Students' associations between microscopic models and macroscopic events in chemistry

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ABSTRACT

[Key words: chemistry education, models, phase changes, transformations of matter, misconceptions, microscopic, macroscopic, constructivism]

Phase changes are one of the events in chemistry that are often misunderstood by entry level chemistry students. A possible cause of misconceptions is students' disability to visualise basic concepts such as atoms, ions and molecules. Along with these inabilities, students have a tendency to make literal deductions from models used in teaching materials. This study aims to investigate first year natural science education students' association between microscopic models and macroscopic events such as phase changes in chemistry.

An empirical study consisting of a mixed method triangular design was conducted on first year education students of the North-West University, Potchefstroom Campus. The investigation was done by means of a questionnaire and interviews. The results of the study were used to identify learning problems that these students have in connection to attributing macroscopic characteristics to microscopic events in phase changes. The results indicated that students encounter problems with visualisation of basic concepts such as atoms, ions and molecules as well as incorrect transfer of macroscopic characteristics to microscopic events. This has a negative impact on a student's understanding of events such as phase changes in chemistry.

OPSOMMING

[Sleutelwoorde: chemie-onderwys**, modelle, fase**veranderinge**,** transformasies van materie**, miskonsepsies,** mikroskopiese**,** makroskopiese**,** konstruktivisme**]**

Faseveranderinge is een van die gebeure in chemie wat dikwels verkeerd vertolk word deur intreevlak chemie studente. 'n Moontlike oorsaak van die miskonsepsies is studente se gebrek aan die visualisering van die basiese konsepte soos atome, ione en molekules. Tesame met hierdie onvermoë het studente 'n neiging om letterlike afleidings te maak vanaf modelle gebruik in onderrigmateriaal. Hierdie studie het ten doel om die eerstejaar natuurwetenskaponderwys studente se assosiasie tussen mikroskopiese modelle en makroskopiese gebeure, soos tydens faseveranderinge in chemie, te ondersoek.

'n Empiriese studie bestaande uit 'n gemengde metode met driehoekige ontwerp, is uitgevoer op die eerstejaar onderwysstudente van die Noordwes-Universiteit, Potchefstroomkampus. Die ondersoek is gedoen deur middel van 'n vraelys en onderhoude. Die resultate van die studie is gebruik om leerprobleme te identifiseer wat ontstaan as gevolg van die verbande wat studente trek tussen makroskopiese eienskappe en mikroskopiese gebeurtenisse tydens faseveranderinge. Die bevindinge dui daarop dat studente probleme ondervind met die visualisering van basiese konsepte soos atome, ione en molekules sowel as die oordrag van makroskopiese eienskappe op mikroskopiese gebeure. Dit het 'n negatiewe impak op 'n student se begrip van die gebeure gedurende faseveranderinge in chemie.

TABLE OF CONTENTS

Chapter 1

Overview and problem statement

Chapter 2

The role of models in chemistry and chemistry education

Chapter 3

Constructivism and chemical education - A Theoretical Framework

Chapter 4

Models used in Natural Science literature to explain the particulate nature of matter and phase changes.

Chapter 5

Research Methodology

Chapter 6

Reporting and analysing results

Chapter 7

Findings, conclusions and recommendations

LIST OF FIGURES

LIST OF TABLES

ANNEXURES

Chapter 1: Overview and problem statement

1.1 Motivation and research questions

As chemistry is concerned with the properties and transformations of materials, it makes chemists essentially modellers of those substances that constitute such materials and of their transformations (Justi & Gilbert, 2002:47). Chemists often use models to explain phenomena they observe by using an analogy they already know. In Chemistry education a chemical model can be used to link students' understanding of macroscopic events with that of microscopic models (Cook, Wiebe & Carter, 2008). Modelling is commonly considered as constructing alternative, less complicated versions of objects or concepts (Suckling, Suckling & Suckling, 1980).

Research evidence related to models in science presents important implications for education practise. The mental model that a student has about a certain topic represents the understanding of related chemical conceptions. This model or representation creates a vehicle through which the idea, object or process can be conceptualised. In essence, models are not fixed, but are thinking tools (Grosslight, Unger & Jay, 1991). Therefore students' conceptual understanding of chemistry concepts may be improved by the use of scientifically correct models (Nakhleh & Postek, 2008). Students are often exposed to visual representations of models in learning materials such as chemistry textbooks, teacher representations and also in computer-based multimedia materials. A study of school textbooks revealed the use of a large number or a variety of models to explain the same phenomenon. Unfortunately some representations in textbooks are not scientifically correct (Whitlock, Van Huyssteen, De Beer & Whitlock, 2005:150-154).

Models are often used in representations of chemical processes such as chemical and physical changes. Physical change, a change in matter that involves no chemical reaction, is one of the key processes in chemistry where misunderstanding regarding the particulate nature of particles is abundant (Johnston, 1991:247). When a substance undergoes a physical change the composition of the molecules remains unchanged, while the chemical identity of the substance stays the same. Melting, evaporation and freezing are the three types of changes that are commonly used to explain physical change (Driver, Asoko, Leach, Mortimer & Scott, 1985:146). Learners observe macroscopic properties such as the shape and size of the substances, but physical changes are explained in terms of microscopic particles, and therefore learners' misunderstandings of the physical changes constitute a teaching-learning problem.

Research in chemistry education indicates that the use of multiple representations can improve conceptual understanding (Nakhleh & Postek, 2008:211). However, the influence of prior knowledge cannot be overlooked. Most students' understanding of chemistry is constrained by the perceptual experiences from their daily lives. During physical and chemical changes students tend to transfer macro properties that they observe to the micro world. For example, the macroscopic models of disappearance, displacement, modification and transmutation are applied to atoms and molecules (Andersson, 1990:23). The association students make between microscopic models and macroscopic events are problematic (Onwu & Randall, 2006:226). Students' reasoning do not always relate to the particulate nature of matter unless they have a scientifically correct representational model on which they base their reasoning and thinking. According to Cook *et al.* (2008:848) students with a higher prior knowledge of concepts in chemistry have a better understanding of the difference between microscopic models and macroscopic events, whereas students with low prior knowledge could not make the transition between the molecular representations that well.

In light of the previous discussion the research questions of this study are:

- What is the state of first year natural science education students' mental models regarding phase changes in chemistry?

- What are their prior knowledge and understanding of models and representations of basic chemistry concepts such as atoms, ions and molecules?

1.2 Aim

The aim of this study is to investigate first year natural science education students' association between microscopic models and macroscopic processes such as phase changes in chemistry.

1.3 Research design

1.3.1 Literature review

A study of literature on the following themes will be conducted:

- The history and philosophy of models in chemistry: As chemistry is concerned with the properties and transformations of matter, chemists are fundamentally modellers of the substances that represent such matter and of their transformations (Justi & Gilbert, 2002).

- The constructivist and social constructivist learning theories: When a researcher is conducting qualitative research in chemistry education, the theoretical framework plays the same role as the role of an instrument (Bodner & Orgill, 2007).

- Models in teaching chemistry: When models are categorized, it highlights the differences among scientific models (Van Driel & Verloop, 1999). Although the models differ there are also a lot of common characteristics.

- Students' misunderstandings in chemistry and models used in educational literature such as school and university text books.

Search engines and resources available from the NWU libraries will be used for collecting data for the literature review.

1.3.2 Research methodology

1.3.2.1 Empirical study: A mixed method triangular design will be used.

A questionnaire firstly investigating the mental models students have about concepts like atoms, ions and molecules and secondly microscopic and macroscopic characteristics in phase changes is compiled by the researcher and completed by students. The questionnaire also included a few questions about the macroscopic and microscopic characteristics of $NaC\ell$ (s) and S_8(s).

Secondly, a study of a certain misconception in phase changes, that the amount of particles decreases when phases change from solid to liquid to gas, is done. Semi-structured interviews will be conducted with a purposive sample of 5-6 participants to determine why the students have an understanding or misunderstanding of the specific model[1] regarding phase changes. The design for the interviews was an exploratory, interactive descriptive design with a specific context (Thorne, 2008). The following questions[2] in general were asked to the students (Cook *et al*., 2008):

- Describe the most obvious features of the model: What happens to the particles during phase changes?

- Explain what you think this model is trying to communicate: Does the amount of particles increase or decrease during phase changes?

A maximum of five to six open ended questions[3] were asked. The interviews were taped with a tape recorder.

A content analysis was done where the content of the questionnaires and the interviews were studied to identify certain patterns, themes, biases or understanding of certain concepts involving microscopic models of macroscopic events. The frequency of certain characteristics and trends were tabulated and descriptive analyses were done with the ATLAS.ti.6.2 programme in order to answer the research question.

1.3.2 Participants

The participants for this study are a convenience sample of all the students registered for the module SNSE 111[4] as well as the first year PHSE 111[5] students. The total population is 120 first year teacher students and the questionnaire will be simultaneously completed by all students. Six interviews were done.

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[1] The questionnaire also included a model from a current grade 8 textbook (Van Aswegen & Van Aswegen, 2005, p 76.)
[2] Annexure B
[3] Annexure B
[4] SNSE 111: Introduction to Learning Area Natural Sciences
[5] PHSE 111: Basic Chemistry Principles and Stoicheiometry of Chemical reactions

1.3.3 Data collection

The data collection was conducted by the researcher herself in the form of a content based questionnaire and semi-structured interviews. The interviews took place after the analysis of the questionnaire was completed. A pilot study was done to evaluate the reliability and validity of the questionnaire. The data of the pilot study, SNSE 111 (2009) was included by the analysis.

1.3.4 Data analysis

Data analysis was done by interpreting the answers of the questionnaire. Me. W. Breytenbach and her team helped with the statistical analysis of the questionnaire. A content analysis is the identification of specific characteristics of a body of material. The focus was on the written answers as well as the verbal comments made by the participants during the interviews.

Although the researcher's biases and values may influence the interpretation of the data, the researcher should do as much as possible to minimize the extent to which prior expectations and opinions enter into the analysis of the data. As advised by Leedy and Ormrod, (2005), the researcher used:

- Two or more different types of collection methods, namely questionnaires and interviews.

1.3.5 Ethical aspects

The study was conducted in accordance with the ethical policy of the North West University, as well as the NWU Faculty of Educational Sciences.

1.4 Potential implications of findings

This study can lead to an improved understanding of the use of models in chemistry education. The findings of the study could give chemistry lecturers a better understanding of how students construct their mental and analogical models. Consequently lecturers can compile materials that effectively and correctly use models as learning aids, which may result in students becoming more positive towards studying chemistry.

1.5 Preliminary chapter division

1. Overview and problem statement

2. The role of models in chemistry and chemistry education

3. Constructivism and chemical education - A Theoretical Framework

4. Models used in Natural Science literature to explain the particulate nature of matter and phase changes

5. Research Methodology

6. Reporting and analysing the results

7. Conclusions and recommendations

Chapter 2: The role of models in chemistry and chemistry education

2.1 Introduction

The purpose of this chapter is to explore and discuss the use of models in chemistry education. It can be difficult to teach chemistry without models. Chemists and educators are therefore constantly searching for new and better models to explain chemistry concepts and processes. Models are thinking tools and educators commonly treat models as the natural language of chemistry (Harrison, 2003.) The mental picture, or conceptual model that a student has, is very personal. This model is influenced by teachers, textbook representation as well as personal experience (Suckling *et al.,* 1980). The rest of the chapter will further explore the origin of models as well as the different types of models. As history and philosophy of models directly concern chemistry this need to be explored further. The micro-macro relationships between models and the microscopic events can be problematic to students. Misconceptions arise and students may make literal deductions from models used in textbooks. The different misconceptions regarding chemistry in general as well as specific misconceptions about the particulate nature of matter found in literature will also be discussed in this chapter.

The study of chemistry is consequently in essence representational or symbolic (Kozma & Russel, 1997). A specialized system is invented to represent concepts of atoms, molecules and many more. Chemists use models to communicate, teach and learn. New technology also strengthens the educational value of models. The significant difference between students' understanding of models and that of chemists shows that students have an inadequate understanding of the model concept (Kozma & Russel, 1997). As a result of these differences, studies recommend the use of models and modelling to sharpen students' modelling skills.

2.2 What are models?

What are models? The word model is documented in CCD[6] (2001:961) as: "a representation, usually on a smaller scale, of a device; structure, etc., a standard to be imitated and a representative form, style or pattern." Gilbert (2002:3) defines modelling as follows: "Modelling is an element in scientific methodology and models are both important aspects of the conduct of science and hence of science education." A model is thus a representation of an object, event

[6] Collins Concise Dictionary

or idea and creates a manner through which a certain event or idea can be understood as well as conceptualized. According to Levy Nahum, Hofstein, Mamlok-Naaman and Bar-Dov *(*2004), the theoretical content of chemistry is best seen as a set of models. Islass and Pesa (2001) define a scientific model as a “type of theoretical construct that – together with the other components of the body of a theory – guides the observation of reality, the posing of a problem, and other characteristics of scientific research.”

A world without models and visualizations can result in a continuous world without structure. Tillery (2005) mentions that often in nature certain parts are too big or too small to be visible to the human eye and a model is needed to understand the concept or phenomena. A model helps a person to visualise something you cannot observe with the naked eye. An example of this is the phase changes that occur when water changes form from ice to water to steam. To be useful a model has to be a simplified representation of a more complex concept (Gilbert, 1998). Cheung and Keeves (2003) explain the structuring of models as a relationship between two variables. Although the relationship between two simultaneous events cannot be proven, a model can specify the relationship on theoretical grounds. In a science classroom, however, most models are based upon relationships that were accepted as a result of experience.

Models and modelling have a distinctive role in the learning of chemistry. Gilbert and Boulter (1998a) list a number of reasons, namely:

- Firstly, the term model or modelling is widely used to describe, from an individual’s idea, to grand scientific concepts.

- Secondly, models play a key role in the scientific process because models are more perceptually accessible than theories.

- Thirdly, the cognitive psychological representation of learning, including chemistry learning, is vested in the development of models by the individual within a peer group. To understand models and modelling it is thus essential to understand the nature of models and modelling.

- Fourthly, models play a very important role in the everyday teachings in the classroom and it is important to explore this further.

Nagel (as quoted by Gilbert & Boulter, 1998a:54) states that a theory has three components, namely:

- an abstract calculus that is the logical skeleton of the explanatory system, and that 'implicitly defines' the basic notions of the system,

- a set of rules that in effect assign an empirical content to the abstract calculus by relating it to the concrete materials of observation and experiment, and

- an interpretation or model for the abstract calculus, which supplies some flesh for the skeletal structure in terms of more or less familiar visualiszable materials (p. 90).

Gilbert and Boulter (1998a) explored the relationship between model, theory and concept. A model can be seen as a link between theory and experiment. Therefore a model assists with the processes of inquiry, summarizing data, justifying outcomes and communication. It is thus suggested by Nagel (as quoted by Gilbert & Boulter, 1998a:54) that a single theory and model can be used as foundation for another theory and model. Inquiries into the connection between models and theory show that models are used from an early age as an aid to the understanding of theories (Gilbert & Boulter, 1998a).

A concept is usually used to design a model and the inclusion of theoretical notions in a model leads to the formulation of predictions (Van Driel & Verloop, 1999). The word "concept" is widely used in science education. There is however not a single generally agreed definition of the word. Carrol (as quoted by Gilbert & Boulter, 1998a:55) suggests that for each individual a concept is a combination of his or her experiences and that it is constantly revised by the specific occurrences that led to the formulation thereof. Even in a controlled environment such as a classroom, the specific concept that a student forms will be dependent on both the socially-sanctioned concept that is taught and the ideas that the student has and this can lead to alternative conceptions.

2.3 History and philosophy of models in chemistry

Justi and Gilbert (2002) state: "As chemistry is concerned with the properties and transformations of materials, chemists are essentially modellers of the substances that constitute such materials and of their transformations." Chemists model their ideas and as the phenomenon grows and becomes more complicated, the model is transformed and updated.

Justi and Gilbert (1999) supports the following four basic arguments regarding the greater role of history and philosophy in chemistry teaching:"

- To teach students about the nature of chemistry.
- To utilize any parallels between the development of subject matter *per se* and the development of an understanding of that subject matter by students.
- To develop students' capabilities for critical thinking.
- To overcome practical problems in the production of schemes of work, classroom teaching, and the facilitation of learning.

Models and modelling can provide a suitable basis for the inclusion of the history and philosophy of chemistry into the science curriculum (Justi, 2000b). In 1638 Galileo used a model to explain basic concepts and theories (Clement, 1983). Apparently Galileo recognized that it was going to be difficult to present his views convincingly to his colleagues when using mathematics and thus he used a conceptual model to change his colleague's viewpoint.

In 1867 and 1869 the first models (*glyptic formulae)* just became available during public debates about the atom theory amongst members of the Chemical Society of London (Knight, 1992). In the second half of the previous century, models started to play such a major role that chemists began to recognize the importance of the use of models in chemistry (Justi & Gilbert, 2002). During the 19th century chemists became aware of the connections between their molecules and basic geometry. They were not able to determine structures metrically but they were aware of certain forces and interactions between molecules (Comba & Hambley 1995:3)

During the 20th century the arrangement of atoms were calculated metrically and certain bond lengths could be determined. The development of the Schrödinger equation leads to the development of empirical models based on experimental data. John Dalton produced the first models of the atom in the beginning of the nineteenth century (Justi & Gilbert, 2002). In the following years, chemists like Kekulè, Van't Hoff, Pauling, Watson and Crick used models more and more to communicate and explain molecular structures (Justi & Gilbert, 2002).

Throughout the nineteenth century the most taught science was chemistry (Knight, 1992.) Chemistry was useful to many people working in applied sciences such as industries. More and more people with knowledge and skills in chemistry were needed. Practical work had to become a necessary part of chemistry education and more and more topics became simplified by the use of models. Models of atomic structures became helpful to students in the learning of chemistry. Researchers also used models more frequently as helpful aids.

During the past decades the value of models and modelling has been recognised by science education reform movements (Gobert & Buckley, 2000). A specialized system is invented to represent concepts of atoms, molecules and many more. Today chemists use models to communicate, teach and learn. New technology also strengthens the educational value of models.

2.4 Types of models

When models are categorized, it highlights the differences among scientific models (Van Driel & Verloop, 1999). Although the models differ there are also a lot of common characteristics. De Vos, (1985) and Van Hoeve-Brouwer, (1996) (as cited by Van Driel & Verloop, 1999) identified the following characteristics that all scientific models, and thus chemistry models, have in common:

1." A model is always related to a target, which is represented by the model. The term 'target' refers to a system, an object, a phenomenon or a process.

2. A model is a research tool which is used to obtain information about a target which cannot be observed or measured directly (e.g. an atom). Thus, a scale model, that is, an exact copy of an object (e.g. a house) on another scale, is not to be considered a scientific model.

3. A model cannot interact directly with the target it represents. Thus a photograph or a spectrum does not qualify as a model.

4. A model bears certain analogies to the target, thus enabling the researcher to derive a hypothesis from the model which may be tested while studying the target.

5. A model always differs in certain respects from the target. In general, a model is kept as simple as possible. Depending on the specific research interests, some aspects of the target are deliberately excluded from the model.

6. In designing a model, a compromise should be found between the analogies and the differences with the target, allowing the researcher to make specific choices. This process is guided by the research questions.

