, which corresponds with the example given in item 4.3.1. More than half of the learners (53%) displayed problems and their responses were classified as unacceptable. Some 38% of the responses were regarded as acceptable. Equations of simple reactions were given and the equations were correct and correctly balanced. Only 9% did not attempt to answer the item.

ITEM 4.5: Do you find the formation of pictures important for understanding a chemical reaction?

The purpose of this item was to test whether learners make use of pictures of the entities in chemical reactions in order to help them to understand chemical reactions. Quite a large number, 77%, of the participating group of learners said that the formation of pictures is important to understand chemical reactions. Most of them stated that it is easier to remember something that you have seen than what you have never seen. Fifteen per cent (15%) of the learners said the formation of pictures does not help them, as it is not important for understanding. Only 8% of the learners had no comment and therefore did not respond to this item. From literature study according to Smit (2001:222) models supply knowledge of reality and thus promote a better understanding of nature and explanation of processes (see paragraph 2.4). Harrison and Treagust (2000:352) stated that analogical models can explain some aspects of scientific content in order to make abstract content more accessible to the learners in familiar and visual ways.

ITEM 4.6: Do you try to make pictures of chemical reactions in your studies?

This item probed into learners' habit to make pictures when learning chemistry. This reflects the ability and habit to visualise. Only 3% of the learners said they always try to make pictures of chemical reactions. The majority (72%) said they sometimes form pictures of chemical reactions, 13% of learners never try to make pictures and 12% did not respond to this item.

ITEM 4.7: Does formation of pictures simplify chemical reactions?

As many as 65% said the formation of pictures simplifies chemical reactions. They find it very difficult to visualise, especially when they have never seen the associated pictures. It is clear that learners did not want to form their own pictures because they were not confident that they might be acceptable ones. Some 19% stated that the formation of pictures does not help in the simplification of chemical reactions, while 16% did not respond to this item.

6.4 DISCUSSIONS OF ALTERNATIVE CONCEPTIONS

Tables 6.2 to 6.5 summarise the most popular alternative conceptions learners have regarding atoms, molecules, ions and chemical reactions. These alternative conceptions were derived from their responses in the questionnaire (Appendix A).

Table 6.2: The most popular alternative conceptions that learners have of atoms

ALTERNATIVE CONCEPTIONS	NUMBER OF LEARNERS	% OF LEARNERS
1. An atom is a molecule.	12	12
2. Atom is a number of neutrons plus number of protons.	8	8
3. An atom is any substance consisting of an element in the periodic table.	6	6
4. An atom is an element.	6	6
5. An atom is something spherical.	5	5

Table 6.3: The most popular alternative conceptions that learners have of molecules

ALTERNATIVE CONCEPTIONS	NUMBER OF LEARNERS	% OF LEARNERS
1. Molecules are small gas particles.	8	8
2. Molecules are elements in the form of liquid.	5	5
3. Molecules are small particles.	5	5

Table 6.4: The most popular alternative conceptions that learners have of ions

ALTERNATIVE CONCEPTION	NUMBER OF LEARNERS	% OF LEARNERS
1. An ion is a hard metal.	11	11
2. An ion is an element.	9	9
3. An ion is a stable molecule.	6	6
4. Ions are formed by joining pieces of metals.	6	6
5. Ions are formed by molecules.	6	6
6. Ions are formed when small particles bond together.	7	7
7. Ions are formed by positive and negative charges.	5	5
8. Ions are a mixture of chemicals.	5	5

Table 6.5: The most popular alternative conceptions that learners have of chemical reactions

ALTERNATIVE CONCEPTIONS	NUMBER OF LEARNERS	% OF LEARNERS
1. Chemical reaction is a reaction between two elements or chemicals.	11	11
2. Chemical reaction is the mixing of elements.	8	8
3. For a reaction of hydrogen and oxygen, you add oxygen to hydrogen.	9	9
4. For reaction of hydrogen and oxygen, hydrogen oxide reacts with oxygen.	5	5

6.4.1 Atoms

The most common alternative conception from the survey resulted was that learners think of an atom as a molecule. They seem to confuse atoms and molecules. This statement relates to the findings from the literature study as discussed in Chapter 3, where Vicente (2002:48) indicated that learners thought all compounds are made of molecules. Learners also believe that atoms are elements and that have to be something spherical. As discussed in the literature review, learners think that analogies or symbols used to represent abstract concepts correspond with the concrete reality. The most probable reason is that in the textbooks used, an atom is represented as spherical, like in Dalton's and Bohr's models of the atom. From the literature study, according to Harrison and Treagust (1998:421), learners believe that models are true pictures of non-observable phenomena and ideas. They do not understand what modelling means.