7. A model is developed through an iterative process, in which empirical data with respect to the target may lead to the revision of the model, while in a following step the model is tested by further study of the target. "

Two groups of different types of models can be distinguished, namely (Gilbert, 1998:160):

Teaching-learning models:

- Mental model – each individual visualises a certain model in his/her mind;
- Expressed model – when an individual tries to explain or present his/her mental model;

Scientific or chemistry models:

- Consensus model – when a model is accepted by a wider group or community;
- Historical model – a consensus model that stood the test of time e.g. the "plum pudding" model of an atom;
- Teaching model – a model specifically designed to teach a difficult consensus or historical model.

Mayer (1989) produced a set of six criteria which he uses to test models. All good models adhere to all six criteria. The criteria are:

- The model should have all the essential elements of the target idea.
- The model should be consistent in its level of detail
- The vocabulary used should be appropriate, so should be the form of the model.
- The relationship between all the parts of the model should be clear.
- The theory in question should be explained by the model.
- The scope and limitations of the model should be clear and obvious.

The different types of models are discussed in the following sections.

2.4.1 Mental Models

CCD (2001:935) defined mental as occurring only in the mind, or involving the mind. According to Borgman, (1986; 48; as cited by Hill, 2010) the general concept of mental models "describe a cognitive mechanism for representing and making inferences about a system or problem which the user builds as he or she interacts with and learns about the system." Scientists sometimes use the term *mental model* as a synonym for *mental representation*. In the theory of reasoning and thinking, a mental model has a much more narrow meaning. What is the point of research on and use of mental models? Gentner and Stevens (1983) answer this question with the following: "Mental models research is fundamentally concerned with understanding human knowledge about the world." They list three key dimensions on which mental model research are based: the natures of the studied domain, theoretical approach and methodology.

Mental models evolve naturally through interaction with people. They need not be technically accurate but should be functional in describing the phenomenon or process (Norman, 1983). A person will keep on modifying the model as he/she continuously uses the model. Mental models will be restricted by the users' own background, experience as well as certain misconceptions. As Norman (1983) states:" The scientist's conceptualization of a mental model is, obviously, a model of a model."

Some observations that Norman (1983) made on mental model led him to make a few generalisations about mental models:

- Mental models are not complete
- People's abilities to use their own mental models are severely limited
- Mental models tend to be unstable if not used regularly
- Their boundaries are not exact, some models tend to overlap with others
- Mental models are "unscientific", and
- Mental models often are the result of parsimonious thinking. People tend to use a model which applies to a variety of devices.

How do people actually apply a mental model? Williams, Hollan and Stevens (1983) explain that psychologists attempt to understand peoples reasoning and thinking about mental models. Their concern is primarily with the descriptive and predictive power of models and how models evolve during use by different people. To actually describe what the term mental model means, one should consider how different reasoning with mental models are from other types of human reasoning.

Fundamentally our conceptions of mental models are that they are composed of autonomous objects together with similar topology. With the use of mental models comes the term autonomous object. Williams *et al.* (1983) defines this term as: "An autonomous object is a mental object with an explicit representation of state, an explicit representation of its topological connections to other objects, and a set of internal parameters". With every autonomous object a set of rules apply with which the models parameters are modified and because of this the behaviour of the autonomous object can be specified. A mental model is formed when a series of autonomous objects are run and the parameters are changed. A mental model can also be run if the autonomous object change of state and one set of behaviour rules is replaced with another.

Because the application of mental models plays a big role in human reasoning, we see the formation of mental models as very fulfilling and thus qualify the effects of certain changes, like phase changes, to a process (Williams *et al.,* 1983). For a student to form a mental model, the student should be able to interpret the rules and propagate the connection between the objects or processes in question. The sequence of the changes should be recorded as part of the complete reasoning system of the student. Each person's internal rules affect their reasoning and thinking.

Because autonomous objects are most of the time not transparent, it can sometimes be decomposed (Williams *et al.,* 1983). With decomposition, a new mental model is formed and this process is very effective when trying to explain the behaviour of a higher level process. Williams *et al.*, (1993) refer to this process as embedding. An embedded model is usually used when, for instance, certain conditions of the higher level model's input/output behaviours are forgotten.

When humans use of what we define as mental models and autonomous objects, it works very well because we live in a world with a nature that is nearly decomposable. Williams *et al.,* (1983) states that they think the process involving the construction of mental models assist human reasoning in many ways. They can be dealt with in the following manners:

- as interference engines to predict the behaviour of physical processes,
- to produce explanations,
- they can serve as mnemonic devices to remember the process.

Harrison and Treagust (2000(b)) raise the question: can people relate to and communicate all their mental models effectively? Kline (as cited by Harrison & Treagust, 2000(b):1017) suggests that people "consciously construct and apply geometries that exist only in human brains and that were never meant to be visualized." A person's imagination makes modelling an effective thinking and teaching tool but it stays a highly personal process.

Research data in various research fields show there is a distinguishable gap between students' mental pictures of certain concepts or phenomena and the scientist's view thereof (Ben-Zvi, Silberstein & Mamlok, 1990). Students start their studies with their own personalised mental pictures. These pictures were created by the students in order to fit a certain concept into their existing framework. It is very important to study these mental pictures in order to understand and evaluate a student's understanding of the specific concept. The wrong mental pictures or models can prevent a student from further meaningful learning (Ben-Zvi *et al.*, 1990).

2.4.2 Expressed models

An expressed model is a version of the mental model whereby a person expresses the model in writing, speech or some kind of action (Gilbert & Boulter, 1998b). It can be a version of

- the mental model of a learner,
- teaching model of the teacher or textbook,
- consensus model of the scientists.

The biggest advantage of an expressed model is that it is in the public eye and anyone can use it to form their own mental model. When using a textbook, a student forms a personal mental model from that expressed model. A mental model which is expressed often changes the specific model according to that students' worldview or framework (Gilbert & Boulter, 1998b).

2.4.3 Consensus model

A consensus model is an expressed model that has been tested by scientists and some of them agree that this model has some merit (Gilbert & Boulter, 1998b). Consensus Modelling is by no means a new concept. This model is one of the most widely used models in chemistry. According to Gilbert and Boulter (1998b) it is: "one of the main products of science"

Any collective group, for example, a group of students, can agree on an actually common expressed model that as a result becomes a consensus model (Gilbert, 2004). There is no guarantee that the model the students reached consensus on is actually scientifically correct.

There are two sides to a consensus model, a scientifically correct one and the one that is not scientifically correct but commonly used by students or teachers. This might lead to misconceptions about the actual microscopic events that take place in chemistry.

2.4.4 Historical model

The use of models in chemistry is so common that it has become a high priority in education or as Luisi and Thomas (1990:67) states: "it has become the dominant way of thinking". Justi (2000a) considers a historical model a consensus model which is developed within a specific context. This context includes philosophical, scientific, technological and social belief systems. This implies that a historical model is not necessarily connected to a specific time or individual.

Justi (2000a) used a framework developed by Lakatos whereby historical models were defined as in possession of a hard core which designates the assumptions that identify the models and guide everybody working within a specific research programme. Each programme is in possession of a set of rules, a kind of hypothesis that helps with protection of the hard core from refutations. This is named the protective belt. Each research programme is also guided by a positive heuristic which guides the modification of the protective belt.

Justi (2000a) discusses in his research two main elements of historical models that play the role of the hard core. Firstly there is the theoretical background. Corresponding with the theoretical background is the following:

- the general scientific ideas,
- the philosophical ideas, and
- the analytical tools used in the compilation of the historical model.

If the above mentioned guidelines are applied it guarantees that the context in which the model was developed, are characterized by the theoretical background (Justi, 2000a).

Fundamental scientific ideas specific to the model are considered as the main characteristic element of historic models. There is however also another characteristic element, namely the secondary attributes (Justi, 2000a). These are ideas that complement the main characteristic of the model to permit extensive characterization of the model. Various secondary attributes can complement a certain historical model and can be discussed separate of each other. When defining the historical models of chemical kinetics, for instance, the theoretical background corresponds to the concept of matter on which it is based as well as the mathematical and statistical tools used in constructing the model. The main attributes are the following:

- meanings of chemical reactions,
- reaction rate,
- the determinants of reaction rate,

While the secondary attributes are:

- ideas about catalysis,
- reaction path,
- influence of energy on the rate of the chemical reaction.

According to Lakatos (as cited by Justi, 2000a:215), a new research programme can replace the old one when it is superior to the previous one. It is however not an immediate process following an experiment that updates the previous model. It is all in all an evolutionary process in which the protective belt is defeated and the hard core should then change in reaction to the new data. The new replaces the old or as Justi (2000a) explains it, the failure or overthrow of a specific research programme is the result of a competition between the 'progressive problem shifts' in the old programme and the 'degenerating problem shifts' of the old one. To characterise historical models, Justi (2000a) investigated some points systematically in order to facilitate competition between the two mentioned problem shifts.

"These were:

- the deficiencies in the explanatory capability of a given model,

- the features of that given model that were modified and incorporated into a new model,
- the way by which the new model overcame the explanatory deficiencies of this antecedents and the explanatory deficiencies of the new model."

When this framework is used the analysis of teaching situations can be used to gather interesting conclusions regarding the use of historical models in chemistry education.

2.4.5 Teaching models

A teacher uses a specially constructed expressed model, the teaching model, to aid students in the understanding of a specific consensus model (Gilbert & Boulter, 1998b). In this way models contribute to the explanations by the whole scientific community. Taber (2001) proposes a checklist when teaching with models. This checklist can be very useful when a teacher introduces analogies or models:

1) Teachers should make sure that the analogy represents the key aspects of the concept that should be explained.

2) Students should appreciate both the positive and negative aspects of the model or analogy used during the teaching of the concept.

3) The analogy or model should actually be more familiar to the students than the concept itself.

The use of models in the classroom plays a key role in explanations (Gilbert & Boulter, 1998b). Although the focus in the classroom is on the content of the models taught, it plays a major part in chemistry education (Van Driel & Verloop, 1999). Teaching models form the basis for all five types of explanations namely:

- Intentional,
- Descriptive,

- Interpretive,
- Causative,
- Predictive.

2.5 Macro-micro relationships

Students live and function in the macroscopic world of matter but unfortunately they do not recognise chemistry as part of their surroundings and do not easily connect the dots between the microscopic and macroscopic (Levy Nahum *et al.,* 2004). Students often find it difficult to explain chemical phenomena by using chemistry concepts. According to Gabel (1996) as cited by Levy Nahum *et al.* (2004):

"The complexity of chemistry has implications for the teaching of chemistry today. We know that chemistry is a very complex subject from both the research on problem solving and misconceptions and from our own experience… Students possess these misconceptions not only because chemistry is complex, but also because of the way the concepts are taught."

Learning problems arise because a student cannot understand the phenomenology and laws of chemistry (Ben-Zvi *et al.,* 1990). To facilitate proper understanding, students should be able to function on all descriptive levels. Ben-Zvi *et al*. (1990) describes the three levels on which a student has to function at the same time by using the example of a chemical formula, e.g. $H_2O_{(\ell)}$. These levels are:

- the macro level where the student need to know the difference between liquid and gas properties,
- the atomic molecular level which explains the bonding of the atoms in $H_2O(\ell)$,

- and the multi-atomic level where the idea that a drop of water consists of many molecules with a certain structure should be considered.

According to Ben-Zvi *et al*. (1990) students have difficulties in understanding macro-micro relationships. These difficulties can, however, be overcome by appropriate attention to teaching methods.

2.5.1 Teaching and learning perspective on macro-micro relationships

One of the biggest problems we have to deal with concerning macro-micro relationships are the big gap between a student's life world thinking and scientific thinking (Linsje, 1990). Knowing all about students' problems regarding the use of models explaining the particulate nature of matter, it seems that they have difficulty with learning in terms of a model they cannot see (Linsje, 1990). In order to understand matter and its changes, students should familiarise themselves with all the terms, meanings of scientific models as well as the significant difference between the macroscopic world and the microscopic models (Levy Nahum *et al.*, 2004).

Some models constructed by other people do not need any explanation to a student whereas some models make no sense to a student. The greater the gap between life world thinking and scientific thinking, the less understanding is achieved. This applies very strongly to the particulate nature of matter (Linsje, 1990).

According to Johnston (1991) as cited by Levy Nahum *et al.* (2004) matter can be represented on the following three levels:

- Macroscopic (physical phenomena),
- Microscopic (particles),
- Symbolic or representational (chemical language and mathematical models).

This relationship can be summarized by the following diagram (Levy Nahum *et al.*, 2004):

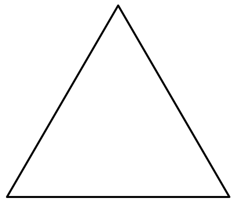


Figure 2.1: Conceptual understanding of chemistry: A model for learning (Levy Nahum *et al.*, 2004)

Teachers unintentionally switch between levels during teaching. Thus, students are not able to integrate the levels and they become confused very easily (Levy Nahum *et al*., 2004). Students should first fully comprehend the conversion from symbol into meaningful information, only then will they be able to deal successfully with the quantitative computation. It is very important to see the difference between internal and external representation. It is possible that persons with very different internal representations could have the same external representations. The teacher writes symbols, a physical reality, and students commonly writes numbers, lines and letters which has no physical meaning to them.

Sequeira and Leite (1990) had done a study on junior high school students to determine how they relate macroscopic phenomena to microscopic particles. During this study they came to the following conclusions:

- The majority of the participants did not spontaneously use the particulate model of matter to explain everyday concepts and phenomena. When asked to make the link *via* the particulate model, very few of them could do so.

- The concept of an atom was very poorly defined even with formal instruction in chemistry.

- It is not good to ask students to use the particle model of matter to relate to everyday phenomena unless they use different teaching on this topic.

- Some students don’t find the particulate model of matter more useful than their own mental models.

- A better understanding of the basic concepts of an atom, particle and molecules leads to a better understanding of the particle model. Otherwise said, students with poor understanding of these basic concepts cannot fully grasp the particle model.

Ten Voorde (1990) asks two very important questions: "Which macroscopic phenomena make it *plausible* to speak of microscopic particles?" and then "Which macroscopic phenomena make it *necessary* to speak of microscopic particles?" We might ask ourselves if the idea of particles is a natural starting point for students - if not we can create a lot of misconceptions and therefore it becomes essential to ask ourselves the second question. The macroscopic phenomena need to become a direct experience for the students. Mostly confusion starts with the premature bridging of concepts before students had the chance to explain the phenomena in their own language (Ten Voorde, 1990).

Linsje (1990) proposes a few levels in concept development. He starts with the life world level. This level should reflect in both the content and the characteristics of life world thinking and reasoning.

- Firstly, one makes a selection of phenomena in a manner that make sense to the students.

- Secondly, the characteristics and relations between them can be described at a qualitative level.

- Thirdly the proposed step following this is to make these concepts and relations quantitative. Most of the time, the relation between life world thinking and scientific thinking is seen as one big step.

Linsje's scheme broke this step up into a few smaller steps. At each level, it deals with a network of applicable concepts and relationships which need to be developed further before there can be a meaningful passage to the next level. Before the transition can be made to the higher level, one should reflect upon the characteristics of the lower level and motivate the transition. It is difficult to establish precisely what these levels look like and how big the gaps are. From the level of learning however, the question is how continuous or discontinuous the process can be during teaching or learning. In Figure 2.2 Linsje (1990) proposes the following steps:

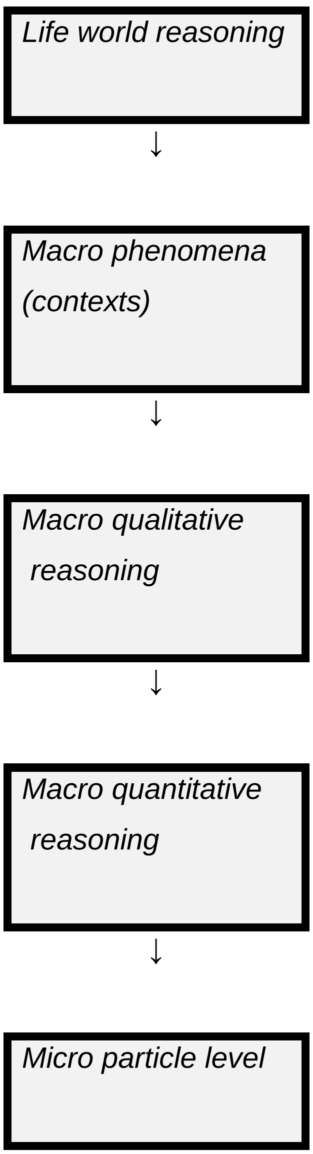


Figure 2.2: Proposed steps by Linsje (1990)

He considers the whole process to be fluid by identifying different ways students can make the transitions themselves. Other important aspects feature analogies, experiments meta-cognition, reflection, social constructs and communication skills (Linsje, 1990).

Instructors need to develop teaching strategies such as pictures or models to help students gain a better understanding of the sub-microscopic levels of chemistry (Kelly, Barrera & Mohamed, 2010).

Kelly *et al.* (2010) made a few recommendations when teaching macro-micro relationships in chemical reactions:

- “Recommendation 1: Connect simplified views to complex views of the sub-microscopic nature of reactions.

- Recommendation 2: Address the connection between the sub-microscopic level and the symbolic nature of the chemical equation.

- Recommendation 3: Address the connection between the sub-microscopic and macroscopic levels.

- Recommendation 4: Address misconceptions directly.

- Recommendation 5: Address the responsibilities of the students. “

Ruthledge (2010) advises the following when teaching very small or invisible particles like atoms:

- Emphasize that atoms are incredibly small.

- Make sure they know that there are an incredible number of particles.

- The nucleus is relatively big and the electrons relatively small.

- The positive and negative forces in an atom balance each other out.

- Two negatives or two positives repel each other.

- At a primary level it is sufficient for the students to know that atoms stick together because the positive and negative attracts each other.
- There is a lot of empty space between atoms.

2.5.2 Teaching and learning with models

When students are learning complex chemical concepts, multiple forms of representations are beneficial. Models are powerful tools and with its use come a great responsibility to handle it carefully. Teachers should know how to utilise these tools in order to be successful (Ainsworth, 2008).

Students are less capable at modelling than teachers expect. A teacher should think of models as thinking tools with limitations and scope (Levy Nahum *et al.*, 2004). Teachers may have misconceptions about chemistry concepts themselves. They need to understand that models are not absolute. Another important aspect highlighted by Justi and Gilbert (2002) is that students have to comprehend that models are not scale models and that they must realise that models have different scopes and subsequent limitations. These findings of Justi and Gilbert (2002) concurs with the findings of Levy Nahum *et al.* (2004) that models should be seen in perspective and not as perfect copies of concepts.

Justi and Gilbert (2002) also strongly recommend that students should learn about the nature of models. Models should be portrayed as thinking tools and not as just an analogue of the reality. The advantages, scope and limitation of models should also be considered. Students' views about the nature of models are not easily changed. Justi and Gilbert found that taking part in modelling itself students begin to understand why different models are used to explain chemistry. It seems that modelling is one of the main activities when students want to develop their scientific knowledge as cited by Justi and Gilbert (2002):

"The involvement of students (at all educational levels) in modelling activities would seem to be an essential part of a more comprehensive approach to learning."

More focus should be placed on modelling as part of chemistry education as there is a great possibility that this can lead to a revolution in chemical education. Teachers should focus more on the nature of models rather than the content of specific models (Levy Nahum *et al*., 2004). In order to use models effectively as a teaching tool, teachers need to have a comprehensive knowledge of the nature of models as well as how different types of models are constructed by students. It is imperative that students realize that models are not entirely correct and that it is more about thinking than a literal model (Levy Nahum *et al.*, 2004). Another problem Levy Nahum *et al.* (2004) highlights, is that teachers hardly ever discuss students' mental models with them and neither do they give attention to the models' limitations. Teachers should be agents in the revolution of the use of models in chemistry.

Learning questions from different points of view need to be addressed in order to explain a model-based teaching and learning approach (Islass & Pesa, 2001). Considering how experts use modelling to teach their students as well as their experiences using and teaching models could help to clarify this problem. Scientists are very conscientious in their work with models and have a great deal of knowledge to share on this topic.

Islass and Pesa (2001) carried out exploratory research specifically aimed at scientists and their knowledge about teaching and learning of models. The scientists mostly talked about their concepts of models and personal experience with models and modelling. The purpose of this research by Islas and Pesa was to use the gathered data and integrate it into a body of knowledge concerning the learning of scientific models. For the purpose of analysing the data, it was divided into three groups (Islas & Pesa, 2001):

- Experiences of these scientists when learning modelling.
- Handling of models within their research activities.
- Handling of models in teaching at university.

For the first group, no scientist could remember any specific explaining of modelling in a classroom when they were students. They mostly used models while doing research. They remember having problems in using models in their first year of university. Not all of them agree that the use of models in the classroom is effective especially when the students have less than adequate conceptual and mathematical skills. One must keep in mind that this was for traditional lessons where the role of the teacher only was to offer explanations and they did not use any other learning strategies. All of the researchers agreed that models definitely became comprehensible when they faced research problems under the supervision of an expert. The only time they experienced progress in their understanding of modelling was when they carried out research and started to design their own models. Their understanding and learning of models and modelling only became better under the influence of a competent scientist (Islass & Pesa, 2001).

The second group used models mainly to guide them through all the stages in the solution of research problems. The model is corrected in every stage through experimental data. It is also useful to explain results and observations by using models. As Islass and Pesa (2001) states:

“The scientist establishes the limits of validity of his model according to the variable selection practised and the verification of the systemic frame of the model within an accepted theory.” Experimental control quantifies these limits. Some models controls the direction research takes in the scientific community.

As for the third group, models used in teaching at university are almost always a simplified version of the research models. A model is selected to coincide with the mental and cognitive abilities of the students. The teaching model is also more rigid and less creative than those used in research. They use mostly consensus models.

Justi and Gilbert (2002) obtained the following results from an interview-based enquiry of grade 7 - 11 students in the USA. The students had no formal instruction on models or modelling. These results concur with the findings of Islass and Pesa (2001) that the mental abilities of the student or otherwise said, the cognitive levels of the students, has a great effect on learning. Higher cognitive levels insure a better understanding of the physical and mathematical models (Islas & Pesa 2001). Treagust *et al.* (2001) also concur with these findings with the following statement:”The results of this study are encouraging with the majority of students having a scientifically acceptable understanding of the models concept and the level of understanding is improving with increasing year levels.” Justi and Gilbert (2002) proposed that: “students’ notions on the *nature of model* formed a distinct hierarchy of stages”.

The hierarchy of stages proposed by Justi and Gilbert (2002) comprehends the following:

- Students in level 1: Models are commonly seen as toys or a copy of the reality. They sometimes leave out certain detail just so the model would fit their expectations.

- Students in level 2: The model is created and tested with a specific reason in mind.

- Students at level 3: Understanding has three parts on this level:

  - a model is created to test ideas,

  - the modeller has a specific role in the formation of the model and he did so for a specific reason, and

  - the model can change and develop according to scientific data and subsequent formation of new ideas.

During the facilitation of the understanding of models, accessible models are used beginning with the simpler concepts to more advance ones. More advance students comprehend much more easily how a model of a concept works. The younger the students are, the simpler the model should be. The fact that a student does not have the conceptual or mathematical skills to use models fruitfully is a big concern to scientists (Islas & Pesa, 2001). They try to overcome this problem by doing the following three things:

1) Explain how they think mathematical entities and concepts are linked.

2) They analyse the physical meaning of the specific problem by using the results they get.

3) Discuss the error intervals shown in the experiment.

According to Islas and Pesa (2001):"Students usually change the direction of the model-reality relationship, considering that reality should obey the rules settled by the model. The vision of the model regulates nature." One should, however, always be cautious to make sure students differentiate between model and reality.

Harrison (2003) collected exciting data when multiple models were used to teach and examine also the teacher's reasons for using models. The teachers used students' prior knowledge whenever possible. He used chemical equilibrium as case study. His view that models are not fixed entities but are thinking tools is assisting students to predict and explain reactions in terms of the phases of matter and the collision theory. He warned that it is important to remember that models are simplified or exaggerated representations and not the real thing.

Chemistry cannot be taught successfully without the use of analogies or modelling (Harrison, 2003). Students can however, use models in unpredictable ways. It is thus very important to plan the use of models during teaching sessions. Even though models are just analogues, they are accepted as legitimate scientific language. The use of analogies is limited and teachers rarely discuss where or when an analogy breaks down (Harrison, 2003). Substantial learning gain is reported when models are used in a systematically planned way. In teaching topics like chemical equilibrium, multiple analogical models facilitate conceptual change better (Harrison & Treagust, 2000(a)).

In addition to Harrison (2003), Justi and Gilbert (2002) also discuss the use of multiple models and the way students deal with it. They agree that the use of multiple models to illustrate the same concept can be confusing to students. Multiple models are better when used in a systematically planned way where the next model is built on the previous one. This ensures that students think about a model's scope and limitations. The following conclusions were drawn from Harrison's (2003) results:

- Teaching with multiple models enhances learning.

- Teachers should have *pedagogical content knowing.* The teacher should thus know what he wants to explain and also have the pedagogical tools to explain the concepts.

- Teachers should work backwards and forwards between models to find the best sense and explanations.

- The final conclusion is that multiple models are effective when they are connected and presented in a systematic way.

Justi and Gilbert (2002) explored the learners' perspective on models and modelling in chemistry education. Learning chemistry involves three aspects:

1) Knowing existing models, scope and limitations.

2) Appreciating the role of models in validating products of the scientific process.

3) Create your own models and test that of other scientists.

Thus, learners should have a broad scope and understanding of models and modelling for effective learning to occur. To clarify the teacher's perspective on learning with models, Justi and Gilbert (2002) proposes that teachers need a broad scope of what the following entails:

- the nature of models in general,
- how students compose and use their models in classrooms,
- how to introduce consensus models,
- correct development of teaching models, and
- how to introduce modelling activities in the correct order in their classes.

Justi and Gilbert (2002) also mention the view of Van Driel and Verloop (1993) that a teacher needs to understand the nature of models and modelling in order to successful use models in chemistry education. Harrison and Treagust (2000(a)) reported that during an interview of high school science teachers, two of which are chemistry teachers, he found that all the teachers has the same opinion, namely that models are major tools of science. As part of another interview, one of Harrison's findings (as cited by Justi & Gilbert, 2002) was that there was a big difference between the number of models teachers present during teaching as oppose to how many models there are available in textbooks.

As part of another inquiry of 39 Brazilian teachers, 21 from a chemistry background, seven ways about how they consider models were identified: "the *nature* of a model, the *use* to which it can be put, the *entities* of which it consists, its relative *uniqueness*, the *time* span over which it is used, its status in the making of *prediction and* the basis for the *accreditation* of its existence and use" (Justi & Gilbert, 2002). In general most of the teachers were convinced that successful teaching with models depends on how the specific model was developed as well as on the type of students in your classroom (Justi & Gilbert, 2002).

Most of the teachers recognized that a teacher needs to modify consensus or teaching models in order to make it more understandable for their students. Because of this realisation, 95% of the chemistry teachers agree that the most important contribution models make to science education involves learning. Some outcomes of this study by Justi and Gilbert (2002) that have a direct bearing on chemistry teaching were:

- Many teachers did not know what their students' knowledge about the nature of models was.

- Nearly half of the teachers involved in this study did not give their students the chance to participate in activities that include modelling.

- About a third of these teachers agreed that students without difficulty discard their own models in favour of a consensus model.

Justi and Gilbert (2002) summarises the existing literature on teaching with models, as follows:

- Chemistry teachers tend to focus more on the content of models rather than on their nature. Teachers views on the use of models as well as the nature of models needs to improve. This will ultimately result in better teaching and learning with models.

- Teachers' pedagogical content knowledge in this field should be promoted. Current research can lead to interesting proposals for curriculum development in the area of teacher training.

Bishop and Denley (2007) also, like Justi and Gilbert (2002), emphasize the importance of the idea that students appreciate that models are only analogues of the concepts they represents. It also applies to concepts that are not at all concrete. Paatz *et al.* (2004) as cited by Bishop and

Denley (2007) offers a summary about the nature of analogy thinking as to how an analogy can develop clear understanding: "Analogical thinking is a process of enriching a person's knowledge about an unknown target domain by using his/her knowledge about a base domain." The use of models as a teaching tool features in numerous literatures. Bishop and Denley (2007) stated that the application of models during chemistry lessons is a characteristic of more accomplished teachers because they know the value of models as teaching tools. "These teachers think carefully about the models they use, understand their different purposes and, importantly, their strengths and limitations" (Bishop & Denley, 2007).

2.6 Misconceptions in chemistry teaching

This section provides a brief prologue to the topic of students' ideas and alternative conceptions they hold about chemistry in general. CCD[7] (2001) defines the word misconception as: "a false or mistaken view, opinion or attitude". Taber (2002a) defines alternative ideas with the following two terms:

- alternative conception – refers to a single idea; and
- alternative framework – refers to a complex or structure of related ideas.

It is less important what terms one uses to describe students' ideas. What is more important is the following:

- to recognise that students have ideas about science that can interfere with learning, and
- to know how to pinpoint them and respond correctly to them (Taber, 2002a).

Many misconceptions make sense to the student but is not scientifically correct (Rutledge, 2010:7). Jean Piaget described how young children would often make up an answer to something they are not all that familiar with (Taber, 2002a). Social pressure, for example a question asked by an adult, can lead to answers just because the students think they ought to answer the question. Research indicates that there is a wide range of ideas held by students that contradicts the science they will meet in college (Taber, 2002a). Teachers cannot assume

[7] Collins Concise dictionary

that students will arrive in their classes with a "blank" slate with which they can start working. Students need training and guidance to become scientists.

2.6.1 The nature of students' ideas

Research indicates that students' informal ideas vary over a wide range (Taber, 2002a). Some ideas are crystal-clear while other is more broad-spectrum. Some ideas are very rare and limited to only one student while others are not limited at all and students all over hold these misconceptions. Taber advises teachers as follows on student thinking and nature of misconceptions:

"The advice I would give teachers can be summarized in three points:

1. In any class, for any science topic, students are likely to hold a wide range of alternative ideas about the topic,

2. not all of these ideas will be highly significant in terms of impending the intended learning, but

3. some of them will."

2.6.2 The significance of students' ideas

Some ideas students bring to class will fade away once the teacher provides the scientific facts (Taber, 2002a). This is however, not always the case. Taber (2002a) proposes different outcomes when students are confronted with scientific ideas opposing their own ideas of the concept.

- Sometimes the new data about the concept cannot successfully displace the alternative ideas without causing a whole set of new problems.

- Sometimes students treat the new ideas as entities not related to their previous thinking.

- The science they learn is stored as separate ideas, totally unrelated to existing ideas.

- This leads to students using two sets of knowledge, one to explain scientific concepts and the other to explain ideas in everyday situations.

- New ideas stored separately are often soon forgotten.

- Students fall back on their original ideas soon after presentation of the new ideas.

- Sometimes no or little learning takes place because the student cannot make sense of the teacher's presentation in terms of their own ideas.

- Sometimes students make sense of teacher's presentation in terms of their own ideas and this leads to a whole set of new alternative ideas. Often the teacher doesn't realise this fact before writing a test and the student already has a hybrid idea between what the teacher intended and the student conceptualized.

2.6.3 Examples of alternative conceptions.

The molecular model of the atom is introduced early in the curriculum and it serves as the basis of many chemical concepts. Many misunderstandings, or misconception, arise because of difficulty in the understanding of the basic concepts of the atomic model. Mongwaketse (2006) identified the following misconceptions of atoms, ions and molecules:

Atoms:

- An atom is a molecule.
- An atom is a number of neutrons plus a number of protons.
- An atom is any substance consisting of an element in the periodic table.
- An atom is an element.
- An atom is something spherical.

Molecules:

- Molecules are small gas particles.
- Molecules are elements in the form of liquid.
- Molecules are small particles.

Ions:

- An ion is a hard metal.
- An ion is an element.
- An ion is a stable molecule.
- Ions are formed by joining pieces of metals.
- Ions are formed when small particles bond together.
- Ions are formed by positive and negative charges.
- Ions are a mixture of chemicals.

An understanding of basic chemical reactions is very important because they represent both macroscopic and microscopic events in chemistry (Johnston, 1991). Familiar misconceptions regarding models in general are that a model is always an exact copy of the concept, that there is only one possible model for each concept and that the value of a model is only determined by a scientist (Treagust, Chittleborough & Mamiala, 2001).

Kelly *et al.* (2010) examined the nature of the misconceptions students had about the microscopic level after they had a lecture emphasizing the macroscopic nature. To summarise their findings this article suggests that:

- students fit their own sub-microscopic level ideas to the equations,
- they do not understand what the symbol (*aq)* entails
- they do not understand the difference between ionic and molecular equations and they consider the total ionic equation as an intermediate step in the reaction,
- they believe that molecules break up which then form new products,
- they have a simple view of chemical equation because they leave out water all together.

These findings of Kelly *et al.* (2010) emphasize the lack of understanding students have about the connection between microscopic and macroscopic levels during chemical reactions. This lack of understanding lays the basis for misconceptions because students draw their own conclusions about the microscopic level on the basis of what they observe during a chemical reaction. One can hardly pinpoint all the possible sources of misconceptions but because children come from various backgrounds this could hinder or help students' conceptions about chemistry concepts (Chiu, 2005).

Driver (1985) explored the different ideas of children during phase changes. Although the outward appearance of a substance changes, it remains the same substance. What do students imagine happens when a liquid changes phase? Driver (1985) explored this with school students from New Zealand and of who the ages varied between 8 and 17. The following table summarizes the misconceptions held by students about what happens to water when it boils, condenses and when ice melts.

Table 2.1: Summary of misconceptions about phase changes of water (Driver, 1985)

Water boiling	***Water condenses***	***Ice melts***
Nature of water change	Nature of water change	Nature of water change
Water changes into air (air and steam seen as the same thing)		
Account only for observable macroscopic changes	Account only for observable macroscopic changes	Account only for observable macroscopic changes
Particles become smaller	Particles become smaller	
		No movement of particles in solid state
Particles get hot, melts or change size	Particles get hot, melts or change size	Particles get hot, melts or change size
		Particles break loose from the ice
		Particles collide within the ice
	No bonds between the particles	No bonds between the particles
Particles expand or shrink	Particles expand or shrink	Particles expand or shrink
Particles disintegrate		
Particles die		
As temperature rises, particles get smaller		Ice becomes water

Although Driver (1995) noticed a strong association between particle separation and temperature, there was little mention of attractive forces between particles. Some students did not even grasp the concept of particles, whilst others seem to think particles change shape etc. Most students in the higher grades (15 years and older) made use of the particle theory although they did not always use it correctly.

Anderson (1990:15) mentions the possibility of language interpretation problems: " If one pupil, for example writes *an oxide is formed* to explain why a copper pipe turns black, one does not know whether this indicates an understanding of chemical interaction or is a pure description, or whether the pupil imagines that some substance in the air forms a coating,"

Table 2.2: Summary of students' conceptions of atoms, molecules and systems of particles.

Atoms	***Molecules***	***Systems of particles***
Considered final link in division process	Macroscopic properties projected onto molecules, phosphorous is yellow therefore the atoms are yellow	Atoms burn up when heated
Vary in form, square or rectangular	If water is hot, so are the molecules	Precipitation a result of adding together of the original particles
No vacuum between them	Molecules in air fuses to existing objects	Cannot touch atoms or molecules, they are thus not matter
Natural to think of matter as an continuum	Molecules form as a result of old and new molecules	Particles are so tightly packed, there are no spaces between them
	Alcohol and water molecules cannot be solid but must be small drops	Particles of a given substance varies in size
	If the substance is soft, molecules should also be soft	Particles can form larger units and disintegrate into smaller pieces
Iron atom expands when heated		

Gillespie and Gillespie (2007) listed some common misconceptions about the particle theory as the following:

- Ice, water and steam are commonly thought of as different substances.

- The word material just means that it is a fabric.

- One can observe an atom through a microscope.

- Snow is just rain that has been frozen.

- The sea makes all sand.

- A substance disappears when it dissolves.

- Foam is a solid substance.

Rutledge (2010) made the following observations regarding misconceptions about the understanding students have on the physical changes in materials. Rutledge also recommends that a teacher prepare himself to deal with these misconceptions during class.

- Many young children do not comprehend the process through which some materials had to go before it reached its current form.

- Confusion exists about the processes involved and raw material used during the manufacturing process.

- Many children are confused about the existence of water as a gas (vapour). They also have difficulty in believing that substances such as vinegar can be a solid.

- Children confuse some terms like melting and dissolving as well as heating and burning.

- They believe material is just material and see no need to explain materials in terms of the particulate model.

- Children sometimes believe that the particles are separate from the material.

- It is difficult to believe that there are spaces between the particles of solids and liquids.

- Children find it difficult to comprehend how small and how many particles there are in materials.

Cross and Bowden (2009) came to the same conclusion regarding misconceptions learners have about materials as Gillespie and Gillespie (2007) did. Children often refer to material as a fabric. Other misconceptions they listed are:

- Is the object hard or is the material hard?
- Material comes from the supermarket.
- If material can soak up water, it is waterproof.
- Wool and other fabrics warm one up.
- If a substance can be poured, like sand, it is a liquid.
- Soft materials are not a solid.
- Gas particles have no weight.
- Air is the only gas that exists.
- Particles are the same size as grains.
- Things solidify because they lose water.
- Puddles just dry up.
- Soft materials, like dough, just go hard.
- No difference between evaporating and boiling.

- Condensation and evaporation are the same.
- Steam and condensation are confused.
- Salt is too heavy to evaporate.
- If a substance dissolves, it disappears.
- When solids dissolve in water, it makes the water cloudy.
- Sugar melts when it is mixed with water.
- Salt can be filtered from a salt and water solution.
- All solids can melt.

During a six-year study of students' conceptions in chemistry in Taiwan, Chiu (2005) came to the conclusion that:

- Many students consider the smallest size of crystal sugar would be visible under a microscope and that the smallest thing one can see will be bacteria.
- Students use weight to answer questions about distribution of particles.
- The volume of particles change when the pressure changes.
- Students consider gas particles at higher pressure to push particles at lower pressure.
- NaCl is considered an organic substance because of the C in the formula.

In chemistry, some misconceptions arise because chemistry is constantly changing and evolving. It is thus important to make sure old misconceptions are corrected before building on current conceptions to explain new conceptions (Anon, 2011).