6.4.2 Molecules

If learners do not know what molecules are, then they would not understand how they are formed. One of the alternative conceptions learners had about molecules was with the descriptions of what they are. Some of the alternative conceptions include the following: molecules are gas particles or molecules are elements in the form of liquid. The reason could be that molecules are mentioned only when talking about water. This was evident when most learners gave water as an example of a molecule when responding to item 2.2

of Appendix A. The confusion was also evident from the literature review in which Taber's research (1998:602) indicated that with regard to covalent bonding, learners' opinion is that two electrons hold molecules together, shared by two atoms. From the literature review it appears that learners refer to ionic molecules. This indicates that learners do not even know how molecules are formed and these alternative conceptions hamper their understanding.

6.4.3 Ions

The survey results revealed that the most popular alternative conception learners had about ions was that of thinking of an iron as a hard metal. According to Harrison (1998:421) as quoted in Chapter 3, the language common to biology and chemistry is a major source of confusion for learners. Similar sounding words such as ion and iron confuse learners'. The descriptions included were that an ion is an element or is regarded as a stable molecule. These descriptions are not in line with the scientific knowledge and they lead to confusion. In the literature, one of the alternative conceptions was of considering ions as altered atoms that have gained or lost electrons rather than being viewed as entities in their own right. The literature also revealed that there was confusion with ionic size and atomic size (see Table 3.1). The findings from the literature and research results relate to one of the problems where (see Table 6.6) learners stated that because they did not know the size and structure of atoms, they could not draw a picture of an atom. This problem was then carried over to ions. This indicates the impact that alternative conceptions have on creativity in the formulation of visual models and understanding.

6.4.4 Chemical reactions

The literature review revealed that alternative conceptions result from thinking that the chemical reactions result from mixing and separating mixtures. From the research results one of the alternative conceptions identified was that a chemical reaction is to mix elements. The implication is that the difference between mixtures and reactions to form new compounds are not well explained in the classroom. Learners confined their descriptions of chemical reactions to a reaction between *two* elements and do not include a reaction of more than two substances. The reason could be that the examples that are used only include a reaction of two substances.

6.5 DISCUSSIONS OF PROBLEMS WITH MODELLING

Tables 6.6 to 6.9 summarise the most common problems learners encounter when trying to make pictures of atoms, molecules, ions and chemical reactions. These problems were derived from learners' responses in the questionnaire (Appendix A, item 4.8).

Table 6.6: The common problems that learners encounter when trying to make pictures of atoms

PROBLEMS ON ATOMS	NUMBER OF LEARNERS	% OF LEARNERS
1. Not knowing the structure and the size of atoms.	9	9

Table 6.7: The common problems that learners encounter when trying to make pictures of molecules

PROBLEMS ON MOLECULES	NUMBER OF LEARNERS	% OF LEARNERS
1. Not knowing the structure of molecules.	6	6
2. Not knowing how to make pictures of molecules.	5	5

Table 6.8: The common problems that learners encounter when trying to make pictures of ions

PROBLEMS ON IONS	NUMBER OF LEARNERS	% OF LEARNERS
1. Knowing little about the concept of ions.	6	6
2. Not knowing the meaning of ions.	6	6
3. Finding it difficult to imagine ions.	5	5
4. Not knowing the difference between cations and anions.	5	5

Table 6.9: The common problems that learners encounter when trying to make pictures of chemical reactions

PROBLEMS ON CHEMICAL REACTIONS	NUMBER OF LEARNERS	% OF LEARNERS
1. To balance equations.	17	17
2. Not knowing the products that are formed during chemical reactions.	10	10

6.5.1 Textbook

The textbook learners use (Horn et al.,1992) place emphasis on the history of the development of atoms and learners end up not learning the structure of atoms but the history. Therefore learners do not use Bohr's model to illustrate the formation of ions or molecules because they do not know the link to atoms. Lewis' structures are used to model the formation of molecules in textbooks, while learners still have a problem with the formation of molecules.