Chapter 3: Constructivism and chemical education - A Theoretical Framework

3.1 Introduction

When a researcher is conducting qualitative research in chemistry education, the theoretical framework plays the same role as the role of an instrument (Bodner & Orgill, 2007). CCD (2001) translates "theoretical framework" as "a structural frame based on theory". Bodner and Orgill (2007) define a theoretical framework as follows: "It is a system of ideas, aims, goals, theories, and assumptions about knowledge; about how research should be reported that influences what kind of experiments can be carried out and the type of data that result from these experiments". This clearly implies that the research will be influenced by the type of framework the researcher chooses. Bodner (2004) explains the role of theoretical frameworks with the help of Figure 3.1 and this indicates the different categories of theoretical perspectives in chemistry/science education.

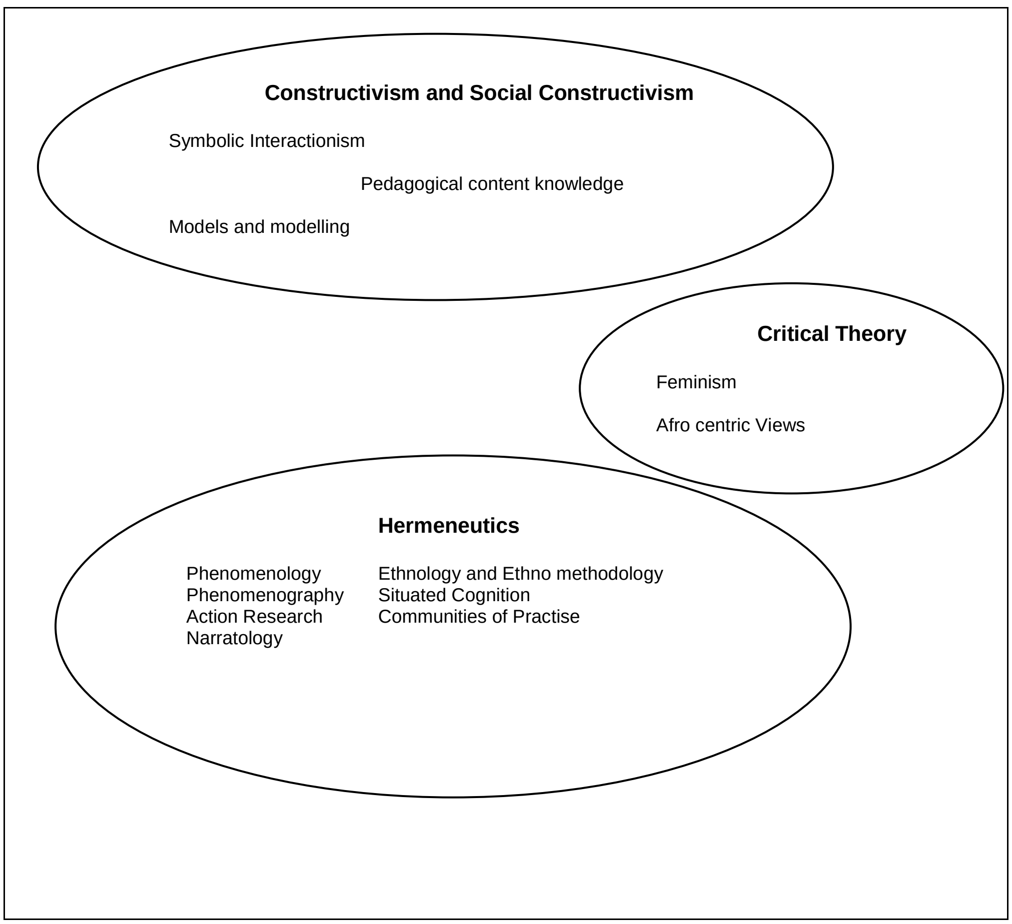


Figure 3.1: Theoretical perspectives for research in chemical/science education grouped into categories of constructivism, hermeneutics, and critical theory (Bodner, 2004).

The frameworks are divided into three groups as shown in Figure 3.1. The first category includes frameworks on theories based on the constructivist mode of thinking. The second group is divided into categories connected to hermeneutics and the third group categorises those topics related to critical theory. In this figure, the broader picture of constructivism in theoretical frameworks can be seen.

In short, constructivism can be summarized as knowledge that is constructed in the psyche of the person assuming that existing knowledge is not discovered, but in fact every person, learner, student or scientist, actively constructs his/her own knowledge (Bodner, 2004). Through the years, Bodner (2004) focused on different types of constructivism, namely:

- personal constructivism which focuses on the individual and his cognition skills,
- radical constructivism which evolution he traces back to Jean Piaget, and
- social constructivism which concentrates on the dynamics of group interactions.

Most learning experiences fall in a category between the radical and social constructivism (Bodner, 2004). Because learning is a complex process, social constructivist tend to view learning more as a social process while radical constructivists argue that learning is ultimately an individual process.

Symbolic Interactionism as a category of constructivism is a derivative from the field of social psychology. Bodner (2004) documented four assumptions on which symbolic interaction is based, namely:

(1) we act towards the environment (including persons and objects) on the basis of what each individual or object means to us,

(2) these reactions are a result of social interactions,

(3) an individual of a group is responsible to interpret the meaning to the rest of the group, and

(4) a person’s action is determined by these constant evolving meanings of a social group.

The term “symbolic” indicates that conversations in these groups involve the use of certain symbols. The term “interaction” indicates the social interaction that takes place when an individual is constructing his own knowledge and understanding of certain concepts. Symbolic interaction implies that the researcher should view things through the view of those under study. In the rest of this chapter there will be a discussion on constructivist frameworks including information on:

- the description,
- when and why it was developed,
- the ontological belief system,
- the methodologies and analysis techniques,
- the advantages and disadvantages, and
- a brief description of such studies in chemistry education .

3.2 Constructivism and Social Constructivism

3.2.1 Introduction

Research in constructivism and education has followed a certain path for several years now. Within the constructivist mode other fruitful ways were developed to explore the problem of knowledge and thus the problem of learning. Because constructivism implies that a student should play an active role in constructing his own knowledge, this leads to more appropriate teaching methods where students are encouraged to construct their own knowledge. Recently the following two questions have been asked by Larochelle and Bednarz (2009):” But how has this basic precept of constructivism contributed to the renewal of day-to-day teaching practises? What sort of participation, construction, and forms of knowledge are involved and valued?” In this chapter these questions will be used as the basic argument.

According to Larochelle and Bednarz (2009), a "softer" version of constructivism is more readily practised. When students' knowledge is taken into account, teaching methods do differ but these teachers do not identify what is wrong with the students' point of view. We are thus once more "dealing with the same *schemata of docility* by which the primacy of pre-established knowledge in teaching practise is asserted" (Larochelle & Bednarz 2009). This pattern allows a students' knowledge to be put into compartments resulting in re-institutionalization of the social order of knowledge. To some extent this interpretation of the constructivism provides evidence of the fact that ultimately all forms of knowledge is influenced by the socio-cognitive experiences of each individual. However, if this was the only principle constructivism was built on, it would not have much to offer to education.

Constructivism is built on thoroughgoing questioning of the basic principles and epistemological breaks that are more extensive than the simple saying "that eventually all roads lead to Rome" (Larochelle & Bednarz 2009). The question:" but what do we understand by the term *constructivism*?" can be answered by the fact that epistemological (the branch of philosophy that studies the nature of knowledge, in particular its foundations, scope, and validity) constructivism is not a method or a teaching model, it centres on the development of a rational model of cognitive activity that gives a student a means to give shape and meanings to his actions (Larochelle & Bednarz 2009).

The main issue here is that we need to move forward from a mountain of facts to a world of symbols and models taking into account the cognitive and specific experiences of a person as well as his social relationships within these experiences.

3.2.2 Constructivism as theory of learning

Constructivism is based on the assumption that a student is actively and purposely participating in the learning process (Trumper, 1991). The student brings prior knowledge to the table in order to give meaning to new information or concepts. According to Ferguson (2004), constructivism is a theory of learning that originated from the cognitive sciences during discussions and applications in both science and chemical education.

Constructivism provides a basis for learning on the grounds of incorporating new knowledge into existing knowledge and then making sense of this new knowledge. As a theoretical framework, constructivism provides a thinking tool with which one, a teacher or researcher, can make sense of a person's interaction with knowledge (Ferguson, 2004).

When applying constructivism to various concepts and ideas, several forms of constructivism was identified by Ferguson (2004) and he associated with an individual whom it was close to:

- "Personal constructivism: Kelly and Piaget.
- Radical constructivism: von Glasersfeld.
- Social constructivism: Solomon.
- Critical constructivism: Taylor.
- Contextual constructivism: Cobern.
- Social constructionism: Gergen".

Ferguson (2004) makes a definite distinction between the two terms "constructivism" and "constructionism". All five forms of constructivism focus on the fact that an individual makes sense of information while social constructionism presumes the knowledge or understanding is held collectively by a group using a certain language as mediator. Ferguson (2004) also argues that the term "constructivism" is reserved for use when focusing on individual sense making and the term "constructionism" when a meaning is collectively generated. Both personal and radical constructivism is based on the individual's experience of making sense of the worldly experiences. When considering personal constructivism in a classroom context, knowledge never stays intact during transfer from instructor to learner.

Solomon and O'Loughlin proposed social constructivism as a constructivist mode rather than the personal constructivism propagated by Kelly and Piaget (Ferguson, 2004). However, one can easily ask the question:"How can constructivism be social? Bodner (2004) answered this question with the following:

“It is tempting to think about radical constructivism and social constructivism as opposite ends of a continuum. At one end, learners construct knowledge in isolation, based on their experiences in the world in which they live. At the other end, learning is embedded in social and cultural factors. Most situations in which learning occurs, however, fall somewhere between these two extremes. Learning is a complex process that occurs within a social context, as the social constructivists point out, but is ultimately the individual who does the learning, as radical constructivists would argue,”

It is however relatively futile to debate the differences between social and personal constructivism. A much more positive outcome can be achieved by comparing similarities. Both theories share the same basic theory. Ferguson (2004) lists a few commonalities:

- both individuals and groups can build up knowledge,
- social interactions, whether they are individual or common, lead to the acquisition of knowledge,
- the language in which the construction takes place must be useful, and
- learning and language makes the individuals’ learning experience coherent and are the building blocks on which a community builds its knowledge.

3.2.3 The ontological belief system of Constructivism

Briggs and Bodner (2005) compared the differences between traditional and constructivist theories against differences between the realist en relativist position in the philosophy of science. The relativists group agrees on one fact, that is: our knowledge is built upon our sensory experiences. The difference between groups arises because they cannot agree on the degree to which the world is knowable. According to Ferguson (2004) critics of constructivism often accuses constructivists of denying the existence of reality. This is not correct because constructivists only question the ability of man to know reality and consequently their ability to distinguish true from false.

Constructivists are realists and the theory does not allow an ontological debate, because as Schwandt (2000) states: "in terms of the ontology the theory is *mute*." Von Glasersfeld (1984) compares the search of the traditionalistic theories of knowledge for similarities between knowledge and reality as basically the same way you would search for matching paint colours. They either match or they don't. The constructivist search for knowledge is more a case of different shades that still match although not exactly the same colour. It can also be explained by the metaphor of slightly different keys opening the same lock. Thus, as Ferguson (2004) states, to the constructivist "knowledge is non-conformable, non-provable, and is not *discovered*."

3.2.4 The history of Constructivism

Constructivism originated as a theory in the cognitive science (Ferguson, 2004). The intended aim with this theory was to explain the integration of knowledge. Because the history of constructivism can be very extensive, it will be presented as a timeline with headlines:

- Sokrates was the first person to express the idea of constructing one's own knowledge.

- Von Glasserfeld credits Piaget as the pioneer of constructivism. The theory developed as a result of his work with children and cognition.

- Piaget stated that the cognitive development of children happens in stages and that cognitive structures are used to construct knowledge. Piaget also provided us with the knowledge that learning is a process that takes place because of an interaction between the individual and the environment. He also notions that knowledge is not absolute; it is constantly being updated and reconstructed according to new experiences.

- The work of Vygotsky was later integrated in constructivism and it separated into the language leg and the social interaction leg. He believed social interaction to be of cardinal importance on how and what a person learns. Vygotsky developed the idea of the Zone of Proximal Development which is concerned with the cognitive limitation to a zone. The learning process is on one hand restricted by the skills or knowledge possessed by the individual and on the other hand skills can only be acquired with outside help. An experience beyond the first boundary of the zone does not demand anything from the individual; they either already possess the skill or comprehend the concept fully. If an individual is placed outside the second boundary, they do not have the cognitive capability to comprehend the concept.

- In 1988 Ken Tobin gave science education research a first taste of radical constructivism when he implemented von Glasersfeld's theory. Tobin and his colleagues proposed constructivism as a framework to analyse traditional high school teachers' teaching methods. These studies in constructivism took the teacher-centred teaching methods away and gave way to a more student-centred and experiential classroom.

- The work of Keulen in 1996 is an example of how constructivism can be used as a curriculum intervention strategy.

3.2.5 The leading questions and methodologies of Constructivism

When studies regarding sense-making and concept construction are done, constructivism can be used to answer the following questions (Ferguson, 2004):

- how have persons in this situation constructed certainty?

- what are the documented perceptions, explanations, thinking, and worldviews?

- what is the cost of their constructions for their performance and for those with whom they work together?

- what is a student's creation of (say) phase changes and how does that structure compare with the epistemological reality of knowledge?

When constructivism is used as an exploratory tool, it is imperative that the researcher asks questions relating to how an individual make sense of certain concepts and phenomena (Ferguson, 2004). Some chemistry education research done from a constructivist point of view, made use of some of the following guiding research questions:

- What alternative conceptions regarding a certain topic or concept are held by teachers and students?

- How do students employ mental models of their conceptions?

- How aware are chemistry instructors of students' alternative conceptions?

According to Lincoln and Guba (2000), the most important aim of constructivism is understanding and conceptual change. It is very important to use the correct methodology in order to be consistent with the basic belief system of constructivism. Lincoln and Guba (2000) suggest that the manner in which the data is methodologically exploited should be "hermeneutic and dialectic". Hermeneutics stem from the ancient Greek mythology where Hermes brought the message from the gods to the people in an understandable form. When doing research in the constructivist manner, it can be compared to the hermeneutics where the message is brought from the learner or student to another participant, the reader.

A dialectic methodology is based on the sharing of the process by two parties, namely the researcher or teacher and the participant, student or learner (Lincoln & Guba, 2000). This process focuses on the researcher listening to the participant answering and explaining the researcher's questions, the post interview where the researcher shares his findings with the participant and dialogues between the researcher and his peers. The dialectic methodology can thus be used as part of a variety of research tools. Ferguson (2004) summarized the use of both hermeneutical and dialectic methods as follows: Methods that side with both hermeneutical and dialectic styles give the researcher a peek into the conceptions held by the participant. They help clarify the understanding that is constructed in the psyche of the participant, and thereby support constructivism as a research tool.

3.2.6 Conclusion: Constructivism and Social Constructivism

Because constructivism originates in the cognitive sciences, it is the dominant epistemology in science education. Constructivism is used in the curriculum as well as a theoretical framework for research (Ferguson, 2004). Symbolic Interactionism as part of the constructivist learning theory will be discussed in the following section. Symbolic interactionism, pedagogical content knowledge and models and modelling reside together under constructivism and social constructivism.

3.3 Symbolic Interactionism

3.3.1 Goals and assumptions

As symbolic interactionism is mainly concerned with the composition of joint meanings, that is symbols, it is achieved through the process of social interaction, sharing and interpretation (Del Carlo, 2007).

Patton (1990) defined the goals of symbolic interaction as the set of symbols used by people to understand their interactions and give it meaning. The meaning that each individual holds about their world is clearly the most important factor in symbolic interactionism. Del Carlo (2007) argues that symbolic interactionism is determined by the following three defined areas:

- Humans act toward the things and persons in their environments on the foundation of the meanings these things and persons have to them.

- These meanings are constructed from the social dealings (communication, generally understood) between and amongst persons.

- Meanings are recognized and tailored through an interpretive method undertaken by persons in dealing with the stuff one comes into contact with every day.

When dealing with symbolic interactionism one makes two overall assumptions: its handling of reality and the nature of contact and activities (Charon, 1998). Although social interactionism is largely influenced by some components of behaviourism, it differs from the traditional behaviourism in the sense that it relies more on the meaning that arises from social behaviour and this in turn further constructs meaning with the help of social interactions. It does not rely on the results of previous conditioning or instinct like the traditional behaviourism does.

3.3.2 Methods and data analysis of symbolic interactionism research

Because symbolic interactionism is mainly concerned with meanings and interpretation of a person's observations, qualitative methods of data collection suits this process better (Del Carlo, 2007). The methodologies that are used the most include participation observations, interviews and life histories. Occasionally mixed methods and social experiments are also used.

Jacob (1987) suggested a research design that is a little more flexible where preliminary data directs the collection of later data through a "sensitizing framework". In this exploration phase of the analysis the researcher adopts new points of view as the study progresses. Taking this new direction is primarily a result of the recognition of relevant data as the researchers initial understanding of the data is bettered because of new points of view or a deeper understanding of the new data.

3.3.3 Potential Educational benefits of Symbolic Interactionistic Research

Educational studies grounded in symbolic interactionism focus more on social interactions and this has a strong influence on learning (Del Carlo, 2007). Students are constantly interacting with new people and new information, exposing both students and teachers to the culture of science and scientific knowledge.

3.3.4 Conclusion: Symbolic Interactionism

The principles of scientific interactionism, including assumptions and perceptions, are all connected to each other to provide a strong network (Del Carlo, 2007). Symbolic Interactionism focuses on the meaning people attach to the behaviour of others. It can provide a broad understanding of civilization when used as a framework in chemistry/science educational research (Del Carlo, 2007). When symbolic interactionism is used as an exploratory framework, a better understanding is generated of the population the researcher is working with and consequently generating a better understanding of other populations for future studies.

3.4 Models and Modelling as a theory of learning

3.4.1 The models and modelling paradigm

As a theoretical framework, models and modelling give insight into the mental activities of an individual (Briggs, 2007). When used as a methodological framework, models and modelling provides a method to verbalize a task or a problem. As an analytical framework a deeper understanding of mental activities are achieved. The models and modelling framework tries to create a deeper insight into the mechanism with which the construction of knowledge occurs.

3.4.2 Origin of the concept of models and modelling

Various attempts have been made to define the characteristics of the term model. Briggs and Bodner *(*2005) made a summary of a few descriptions to contextualize the model within science education:

- A model is a depiction of an idea, object, event, process, or system, which focuses awareness on certain aspects of the system – thus facilitating scientific investigation

- Mental models represent important aspects of our material and societal world, and we manoeuvre elements of these models when we think, plan, and try to explain dealings in that world.

- A model relates to a particular system or occurrence with which we have a familiar experience or set of experiences.

- Models are intellectual entities that persons create with which they reason; all of our understanding of the world, therefore, depends on our capacity to assemble models of it.

- Scientific models are abstract systems mapped onto a detailed blueprint of the structure/behaviour of a material system within sure confines of dependability.

The concept of mental models can be traced back to Plato about 2500 years ago (Briggs, 2007). Johnson-Laird (1989) gave a more modernistic view of the model concept:

“We seem to perceive the world directly, not a representation of it. Yet this phenomenology is illusory: what we perceive depends on both what is in the world and what is in our heads – on what evolution has *wired* into our nervous system and what we know as a result of experience. The limits of our models are the limits of our world."

3.4.3 Components of the Models and Modelling Framework

During a study of middle-school students' mathematical problem solving skills, one of the outcomes of the study was the recognition of the following five components of a mental model (Briggs, 2007):

- the referents or symbols of the models, either physical or mental objects,
- the relationships between the referents, either a physical location, cause and effect, host and symbiont, multiplier to multiplicand,
- a set of rules which gives order to the relationships,
- results gives new perspectives from experiences and mental activities,
- the dynamic component, operations such as mental rotation of a molecule.

3.4.4 Alternative conceptual basis for the models and modelling perspective

The studies of Case, Okamto, Stephanson and Bleiker (1996) provide an alternative basis for the models and modelling framework. They concentrated on the mental structures and processes that led to cognitive maturation in children. Mental models are divided into two parts namely: local or global.

Local mental models are constructed as needed and discarded after use while global mental models are more permanent. These two parts are used in cooperation when circumstances expect it and this interaction facilitates the forming of new knowledge and the use of existing knowledge.

3.4.5 Implications of using a models and modelling theoretical framework

This theoretical framework has a labour intensive nature (Briggs, 2007). The best time to interview participants on a certain mental model is when they are actively constructing the model. This also implies that ample time will be available to think of an answer to the questions. This framework is useful when dealing with learning and knowledge construction and according to Briggs (2007): "Models and Modelling can provide answers to questions that deal with how a learner conceptualizes a substituent, the structure and properties of a molecule, and its reactions."

Models and modelling theoretical framework provides the researcher with a figure of speech for learning. Seemingly it is the best description of how the construction of knowledge takes place (Briggs, 2007). A deeper understanding of mental activity and construction is achieved and is very useful for teaching and learning.

A theoretical framework is only useful when it is able to predict and explain certain concepts. When a participant is unable to operate a mental model properly, the conclusions drawn from this model will almost certainly be incorrect (Briggs, 2007). Proper operation of a physical model into a mental image leads to better facilitation by the instructor and thus only fill in a few missing or immature constituents.

3.5 Pedagogical Content Knowledge

3.5.1 History of Pedagogical Content Knowledge

Patton (1990) described Pedagogical Content Knowledge (PCK) as:

"The social and behavioural sciences have evolved into disciplines by focussing over time on different core questions. Those differences in focus have implications for the kinds of questions a particular researcher will ask and the scholarly tradition within which a specific study is placed."

At the end of the 20th century, educators and politicians in the United States participated in a debate about PCK. A big concern was the little amount of time spent on content knowledge during teacher preparation programs. The initial model of PCK was developed and resulted from the blending of content knowledge with pedagogical methods (Miller, 2007).

Miller (2007) made a summary of the various categories of teacher knowledge: (Table 3.1)

Table 3.1: Categories of Teacher Knowledge

Knowledge category	***Description***
Pedagogical	*Encompasses the general knowledge, beliefs, and skills about method for teaching*
Content	*The facts, concepts, principles, and procedures taught about respective subject*
Curricular	*Understanding how particular concepts fit into the grade level at which it is taught*
Student	*The prior knowledge of students and how students will most likely enhance or change that knowledge*
Contextual	*Specific knowledge that is unique to the learning setting*
PCK	*An amalgam of content and pedagogy unique to a subject matter teacher. The blending of content and pedagogy into an understanding that allows the teacher to more thoroughly understand how to present a topic*

Ultimately, Miller (2007) concludes that effective teaching appeared to be dependent on the quality of a teacher's PCK.

Cochran *et al.* (1993) hold a different opinion of PCK. They believe the word *knowledge* is too stagnant for the constructivists. These researchers replaced the word *knowledge* in PCK with *knowing* because of the dynamic participation of this knowledge in a constantly changing classroom environment. PCK should be allowed to adjust to fit the needs of individual instructors and thus results in active learning (Miller, 2007).

3.5.2 Assumptions of Pedagogical Content knowledge

The following assumptions will be discussed:

3.5.2.1 PCK as a category of knowledge (Miller, 2007).

- First the assumption that teachers build an expert knowledge about a certain topic through a superior method leads to the statement that a specific method of teaching is more suitable for a certain topic.

- Second, researchers believe that a specific instrument can be devised to quantify and recognize PCK.

- Third it is assumed that educators can share PCK with other educators for use in the classroom.

- Fourth it is assumed that articulations by teachers about thinking and awareness reflect teacher practise in the classroom.

If the first assumption is analysed closely, Coll and Treagust (2002) stated that if PCK is a personal transformation of knowledge, each instructor will have a different method of teaching and not a general method for a specific topic.

The second assumption is shown by Van Driel and Verloop (2002) as not true because there are no specific measures available to quantify and recognize PCK.

According to Miller (2007) constructing PCK is such a personal process that one educator might not be able to fully comprehend and use another educator's PCK.

On the final assumption that a teacher's beliefs and knowledge actually has an influence on classroom practise, Miller (2007) comments the following: "Yet, many teachers quote constructivist ideas but fail to support those ideas with constructivist methods. Therefore, the assumption that teacher articulations of beliefs and knowlegde represent actual teacher practice is questionable."

3.5.2.2 PCK as a Theoretical Framework (Miller, 2007).

- PCK represents a class of teacher knowledge that is the core of a specialist teacher.

- PCK represents an epistemological approach to how the teacher constructs his own teaching knowledge.

- PCK is a constructivist practice and therefore, a constantly changing body of information.

Unfortunately, according to Miller (2007), PCK remains an ill-defined category of knowledge that is difficult to separate and study. For researchers, PCK provides an initial point for collecting and analysing data about teacher knowledge. Through systematic PCK research, researchers may soon sketch out methods teachers may use to construct significant teaching concepts (Miller, 2007).

Finally, as a constructivist undertaking, PCK is a constantly changing unit and as Miller (2007) states: “The ever-changing nature of PCK challenges the researcher to consider longitudinal methods to determine the impact of experience on PCK.”

3.6 Constructing scientific knowledge in the classroom

The term constructivism can be used in education to describe learning and teaching as well as curricula and assessment (Sjoberg, 2007). It is also used in a more philosophical sense. The influence of constructivism has been the largest in the fields of science and mathematics.

Not all the highly proficient science teachers would have describe their way of teaching as solely constructivism, but rather as a practice featuring elements of constructivism (Bishop & Denely, 2007). For example, the method of eliciting students’ preliminary ideas at the beginning of a topic was common. It was also common to realise that students sometimes have their own, frequently alternative, explanations for certain scientific concepts. Less obvious, however, was any evident identification of the more social aspects of constructivism.

Driver and Oldham (1986) explored the origin of constructivism in cognitive psychology which takes one back to Ausubel and his famous quote:”The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.” This somewhat one-dimensional view does not take into account the social and emotional life world of the child.

Learning is a very personal experience; it is different for all learners (Cross & Bowden, 2009). A learner starts the learning process from where they are - it is thus the first cause of action for the educator to determine each learner's starting point. This elicitation is the first step of the constructivist theory. The social constructivists see this process as occurring alongside the other learning processes. To effectively make use of constructivism in the classroom, learners need to be fully engaged in the learning of their science (Cross & Bowden, 2009). The teacher needs a constantly growing range of ideas to capture and hold the attention of the learners.

Constructivism promotes meta-cognition which enables one to determine what we don't know (Van Rooyen & De Beer, 2006). Various classroom strategies can be employed to promote meta-cognition such as verbal communication during problem solving, mind mapping and brainstorming.

Supporting modern perspectives on science education is the outlook that knowledge cannot be transferred but should be constructed by the intellectual activity of students (Driver, Asoko, Leach, Mortimer & Scott, 1994). The following section presents an academic perspective on the nature of teaching and learning science. The view of science learning as an individual activity and the view of science learning as a social activity are compared.

3.6.1 The nature of scientific knowledge

In order to explore teaching and learning, one needs to consider the nature of the knowledge that is taught (Driver, *et al.*, 1994). The nature of science cannot be simplified as one single "nature of science". Driver *et al.* (1994) argues that scientific knowledge is both symbolic in nature as well as negotiated in a social context. Scientific knowledge is not only happenings of nature but it also depends on scientists to interpret the phenomena. Scientific knowledge in many domains such as chemistry consists of specific formulated entities and the close relationships between the different domains. Scientists invent constructs to explain and communicate certain phenomena which are often the result of significant intellectual struggles. Once this specific knowledge has been constructed and approved by the scientific community, it becomes part of the everyday way this knowledge is seen by the community.

The view of scientific knowledge as a socially constructed and validated occurrence has significant implications for science education (Driver *et al.*, 1994). This means that with the accumulation of scientific knowledge goes the scientific way of doing. Learning science implicates initiation into the scientific community and its practises and then making the learning thereof an individual process. The main role of science educators is to make this process a meaningful experience.

3.6.2 Learning science as an individual activity

Piaget holds the view that knowledge is constructed by the cognizing subject (Driver *et al,* 1994). His main concern was the process by which a person constructs knowledge of his life world. Driver *et al.* (1994) states: "In broad terms, Piaget postulated the existence of cognitive schemes that are formed and developed through the coordination and internalization of a person's actions on objects in the world." This is an evolving process forming simple concepts to more complicated concepts. Old concepts can be altered or modified. In this way a person adapts his personal cognitive schemes to the physical milieu. Although Piaget acknowledges that social interactions can be helpful in a person's cognitive development he deemed equilibration at the individual level vital.

The teacher's role in this process is to provide the physical know-how and to support and facilitate reflection (Driver *et al.,* 1994). The meanings of learners should carefully be listened to and handled in such a way that the respect between both parties remains. There is, in the viewpoint of Driver *et al. (*1994), an important oversight in this perspective on knowledge construction and that is: "Development in learners' cognitive structures are seen as coming about through the interaction of these structures with features of an external *physical* reality, with meaning-making being stimulated by peer interaction. What is not considered in a substantial way is the learners' interaction with *symbolic* realities, the cultural tools of science."

3.6.3 Learning science as the social construction of knowledge

Social constructivism in the classroom concentrates more on the introduction into a symbolic world (Driver *et al.,* 1994). From this perspective knowledge is constructed by engaging into communication and activities about a shared topic or problem. Constructing knowledge involves the introduction of individuals to constructs by more skilled persons. The less experienced person internalises the knowledge and skills provided by interacting with more skilled persons. This process is thus used as a learning tool.

An important issue arises here for science education: if knowledge construction is exclusively seen as an individual process, it is then the same as what has traditionally been identified as discovery learning (Driver *et al.,* 1994). If however learners are exposed to not only physical experiences but also to other knowledge systems of science, knowledge construction goes beyond individual pragmatic enquiry. The challenge lies in helping learners to internalize these models for themselves and be able to use these other applicable domains. A teacher should provide proper experimental evidence to lead students towards conventional science ideas. The challenge is how to achieve this successfully in the conventional classroom. A further complication can arise when the teacher presents an idea which conflicts with the learner's prior knowledge constructs.

Young people have their own range of knowledge schemes that they construct based on the daily encounters with everyday life (Driver *et al.,* 1994). These structures are strongly supported by their own experiences and socializations. Most of these knowledge schemes are constructed informally and research has shown that children's informal ideas are not completely individual. There are some interpretations to phenomena that are found among children of different cultures and countries. An example of this is when a log fire burn children state that matter is "burnt away" (Anderson, 1990).

To develop a constructivist perspective learners will need to beware of the diverse purposes of scientific knowledge, its boundaries and the bases on which it is build. The biggest challenge in the classroom is thus to make these epistemological characteristics a clear focus of conversation and therefore to socialize learners into a vital perception of science as a way of knowing (Driver *et al.,* 1994).

3.6.4 Molecular visualization in chemistry education

Images fundamental to chemistry can cause difficulties for novice chemistry students (Jones, Jordan & Stillings*,* 2005*)*. Chemistry today focuses increasingly on visual representations. Jones *et al.* (2005) states: "The knowledge and skills required to produce pedagogically effective visualization and to apply them appropriately for learning go beyond the knowledge of chemistry to encompass the findings of cognitive science and the principles of pedagogy." Images are used to communicate complex molecular interactions that are difficult to describe in words. For learners to learn from a model or visualization, they should focus on its relevant features and understand how they display new concepts.

Cognitive scientists divide the problems learners have understanding molecular visualizations into categories (Jones, Thomas, Berens & Johnston, 2005):

- Visual detail: spatial interactions in molecular visualizations can be difficult to understand .
- Complexity: interpreting molecular structure may be a complex process when the number and depth of the representations are large and the learners should compare different representations.

- Abstractness and conceptual depth: novice students should learn to understand the set of conventions used to embody phenomena not normally visible.

In the chemistry classroom the teacher should use a variety of instructional visualizations (Jones *et al.,* 2005). Curricula based on multiple representations have been found to provide teachers with a larger assortment of instructional and evaluation approaches than the traditional curricula (Cuocu & Curcio, 2001).

3.6.5 Conclusion

In this chapter a theoretical perspective for a chemistry research is discussed. In educational research a theoretical framework serves as a paradigm (Bodner, 2004). When one learns to do educational research two major challenges are faced;

- First one should try to understand some of the theoretical perspectives, and

- then the researcher should decide what framework will be appropriate to address the questions she wants to answer with this study.

In this study, constructivism is used a theoretical framework. In Figure 3.1 the other types of frameworks are included just to orientate constructivism in the context of all the different types of frameworks.

Constructivism is the foremost research program in science education (Driver *et al.*, 1994). The nucleus set of ideas of constructivism is widely established. Some educators deem these constructivist ideas to be trivial and that in itself is a sign of its current dominance. Although there is a set of principles it doesn't necessarily mean that it leads to good teaching. Driver *et al.* (1994) supports this principle with the following: "One cannot logically deduce a scientifically based pedagogy from a theory of learning."

One of the most important actions in a constructivist classroom is problem solving (Van Rooyen & de Beer, 2006). As they explore concepts they draw conclusions and as the investigation continues they revisit those conclusions. Lessons must be planned so that skills such as active listening, staying on task, individual responsibility as well as interdependence are developed.

Another important feature of a constructivist classroom is the fact that learners are often presented with a concept which is directly opposite to their life world experience. The educator should be aware of such alternative conceptions and address these issues effectively.

Van Rooyen and de Beer (2006) summarises constructivism in the classroom as follows:

- The best way to understand constructivism is to see actual examples, speak to others and try it in the classroom.

- When learner's question themselves and their learning strategies constantly, they become more efficient and reflective learners. The teacher fulfils the role of facilitator to facilitate the reflection process.

- Constructivist classrooms demand a highly motivated educator in terms of preparation and supervising teaching-learning activities.

- As learners gains knowledge they are starting to feel more empowered and this creates increasingly stronger abilities to integrate and internalize new information.

Chapter 4: **Models used in Natural Science literature to explain the particulate nature of matter and phase changes.**

4.1The particulate model of matter

Although the molecular model of matter is very familiar to chemistry teachers, they should not forget how difficult particle ideas are for students (Taber, 2002a). When explaining chemical phenomena, a student does not instinctively use appropriate particle ideas to do the explanation with. When the difficulties students have in learning the particle model are taking into account, this is logical. The word particle is used as a collective word for a wide variety of matter. For example, rice or dust specks are both referred to as particles of the substance. Research has shown that this confuses learners (Taber, 2002a).

A more difficult problem is what term to assign to the building blocks of matter. Teachers like the convenience of one term to describe all particles. Wightman, Green & Scott (1986) showed that this could lead to inaccurate use of language with the following classroom observation:

“the teacher conjured up an image of diffusion in solutions by referring to blue copper sulphate ‘atoms’ and colourless water ‘atoms’ wriggling slowly past each other at the junction of the two layers”

In general it is relatively accurate to refer to particles as molecules. It would for example be correct for sugar, water, salt etc. Problems arise because not all materials are molecular, for example sodium chloride which has no molecules (Taber, 2002a). To teach learners that everything is made out of molecules, can lead to problems with concepts they need to understand later on.

One can use the word atom because chemistry books often imply that everything consists of atoms. This can also become challenging (Taber, 2002a). A very few substances (*i.e.* the noble gases*)* are in reality composed of particles as such.

Taber (2002a) compiled a figure to explain the proposal of atoms as the building blocks of matter (Figure 4.1).

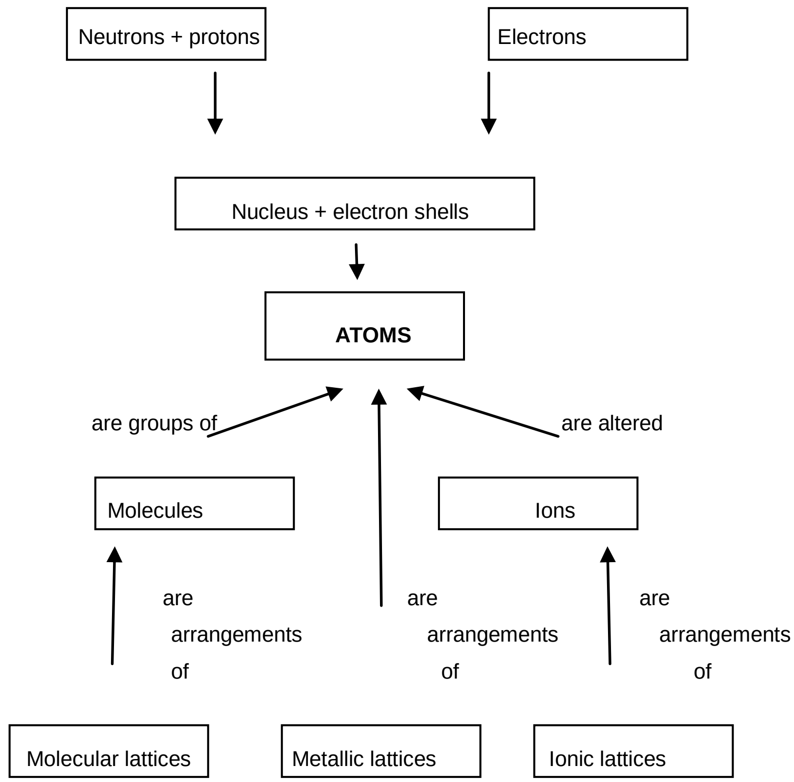


Figure 4.1 Seeing atoms as the building blocks of matter (Taber,2002a)

Another common saying during teaching is that:" a molecule of say water contains two atoms of hydrogen and one atom of oxygen". Although it can be seen as hair-splitting this leads to the misconception that electrons only belong to one atom and cannot be shared (Taber, 2002a).

Taber (2002a) proposed that on secondary level all matter should be labelled as consisting of protons, electrons and neutrons. This view is however not suitable for an introductory level learner. Before matter can be described in terms of arrangements of atomic cores and outer shell electrons, the simpler view, although sometimes inadequate, should first be conceptualised by students.