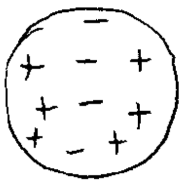
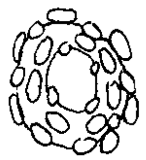
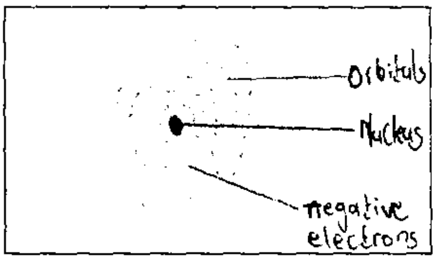
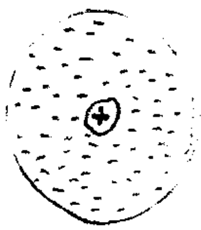
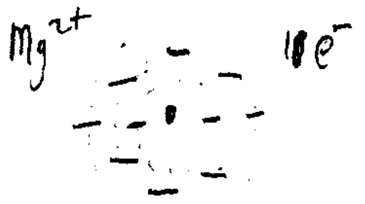
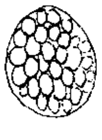
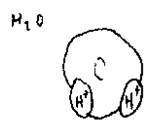
Three possible reasons why learners did not use Lewis' or Bohr's models were:

1. Educators did not teach the chapter on atoms and formation of bonds using Lewis' structures.
2. Learners did not understand Lewis' or Bohr's models of the atom.
3. Learners did not respond to the question asked in the questionnaire.

6.5.2 Progression and consistency

There is progression in the learners' models of atoms, to ions, to molecules, and finally to chemical reactions. These problems were also consistent, because if a learner used the ball model for atom, they used it for ions and molecules too. The basic structure of models is of atoms and learners who did not get it right could not get the other correct.

Table 6.10: The progression of learners' models

	Typical learner model
Atoms	   
Ions	
Molecules	  

6.5.3 Problems relating to descriptions

Learners had problems with similar sounding words. For example, learners confused cations with caution; iron with ion and this affected their descriptions in a negative way. The other common problem was not being able to express themselves, because it was more difficult for second-language users.

6.6 SUMMARY

This chapter has dealt with learners' responses to the items in the questionnaire (Appendix A). It gave an indication of learners' ability to visualise and describe entities and processes relevant to chemical reactions. The responses were discussed.

The chapter attended to objectives 1.4.2 and 1.4.3 of this study. Objective 1.4.2 was on how learners visualise atoms, compounds and ions in the context of chemical reactions, while objective 1.4.3 aimed at investigating how learners visualise simple chemical reactions.

In the next chapter (Chapter 7), conclusions are drawn and recommendations based on the results are presented.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

This chapter consists of conclusions and recommendations. The conclusions and the recommendations are based on the results of the empirical survey. The aim of the recommendations is to help alleviate problems Grade 11 learners experience when learning chemistry.

7.2 CONCLUSIONS

7.2.1 Atoms

Learners have problems to understand what an atom is. From the results summarised in Table 6.1, it is evident that learners do not have the scientific correct picture of an atom in their minds. The inclusion of atoms as one of the topics in the syllabi of grades 10 and 11 had a positive influence on learners' responses. Some responses indicated that learners knew a lot about atoms. The basic idea of learners about how atoms look like from pictures drawn was that of a sphere or a circular shape. Learners had a problem in defining an atom. The concepts of an atom and an element confused the learners. Atoms are the basic units of matter and for learners to understand chemistry better, they need to understand what atoms are. The alternative conceptions were identified from the research results. The most common alternative conception was of referring to atoms as molecules. Learners believe that models are true pictures of non-observable phenomena and ideas, and this make it difficult for them to formulate pictures of atoms.