Taber (2002a) compiled a more scientific, although more complex, model of the building blocks of matter as shown in Figure 4.2:

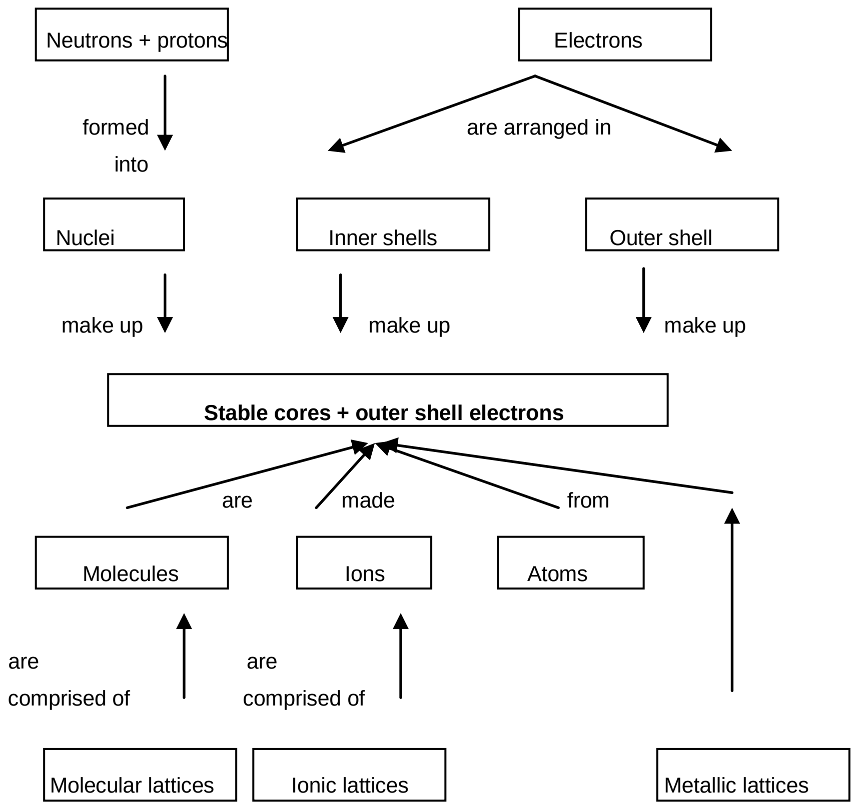


Figure 4.2: A more scientific, but more complex, model of the building blocks of matter (Taber,2002a)

Taber (2002a) proposed the use of the word "molecule" in the introductory courses but at the same time made it clear to learners that some materials are composed slightly different. It is imperative to emphasise to learners that they are taught an important but incomplete model which will evolve with the level of education.

4.2 Applying the molecular model

Research has shown that even when it seems that learners comprehend the "everything is made up of particles" concept, there can be serious flaws in their understanding of the concept (Taber, 2002a). Even when learners grasp this concept fully, they fail to understand the value of this model to science. The success of the particle model lies in the fact that "a large number of macroscopic properties of substances can be explained in terms of the conjectured properties of the systems of particles" (Taber, 2002a). An explanation is given in Fig 4.3 (Taber, 2002a).

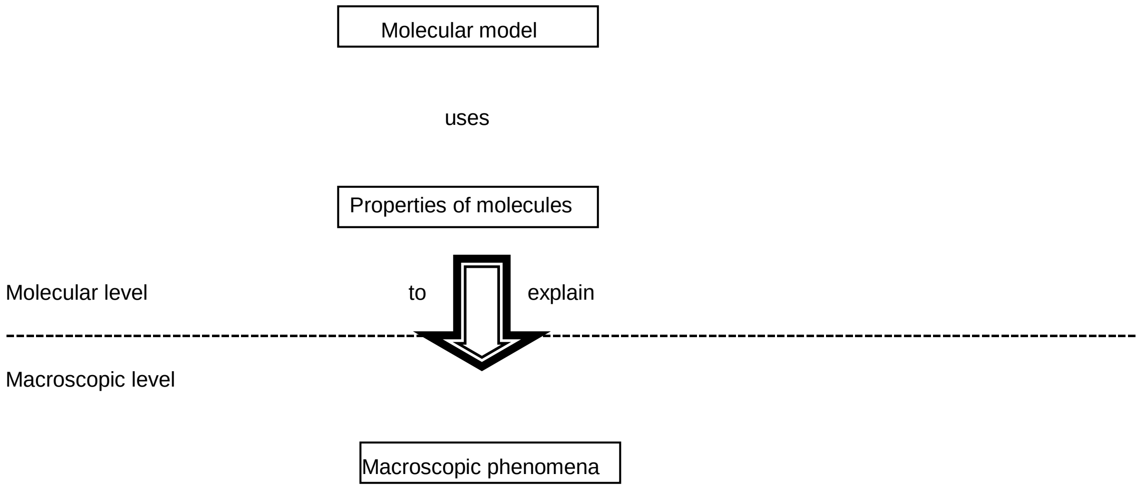


Figure 4.3 How science uses the molecular model (Taber,2002a)

Without appreciating this perspective, the underlying principle of the molecular model is lost. Research shows that learners frequently fail to understand this. Although the term "particle" is used when they describe macroscopic phenomena, they often shift the property to the molecular level as illustrated in the following figure from Taber (2002a) (Figure 4.4).

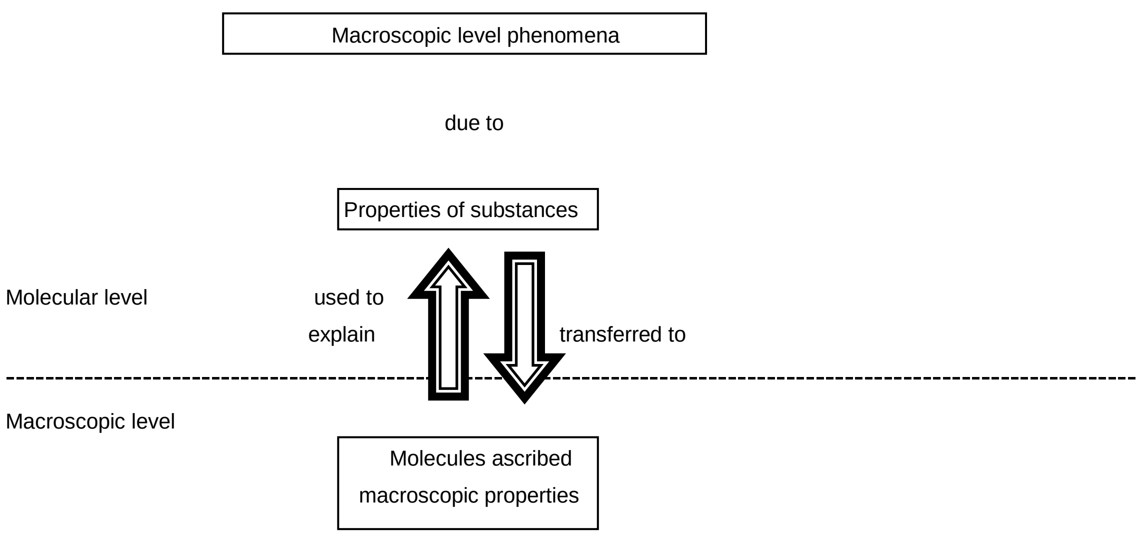


Figure 4.4: The way many students apply ideas about molecules Taber (2002a)

4.3 Phase changes

The distinction between physical and chemical change is sometimes problematic for teachers and learners. A change of state is a physical change. At the beginning of their chemistry education, learners comprehend that both ice and steam are forms of water even though the physical properties differ. This becomes clearer when viewed from the “molecular” level. Taber (2002a) argued that it is actually easier for students to judge whether a change is physical or not by using the particle model diagrams than looking at the process itself. Changes of state involve the breaking and forming of bonds and this explain why the physical appearance of the same molecules can differ so significantly.

4.4 Conservation of matter in chemistry

The conservation of mass is a very essential and fundamental idea in chemistry. Its application is yet again tied directly to the particle ideas (Taber, 2002a). The original mass of a fixed number of particles is the same as the sum of all the constituents it is divided into.

Two key instruction points during phase changes are:

- the same number of “particles” are present at the beginning and the end, and
- the total mass stays the same.

The particles are rearranged during phase changes but the total mass stays the same. In this sense we are not indicating the particles or molecules but the atomic constituents (Taber, 2002a).

4.5 Models of phase changes

4.5.1 In literature

Anderson (1990:28) has the following criticism regarding textbooks for chemistry:

- Atoms and molecules are seldom perceived in the hypothetic deductive sense.

- Students are required to learn facts about chemistry the same way they learn facts about the observable world

- Too many different atomic models are used

- No clear distinction is made between atoms, molecules and substances

A student who cannot distinguish between model and observation makes literal deductions, for example according to Linsje (1990) they may think that both molecules and ordinary water are present in a beaker of water.

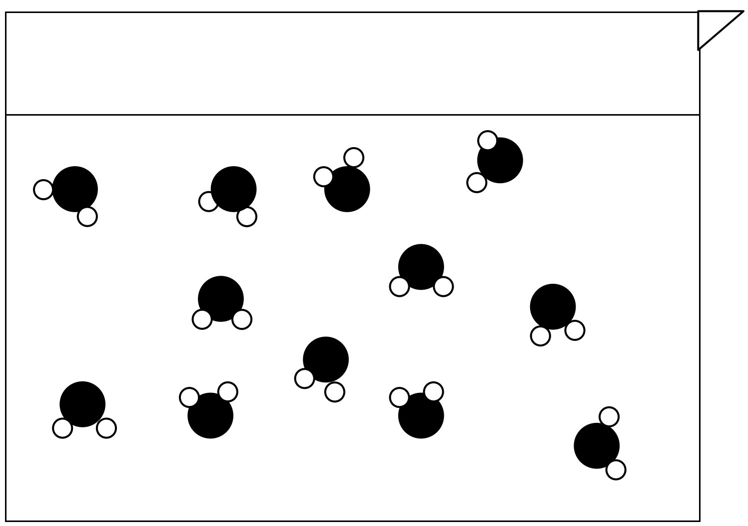
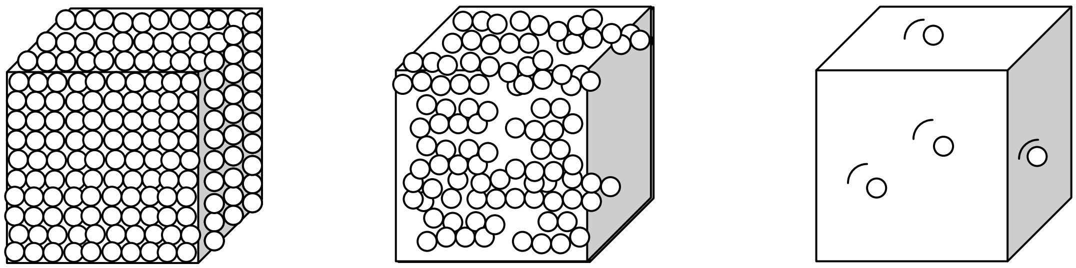


Figure 4.5: Molecules in a liquid. An example of a textbook illustration (Anderson, 1990:29).

4.5.2 In textbooks

With the above mentioned in mind, the researcher studied models of phase changes in different textbooks. The results are shown in Figures 4.6 to 4.25.

Figure 4.6: Jones *et al.,* 2005, p 39 – 40.



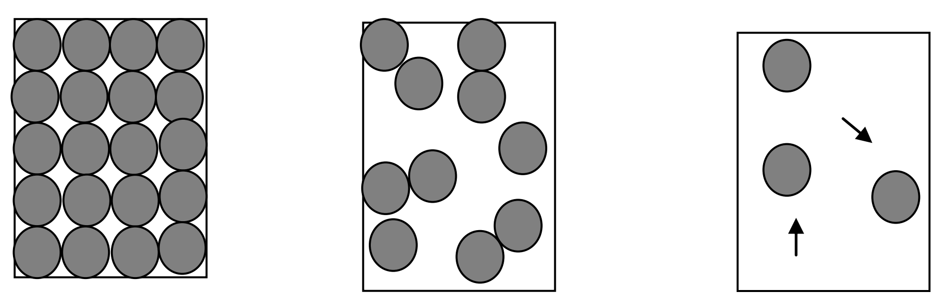
Solids have shape and their particles are vibrating all the time.

Liquids take the shape of the container in which they are placed. The particles move amongst one another.

A gas fills the container into which it's placed. The particles are far apart And move at high speed.

Although this model illustrates the movement of the particles, there is an enormous difference in the number of particles between the liquid and gas phases. Instead of conservation of matter, students may deduce that some of the particles disappear during phase changes from liquid to gas.

Figure 4.7: Van Aswegen & Van Aswegen, 2005, p 76.



Solid (molecules are packed Closely together and only Vibrate)

Liquid (molecules move freely)

Gas (molecules move around fast and are far apart)

The number of particles in this model also gradually decreases from the solid phase to the gas phase. Although the motion of the particles is described below the sketches, only the last sketch (for the gas) indicates motion with the aid of arrows.

Figure 4.8: Whitlock *et al.,* 2005, p 151 - 154

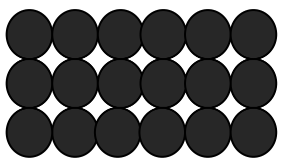


Figure 119: How particles are arranged in a solid

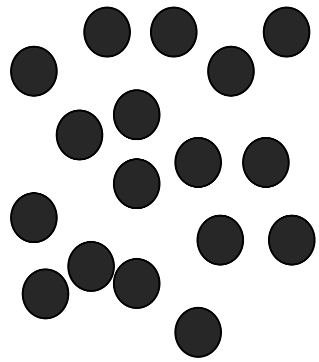


Figure 121: How are the particles arranged in a liquid?

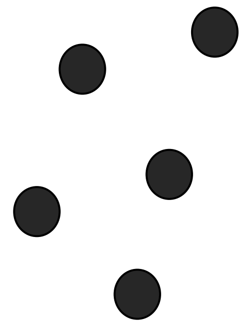
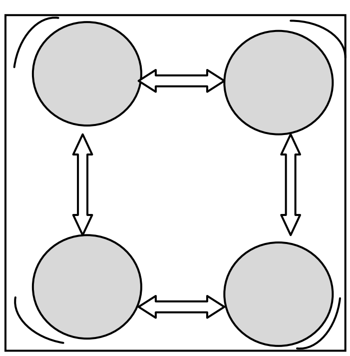


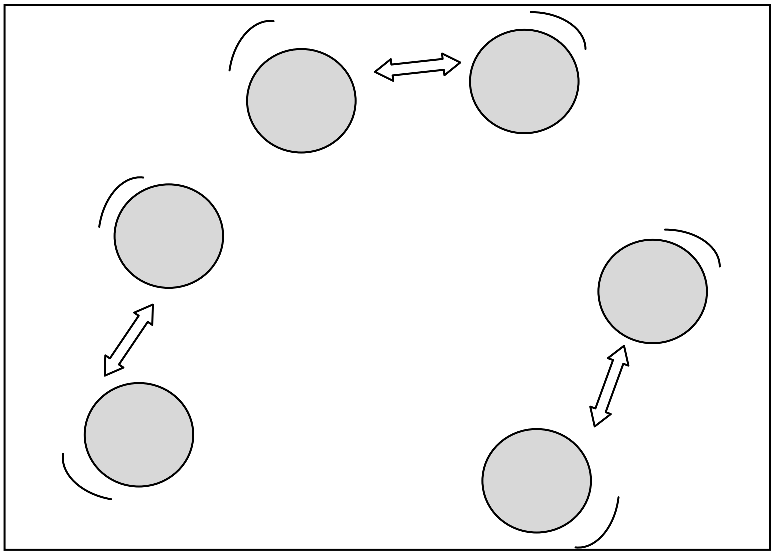
Figure 124: How are the particles arranged in a gas?

In this model the number of particles in the solid and liquid phases is the same but the gas phase has less than half the particles of the solid and liquid phases.

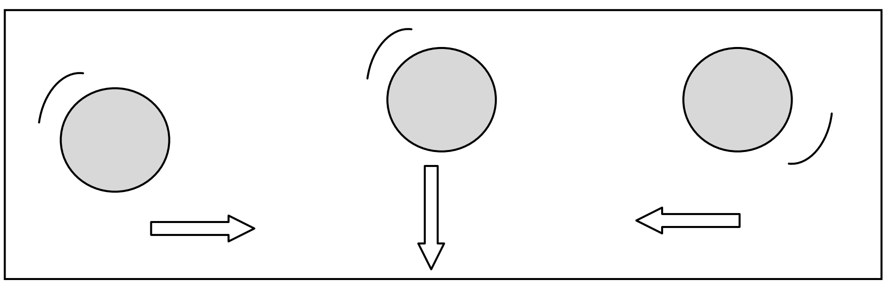
Figure 4.9: Tillery, 2005, p 87, figure 4.3.



A. In a solid, molecules vibrate around a fixed equilibrium position and are held in place by strong molecular forces.



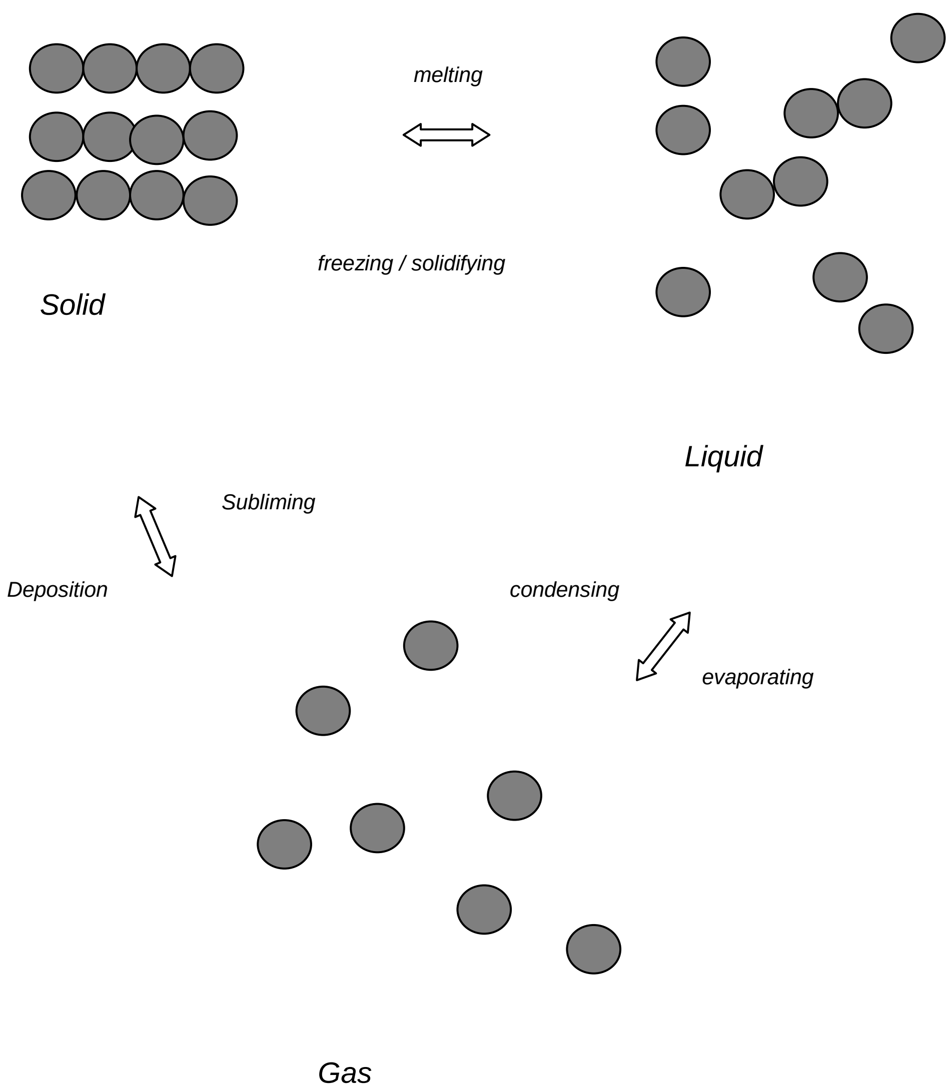
B. In a liquid, molecules can rotate and roll over each other because the molecular forces are not as strong.