7.2.2 Molecules

There were problems with the concept of molecules when it came to descriptions of what they were, including explanations of how they were formed. The most common example given by the learners was that of a water molecule. The problem might be that in classroom situations the only example given was that of water. The fact that molecules are not given sufficient attention in the Grade 11 syllabus might be one of the contributing factors of no response by learners in the items on molecules (Table 6.1). Atoms are basic to the understanding molecules. If learners do not understand atoms they are most likely to have problems in the understanding of the formation of molecules and even in visualising molecules. Alternative conceptions about molecules were mainly on descriptions of what molecules are.

7.2.3 Ions

The responses to the items on ions (see Table 6.1) indicated that almost all learners had no idea of what ions are. Only a few learners gave acceptable responses while other learners knew nothing about ions. Learners did not know what ions are and would therefore not be able to give acceptable responses to the remaining items regarding the concept of ions. They could not tell what cations and anions are, and could not give examples and pictures of cations and anions. Understanding ions depends on learners' knowledge of atoms. It was not surprising that learners found it hard to understand the concept of ions, considering the ideas they had about atoms. The concept on which learners had many alternative conceptions, was that of ions (see Table 6.4). This concept needs to be attended to at classroom level. Learners described iron instead of an ion because the two words sound similar and thus confused them.

7.2.4 Chemical reactions

More than half of the learners' responses indicated that they did not know what a chemical reaction is. They pictured chemical reactions as symbols, for example hydrogen was visualised as a capital letter H with a sub-script 2 (H_2) and oxygen as (O_2). The problem arises from their lack of visualisation of molecules, ions and atoms. Learners could balance the equations, but there were those who still needed help. It was very challenging for learners to give examples of equations. This corresponded with their response to item (4.1), which required them to define a chemical reaction. Most learners value the importance of the formation of pictures to understand chemical reactions. From the learners' response to item (4.6), it was evident that most learners did not try to make pictures of chemical reactions in their studies but were of the opinion that visualisation simplified chemical reactions. A description of a chemical reaction was confined to a mixture of two elements or chemicals.

7.3 SUMMARY OF CONCLUSIONS

The common problem to all the concepts (atoms, ions, molecules and chemical reactions) was the definitions and visualisation. Learners found it difficult to understand and visualise atoms, which resulted in problems with the understanding of other concepts such as ions, molecules and chemical reactions.

There is progression and consistency with learners' models and with their problems from atoms to ions to molecules and chemical reactions. Feynman (1998:4) stated that if all scientific knowledge was to be destroyed and only one sentence passed on to the next generations of creatures, he would choose the statement of atomic fact that all things are made of atoms. "*atoms which are little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another*" Feynman, 1998:4). This indicates that atoms are basic to understanding ions, molecules and chemical reactions.

7.4 RECOMMENDATIONS

The results of this study indicate that Grade 11 learners have difficulty in visualising chemical reactions and sub-microscopic entities and processes. This confirms the hypothesis of this research.

It is recommended that educators should use teaching and learning strategies that include the use and construction of models of atoms, ions, molecules and chemical reactions more often. If there were more emphasis on the structure of atoms, it would be easier for learners to make pictures of ions and molecules and to see the difference between these concepts and the relation between them. If learners could master the visualisation of atoms, molecules and ions, it would be possible for them to visualise chemical reactions and therefore make it easier to understand chemical reactions. With this as a starting point, it would transfer to all chemical reactions and eventually to other processes and complex chemical reactions in chemistry.

It can be remarked that chemistry should not be taught without the use of and reference to models. Models play a pivotal role in the description and explanation of chemical and physical properties and changes. This dependency of chemistry on models is outlined in Chapter 2. A sound knowledge of and mastery of models involved in chemical reactions is thus indispensable for meaningful teaching, i.e. teaching that leads to comprehension of scientific concepts and processes involved in chemistry.