C. In a gas, molecules move rapidly in random, free paths.

In this instance, the number of particles is nearly the same for all three phases. From the solid to the liquids phase one molecule is gained and from the liquid to the gas phase two particles are lost. This model also illustrates the motion of the molecules during the phase changes but never the less can lead to confusion about the number of molecules present in each phase. The use of the arrows and double arrows is confusing.

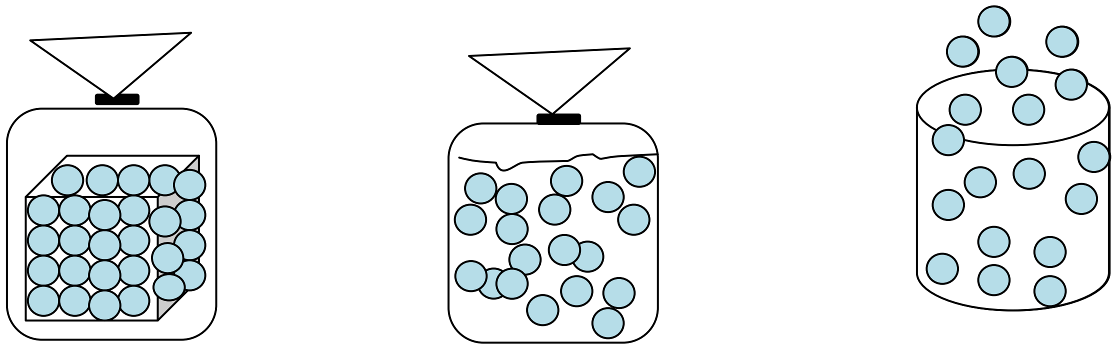
Figure 4.10: Cross & Bowden, 2009, p 136.



Particle theory showing how a substance can exist as a solid, liquid or gas

Again the principle of conservation of matter is not adhered to. From the solid to the liquid phase two particles are lost while the difference in particles between liquid and gas phase are three particles.

Figure 4.11: **Akoojee *et al.,* 2000, p 124.**



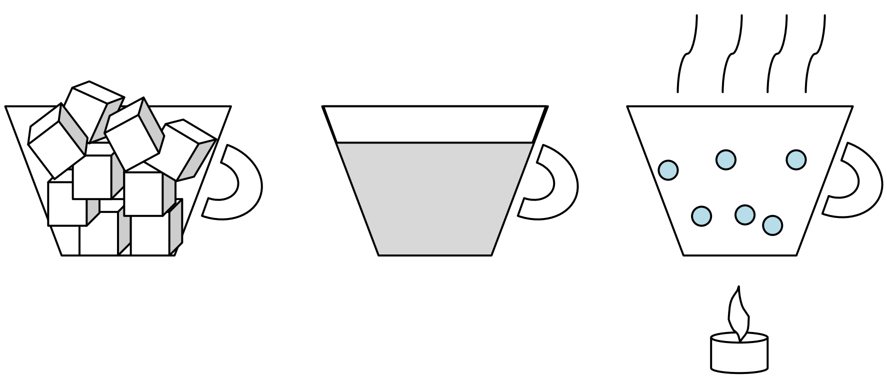
In ice, there are forces between the molecules that hold them together in a rigid pattern

In a liquid, the forces between the molecules are not so strong and the molecules can move freely

In water vapour, there are no forces holding the molecules together and the particles move around and bump into each other.

This model is probably less confusing to students as the number of particles does not differ so much. The ice cube melts and when the bag is opened, the gas particles escape.

Figure 4.12: Herman, 2004, p 56.

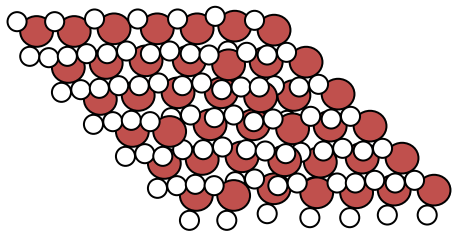


Solid *Liquid* *Gas*

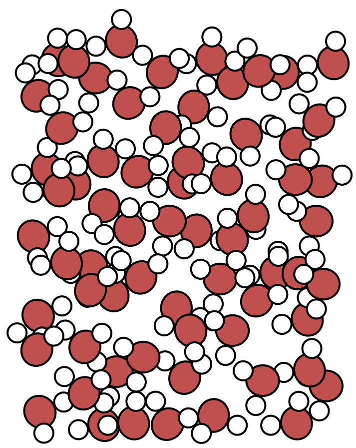
When the temperature of water is less than 0 °C it freezes. If the temperature of water rises above 100 °C it becomes a gas.

This is a less confusing model as the phase changes are portrayed in the macroscopic sense. The ice cubes change to water and the water changes to separate particles. However the particles of the ice and water are not shown. Therefore this model may cause the misconception that only a gas consists of particles.

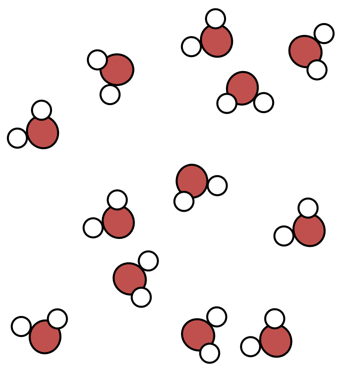
Figure 4.13: Trefil & Hazen, 2010, p205



Solid, molecules stay rigidly in place



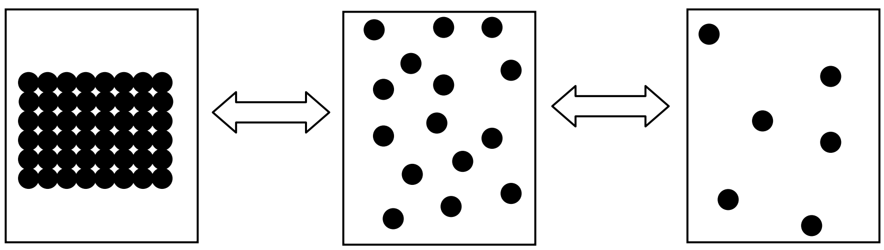
Liquid, molecules slide past one another



Gas, molecules widely spaced apart

This model concerns itself with movement and configuration. It does not use balls to represent particles as in the previous models, but illustrates the molecular configuration of the water molecules. However there is also a sizable difference between the number of particles between the liquid and gas phase.

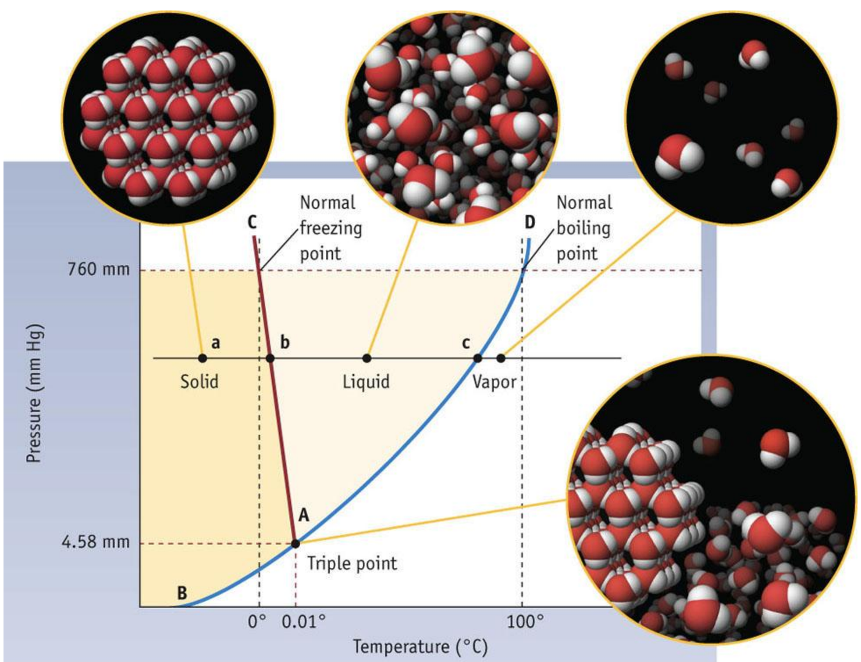
Figure 4.14: Botha *et al.,* 2000*,* p 172.



A representation of the phase change of water.

In this model the number of particles nearly halved during each phase change. Conservation of matter is not indicated.

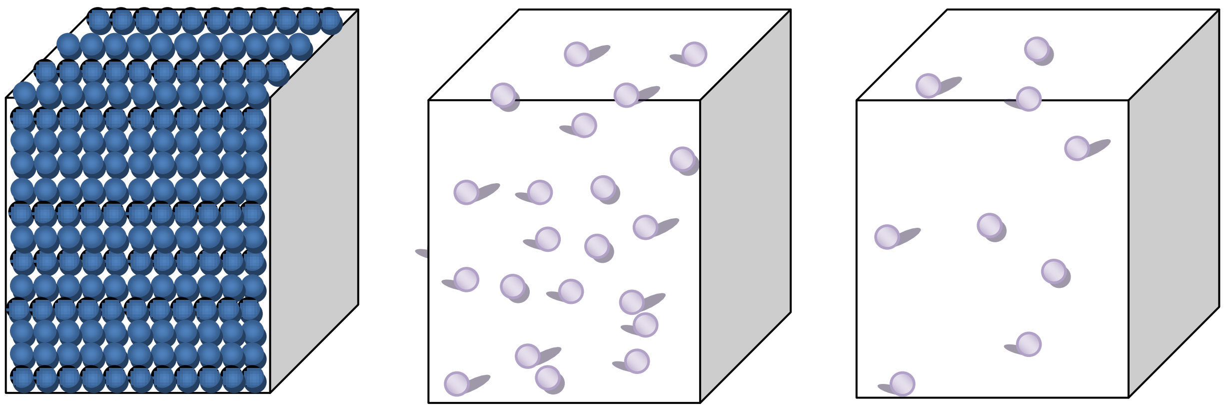
Figure 4.15: Kotz *et al.,* 2010, p 608



Although this model is a phase diagram it may also lead to some degree of confusion as to the disappearance of particles.

Figure 4.16: Mallison *et al.,* 1991, p 203.

Particle motion

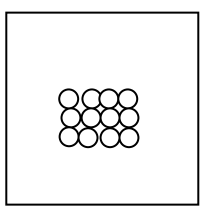


Solid *Liquid* *Gas*

Although this models also illustrate the movement of the particles during phase changes, the particles also becomes fewer during the phase change from solid to liquid to gas. The use of shadows in the sketches of the liquid and gas phase is not clear.

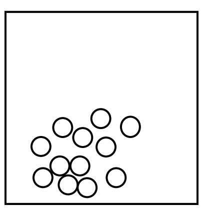
Figure 4.17: Gillespie & Gillespie, 2007, p 88.(*Typical arrangements of particles in the three states of matter)*

SOLID



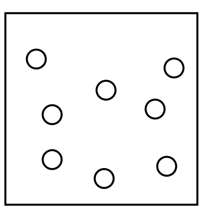
particles bonded together
particles can only vibrate
particles in a fixed arrangement
particles are very close

LIQUID



particles bonded, but weaker than solids
particles can move around each other
particles arranged randomly
particles are very close

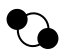
GAS

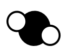


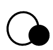
no bonding between particles
particles can move anywhere
particles arranged randomly
particles are far apart

This is a very clear and understandable model except for the difference between the number of particles in the liquid and gas phases. In the gas phase there are four particles, nearly half, of that in the liquid phase.

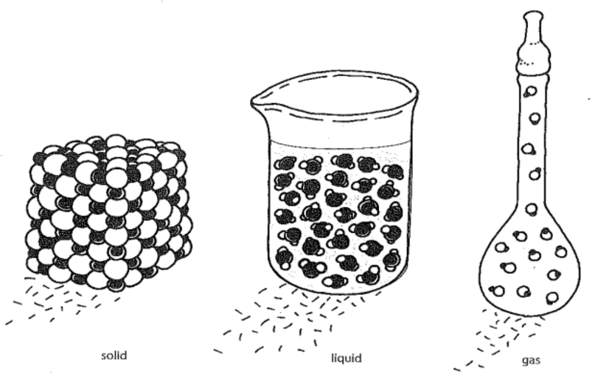
Figure 4.18 Young *et al.* (2005), p 163 presented a model where the number of particles also differs from one phase to another. What makes this model also confusing is the use of differently composed molecules:

Solid: 

Liquid: 

Gas: 

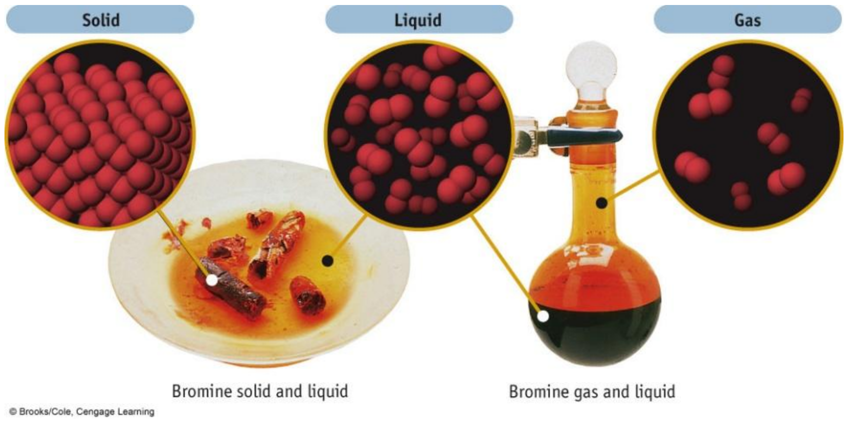
This type of model can lead to a lot of confusion. The student can deduct that not only does the molecules disappear during phase change, the composition of the molecules also change.



The arrangement of molecules in different states

Figure 4.18: Young *et al.* (2005), p 163

Fig. 4.19: Kotz *et al.,* 2010, p 8



This figure illustrates what a sample of the specific phase would consist of. The distribution of the particles is illustrated clearly.

Figure 4.20: Young *et al.* (2010) p 296 & 297 used the following three figures to explain the different states of matter. The number of particles in each figure differs drastically. Only the gas particles seem to move.

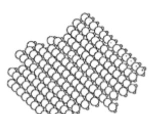


Fig. 44.1 In a solid, the particles are closely packed together and vibrate around fixed sites.

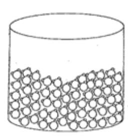


Fig. 44.2 In a liquid, the particles are in constant random motion, but are quite closely packed together.

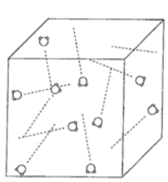
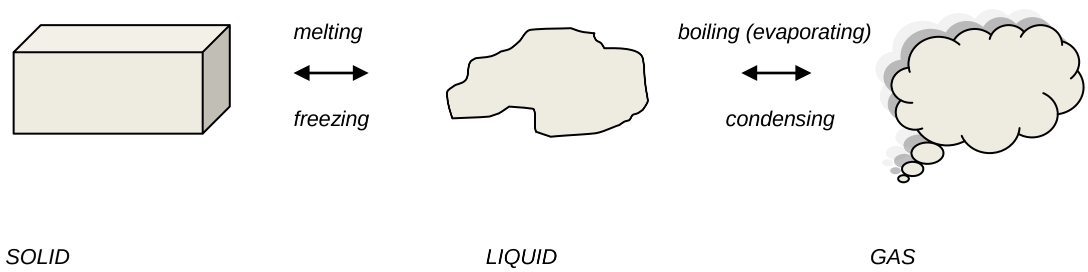


Fig. 44.3 In a gas, the particles are in constant random motion through mostly empty space.

Figure 4.21: Gillespie & Gillespie (2007) p 90 presented another model of phase changes that avoids the use of particles altogether. This is an excellent model for use in the primary school when phase changes are explained (Gillespie & Gillespie, 2007) without reference to the particle model.



Changes of states

Figure 4.22: Taber (2002b) p23

In this example the difference in particles between the phases is not so drastic although the number of particles differs.

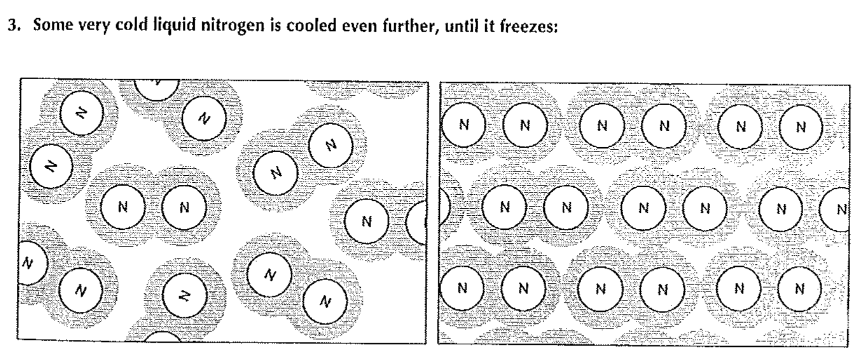
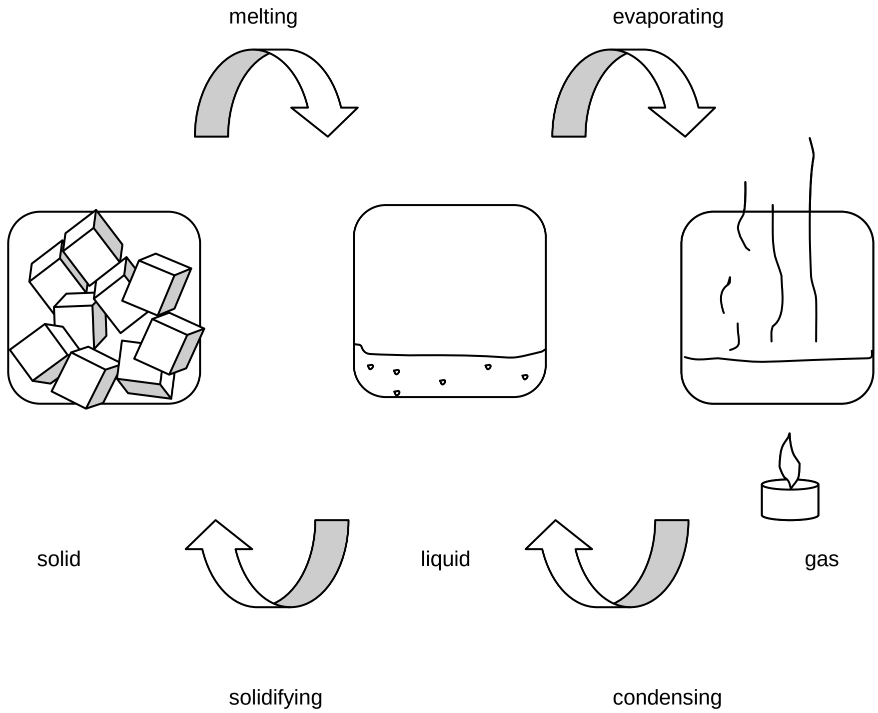


Figure 4.23: Young *et al.* (2005), p 162 presents a model similar to that of Gillespie and Gillespie (2007) without referring to particles within the substances. It only focuses on the macroscopic properties and the processes of phase changes.