The constructivist point of view where learners' pre-knowledge is taken into account also stipulates that learners should be actively involved in the learning process. This is supported by outcomes based education (OBE). The OBE approach is recommended in the teaching and learning situation. This will allow learners to express their views and to construct mental pictures of concepts.

Learners need guided lessons on how to construct and interpret models. Having learners generate their own analogies increases learner ownership, but that analogies are often inappropriate for building an expert-like model. This may lead to the formation of alternative conceptions. Learners and educators need to develop more sophisticated views of how science is learnt. This was discussed in Chapter 4.

The dynamic nature of learners' conceptions makes them elusive and difficult to monitor, but also makes learning possible. Learners cannot be expected to reliably interpret models they have not designed nor previously experienced. Learning to become a skilled modeller is like learning to write creatively; it is only achieved through ample practice over a lengthy period.

Computer simulations of the visual pictures of atoms, ions and molecules can be used in order to help learners to understand chemistry better. Simulations can also be used to show learners the steps and processes involved in chemical reactions by looking at reactants and products. From learners' responses to items 4.5 and 4.7, the formation of pictures simplifies chemical reactions and is important for understanding chemical reactions and chemistry at large.

7.5 CONCLUSION

In conclusion, the results of this study indicate that the lack of visualisation affects learning in a negative way. Visualisation is one of the factors that affect learners' understanding of chemical reactions. It should be part of teaching and learning and should be monitored and guided by educators in order for learners to have scientifically acceptable models or pictures of concepts for better understanding.

The hypothesis stated in Chapter 1 was successfully tested and proved to be positive. The outcome was that most of the Grade 11 learners were unable to form visual models of sub-microscopic entities such as atoms, ions, and molecules and processes involved in chemical reactions. This created problems with the understanding of chemical reactions.

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APPENDIX A

LEARNERS' QUESTIONAIRE

Pleasc answer all items in this questionnaire, either describe in the space provided or mark the correct answer with a cross where necessary.

(This questionnaire deals with descriptions and visual images of atoms, molecules, ions and chemical reactions.)

1. Atoms

1.1 Can you form a picture of an atom in your mind?

YES	NO

1.2 If your answer is YES draw in the space provided the picture as it appears in your mind.

1.3 Describe in your own words what an atom is.

....
....
....
....
....

1.4 Give an example of an atom

....
....
....

1.5 A statement is made below. Indicate with a cross (x) whether you agree, disagree or are unsure of the truth of the statement.

Statement: *"All material objects (books, humans, animals, plants, the earth, air, ...) are made of atoms"*

AGREE	DISAGREE	UNSURE

2. Molecules

2.1 Can you form a picture of a molecule in your mind?

YES	NO

2.2 Give example of a molecule and draw the picture of this molecule as it appears in your mind in the space provided.

2.3 Describe in your own words what a molecule is.

....

....

....

....

....

2.4 How are molecules formed?

....

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....

....

3. Ions

3.1 What is an ion?

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....

3.2 How are ions formed?

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....

....

....

3.3 What is a cation?

....

....

....

3.4 Give an example of cation and draw its picture in the space provided.

3.5 What is an anion?

....

....

....

3.6 Give an example of an anion and draw its picture in the space provided.

4. Chemical reactions

4.1 What is a chemical reaction?

....

....

....

4.2 A chemical reaction is only possible if the atoms participating in the reaction are moving.

TRUE	FALSE

4.3 Consider the reaction

$$H_2 + O_2 \rightarrow H_2O$$

4.3.1 How do you picture the chemical reaction above? Also describe what happens in words.

....

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4.3.2 How would you balance this chemical equation? Indicate the steps you would follow.

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4.4 Write down an example of a chemical reaction (not the one above).

....

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4.5 Do you find the formation of pictures important for understanding chemical reactions?

YES	NO

Give a reason for your answer.

....
....
....
....
....

4.6 Do you try to make pictures of chemical reactions in your studies?

ALWAYS	SOMETIMES	NEVER

4.7 Does formation of pictures simplify chemical reactions?

YES	NO

4.8 Which problems do you encounter when trying to make pictures of atoms, molecules, ions and chemical reactions?

Atoms

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Molecules

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Ions

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Chemical reactions

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