All matter takes the form of either solid, liquid or gas

Figure 4.24: Rutledge (2010), p 39 - 40 proposed a model where children act out water in the three different phases. Because the number of particles (children) stays the same, it is an excellent model to use when phase changes are explained to young children.

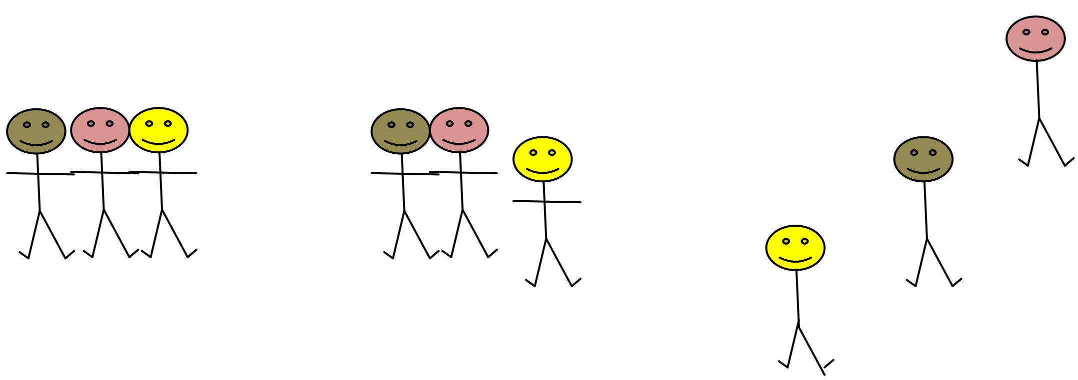
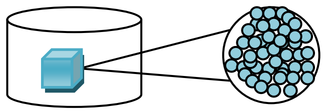
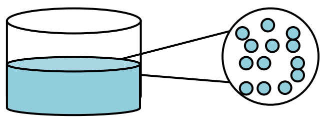
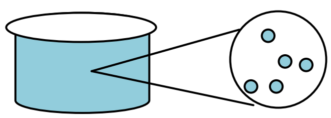


Diagram of children acting out water in its ***solid form as ice***

Diagram of children acting out water in its ***liquid form***

Diagram of children acting out water in its ***gaseous form as*** *water vapour*

Figure 4.25: Broster *et al.* (2011), p 30

State	Illustration	Characteristics of state
Solid		• Solid substances have definite shape and volume • Substances will resist forces that try and change the volume or the shape
Liquid		• Liquid substances have definite volume, but can change shape • Liquids flow and take the shape of the container
Gas		• Gaseous substances have no definitive volume or shape • Gasses expand to fill container

The above mentioned model can be used to explain the phases of matter without reinforcing or introducing harmful misconceptions (Rutledge, 2010). It connects macroscopic events with microscopic models. The only problem is that matter is not conserved.

4.6 Conclusion

As illustrated, many textbooks make use of a model that show that particles moves away from each other during phase changes. The fact that the model indicates fewer molecules, in order to illustrate the increase in distance between particles in different phases, can lead students to make the literal deduction that particles disappear[8] during phase changes. It seems as if the textbook authors do not consider it important to demonstrate conservation of matter, although it is an essential and fundamental idea in chemistry (Taber, 2000).

[8] As investigated in questionnaire: Annexure A

Justi and Gilbert (2002) hold the opinion that chemistry textbooks have a great influence on chemistry education. The analysis of textbooks is of critical importance because they are used at all educational levels. There is no mention of the meaning of the word model or the nature of models and modelling. According to Justi and Gilbert (2002) there are two angles to the role of chemistry textbooks in the teaching and learning of models and modelling: “the way that chemical models are introduced in them and the teaching models that they present.”

Inaccuracies in textbook models can be expected to enhance learning problems in chemistry. The empirical study reported in the following chapters investigated students’ mental models and their understanding of basic concepts related to phase changes.

Chapter 5: Research Methodology

This chapter gives an overview of the quantitative as well as the qualitative parts of the empirical study done by the researcher as part of this dissertation. The objectives of the study were to investigate the state of first year natural science education students' mental models regarding phase changes in chemistry and what prior knowledge and understanding they have of models and representations of basic chemistry concepts such as atoms, ions and molecules.

5.1Quantitative Study

5.1.1 Population

The population for this study consists of two first year groups, namely SNSE 111 and PHSE111 students in the Faculty of Educational Sciences of the North West University Potchefstroom Campus. Two separate years, 2009 and 2011 first year students completed the questionnaire. The module SNSE 111 introduces the first year students to one of the eight learning areas that are presented in the Intermediate and Senior Phases, namely Matter and Materials. This is a compulsory module of the B.Ed. programme (Intermediate, Senior and FET phases). SNSE 111 gives students the opportunity to get to know more about the subject content of the Learning Area Natural Sciences as well as the teaching strategies that can be successfully used in the Natural Science classroom. Furthermore, at the end of this module, the students should be better equipped to integrate other learning areas with Natural Sciences in the context of OBE. Most of these students only had Natural Science up to grade 9. A few of the students had Physical Science up to grade 12. The questionnaire was completed by the students before they were lectured about the particle nature of matter. One must keep in mind that this group were last exposed to natural science in grade 9 between three and four years ago.

The first year PHSE 111[9] students are a small group of students (12) who also completed the questionnaire[10]. These students completed Physical Science Gr. 12 with an average percentage of 50% or more. This questionnaire was also given to these students to compare their knowledge of the concepts with those of students that only had Natural Science up to grade 9. This group completed grade 12 Physical Science the previous year.

[9] First year module in Chemistry for Education.
[10] Annexure A contains the questionnaire.

5.1.2 Questionnaire

A questionnaire was compiled to test students' basic knowledge of atoms, ions and molecules as well as their mental models of certain concepts. In order to test student's mental models the first question regarding each concept (atoms, ions molecules) was a request to draw their own personal mental model. To be able to test the student's verbalisation of the specific concept, the student had to explain his/her understanding of the concept in words.

The questionnaire also included a model from a current grade 8 textbook (Van Aswegen & Van Aswegen, 2005, p 76.). This model depicts the number of particles becoming less and less during each phase change. This model was included to further explore the findings[11] of Linsje (1990).

To test the direct association between microscopic models and microscopic events questions were included that directly tested the association between how the macroscopic molecules look, e.g. colour, and the student's perception of the microscopic compilation.

The questionnaires were completed under supervision of the researcher and no time limits applied.

The questionnaire[12] consisted of 41 items grouped as follows:

- Nine (9) were the students' own mental models of atoms, ions and molecules they had to draw. These questions were included to see what type, if any, models the students had.

- 14 were open ended questions where they had to explain the concepts atoms, ions and molecules as well as explaining certain answers they gave to yes/no type of questions. These questions were included to determine if students could verbalize the models of the concepts tested in this questionnaire. A correct model may or may not be verbalized correctly by the students.

- 18 questions were yes/no type of questions. These questions were included to test students' knowledge and perceptions about the conservation of matter during phase changes.

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[11] A student who cannot distinguish between model and observation makes literal deductions from models.
[12] Annexure A contains the questionnaire.

5.1.3 Processing of questionnaires

All the students present on the day the researcher administered the questionnaires, completed it. The statistical analysis was done by Me Wilma Breytenbach of the NWU Statistical Consultation Service. The analysis of the open ended questions as well as the mental models was done by the researcher.

5.2 Qualitative study

5.2.1 Participants

The participants in the qualitative part of this study were a purposive sample. Six students were selected on grounds of certain answers in the questionnaire: Four with misconceptions regarding the disappearing of particles during phase changes and two without misconceptions were selected to do the interviews with. Due to the students class schedules and the analysis of the statistical data the interviews were done after they were lectured about the particulate nature of matter and phase changes.

5.2.2 The nature of qualitative data

Qualitative data is in the form of words and images (Miles & Huberman, 1994:10). These words are based on observations, interviews or documentation. The researcher's ability to analyse the data has a certain effect on the research done.

Miles and Huberman (1994) proposed three steps to be followed by the researcher during qualitative data analysis:

- Reducing data by selecting, simplification, abstracting and transforming the transcribed data.

- The exposition of the data which demonstrate the expanded text in the form of matrixes, graphs and charts.

- Conclusions and verification, where the conclusion becomes more and more evident and clear as the analysis progresses.

During the data collection process, there already occur data analysing to some extent (Merriam, 1998). It is a progressive cyclic process subject to a saturation criterion; this is when no new insights or ideas emerge any more. Merriam recommended that the researcher probe deeper than the obvious summary of the data and thus keeps in mind processes, functions, tensions and contradictions.

5.2.3 Interviews

Interviews were done with the six selected students. An interview is a two-way communication between the researcher and the participant in which the researcher poses questions to the student about the student's opinions, ideas and believes regarding certain concepts (Merriam, 1998). The aim of interviews is to acquire rich descriptive data from the participant to enable the researcher to understand the participant's construction of knowledge (Nieuwenhuis, 2007a:87). In order for an interview to be successful the interviewee should be willing to participate. Interviews can be divided into three categories:

- open-ended interviews: mostly in the form of a conversation,
- semi-structured interviews: structured around a few predetermined questions with the option to be explored further if necessary, and
- structured interviews: questions are determined in detail beforehand (Nieuwenhuis, 2007a:87).

According to Creswell (2003) interviews as a qualitative means of data gathering, has the following advantages:

- It is useful when participants cannot be directly observed.
- Participants can provide historic information.
- The researcher has control over the direction in which the interview heads.

Creswell (2003) highlights the following disadvantages of interviews:

- Filtered and indirect information is supplied by the interviewee.
- Information is supplied in a designated place and not in the natural setting.

- The presence of the interviewer can cloud the answers of the interviewee.

- Not all people are well-spoken and can give insightful answers during an interview.

During the semi-structured interviews of this study the questions posed to the students were prepared beforehand[13]. The interviews were recorded[14] with a digital recorder and were done by the researcher herself.

The results obtained with the aid of the questionnaire and the interviews are given and discussed in Chapter 6.

[13] Interview questions in Annexure B
[14] Transcriptions of interviews in Annexure C

Chapter 6: Reporting and analysing results

In this chapter the results of this study is firstly reported and then the students' responses to questions in the questionnaire analysed and discussed. The information gathered from the questionnaires is summarized in tables where after each question of the questionnaire is discussed. In Table 6.1 the biographical information is summarised and then a summary of all the information from the questionnaires are tabled. The separate tables for the different groups[15] are listed in Annexure C.

6.1 Biographical information of participants

In table 6.1 the biographical information of the participants are listed. This includes the following:

- The sex of the participants
- Up to which grade the participant took Physical Science as a school subject. This implies that some students, who did not take Physical Science as a subject, only had Natural Science up to grade 9.
- Information about which year the students matriculated.

The detailed tables are listed in Annexure C.

Table 6.1: Sex of participants

Response	**SNSE 2009 Percentage**	**SNSE 2011 Percentage**	**PHSE 2011 Percentage**
Male	17	26	29
Female	76	67	71
Not responded	7	7	0
Total	100	100	100

[15] PHSE 111, SNSE 2009 and SNSE 2011

Table 6.2: Physical Science as subject to school grade

Grade	SNSE 2009	SNSE 2011	PHSE 2011
9	61	73	0
10	11	9	0
11	7	1	0
12	15	6	100
Not responded	6	11	0
Total	100	100	100

Table 6.3: School year matric

Year	SNSE 2009	SNSE 2011	PHSE 2011
1998 – 2006	10	9	0
2007	28	7	0
2008	54	4	7
2009	4	23	0
2010	0	57	93
Not responding	4	0	0
Total	100	100	100

6.2 Discussion of biographical information of participants

In Table 6.1 the summary of the information reveals that 24% of the participants were male and 71% of the participants were female. 5% of the participants did not respond to the question. These percentages are an average of all three groups[16].

When summarised in Table 6.2 the average of the students that took Physical Science up to grade 12 are as follows: 40% of the students took Physical Science up to grade 12. 45% of the participants had only Natural Science as a subject till die end of grade 9. 7% of the students took Physical Science up to grade 10. 3% of the students took Physical Science up to grade 11.

[16]SNSE 111(2009), SNSE 111(2011) and PHSE 111(2011)

From Table 6.3 the average percentage of students finished school (matric) in the corresponding years is:

- 1998 - 2006: 6.3%
- 2007: 11.7%
- 2008: 21.7%
- 2009: 9.0%
- 2010: 51.3%

This information was collected to see how long ago these students were confronted with any kind of Natural Science information. The bulk of the students (93.7%) left school less than five years ago and their knowledge should not be out dated.

6.3 Results of the empirical questions in questionnaire

The response of all three groups[17] is summarised in Table 6.4. The answers to the empirical questions were summarised from Tables 4-6 in Annexure C. The answers to the questions listed in Table 6.4 were statistically analysed by Me Wilma Breytenbach from the North West University**.** The percentage of correct responses was significantly more from PHSE 111 students. This is contributed to the higher level of exposure that these students had to the application of the particulate nature of matter[18] and the phase changes[19] in general.

TABLE 6.4: Summary of empirical data from questionnaires[20]

		% Students		
Question	**Analysis**	**SNSE 2009**	**SNSE 2011**	**PHSE 111**
4.7.1 Are there spaces between the particles of a solid?	Yes No No Answer	17 74 9	11 81 7	29 71 0

[17]SNSE 111(2009), SNSE 111(2011) and PHSE 111(2011)
[18] Paragraph 4.2
[19] Paragraph 4.3
[20]Ouestionnaires were completed by the students and send to Me Breytenbach for analyzing.

4.7.3 Are there spaces between the particles of a liquid?	Yes	80	74	100
	No	17	13	0
	No Answer	14	13	0
4.7.5 Are there spaces between the particles of a gas?	Yes	78	73	100
	No	7	17	0
	No answer	15	10	0
4.8.1 When a solid changes to a liquid, the spaces between the particles become	Bigger	87	80	100
	Smaller	9	7	0
	Stay the same	2	4	0
	No Answer	2	9	0
4.8.2 When a solid changes to a liquid, the movement of the particles becomes	Faster	74	70	86
	Slower	19	17	7
	Stays the same	6	4	7
	No Answer	2	9	0
4.8.3 When a solid changes to a liquid, the force between the particles becomes	Bigger	24	26	7
	Smaller	50	56	93
	Stays the same	19	7	0
	No answer	7	11	0
4.8.4 When a solid changes to a liquid, does the particles' shape change?	Yes	20	27	7
	No	74	66	93
	No Answer	6	7	0
4.8.6 When a solid changes to a liquid, the number of particles becomes	Bigger	13	13	0
	Smaller	43	53	14
	Stays the same	39	24	86
	No Answer	6	10	0
4.9.1 When a liquid changes into a gas, the spaces between the particles become	Bigger	91	77	100
	Smaller	6	14	0
	Stay the same	2	0	0
	No Answer	2	9	0
4.9.2 When a liquid changes into a gas, the movement of the particles becomes	Faster	72	54	79
	Slower	24	36	14
	Stays the same	0	1	7
	No Answer	4	9	0

4.9.3 When a liquid changes into a gas, the force between the particles becomes	Bigger Smaller Stays the same No answer	37 48 9 6	30 59 11 0	0 93 7 0
4.9.4 When a liquid changes into a gas, does the particles' shape change?	Yes No No Answer	26 69 6	21 69 10	14 86 0
4.9.6 When a liquid changes into a gas, the number of particles becomes	Bigger Smaller Stays the same No answer	15 46 31 7	16 57 19 9	7 14 79 0
5.1.1 A table salt crystal consists of one molecule	Yes No No Answer	22 69 9	34 54 11	43 57 0
5.1.2 The NaCl molecule is white like the crystal	Yes No No Answer	67 24 9	76 14 10	57 43 0
5.1.3 When a salt crystal dissolves in water, the molecule becomes invisible	Yes No No Answer	76 17 7	79 11 10	71 29 0
5.2.1 The colour of a sulphur atom is yellow	Yes No No Answer	69 24 7	67 23 10	50 50 0
5.2.2 Sulphur powder (S_8) consists of 8 sulphur atoms	Yes No No answer	69 20 11	71 19 10	79 21 0

6.4 Results of qualitative questions in questionnaire

These questions were questions where students described certain concepts with the help of mental models[21]. The students had to verbalise their own models in follow-up questions. The students had a significant problem verbalising a concept even if they had a scientifically correct mental model of the concept**.** The responses were categorized as scientifically correct, wrong or other ideas. The other ideas were mainly unanswered questions.

TABLE 6.5: Summary of responses

		% students		
Question	**Analysis**	**SNSE 2009**	**SNSE 2011**	**PHSE 2011**
1.1 Draw a picture of an atom as seen in your mind	Scientifically correct	30	6	50
	Wrong	44	69	50
	Other	26	26	0
1.2 Explain the word atom in your own words	Scientifically correct	31	4	50
	Wrong	44	67	50
	Other	24	29	0
1.3 Give an example of an atom	Scientifically correct	28	16	64
	Wrong	37	31	36
	Other	25	53	0

[21] Paragraph 2.4.1 Mental models

2.1 Draw a picture of ion as seen in your mind	Scientifically correct Wrong Other	2 26 72	4 13 83	50 50 0
2.2 Explain the word ion in your own words	Scientifically correct Wrong Other	7 24 69	4 13 83	29 71 0
2.3 Give an example of an ion	Scientifically correct Wrong Other	7 35 57	7 7 86	50 50 0
3.1 Draw a picture of a molecule as seen in your mind	Scientifically correct Wrong Other	35 35 30	16 60 24	57 43 0
3.2 Explain the word molecule in your own words	Scientifically correct Wrong Other	11 63 26	7 56 37	71 29 0
3.3 Give an example of a molecule	Scientifically correct Wrong Other	44 22 33	33 20 47	86 14 0
4.1 Explain the word "solid" in your own words	Scientifically correct Wrong Other	13 78 9	10 77 13	36 64 0
4.2 Give an example of a solid	Scientifically correct Wrong Other	87 2 11	86 1 13	100 0 0

4.3 Explain the word "liquid" in your own words	Scientifically correct Wrong Other	9 83 7	9 87 4	36 67 0
4.4 Give an example of a liquid	Scientifically correct Wrong Other	94 6 0	96 1 3	100 0 0
4.5 Explain the word "gas" in your own words	Scientifically correct Wrong Other	13 67 20	11 74 14	43 57 0
4.6 Give an example of a gas	Scientifically correct Wrong Other	70 11 19	66 16 19	100 0 0
4.7.2 Draw a model of a solid's particles	Scientifically correct Wrong Other	65 20 15	60 27 13	100 0 0
4.7.4 Draw a model of a liquid's particles	Scientifically correct Wrong Other	65 20 15	66 24 10	100 0 0
4.7.6 Draw a model of a gas's particles	Scientifically correct Wrong Other	56 24 20	73 23 4	100 0 0

4.8.5 When a solid changes into a liquid: If your answer is yes, explain how the particles changed	Scientifically correct Wrong Other	78 17 6	64 24 11	93 7 0
4.9.5 When a liquid changes into a gas: If your answer is yes, explain how the particles changed	Scientifically correct Wrong Other	63 20 17	79 10 11	93 7 0
5.1.4 Draw your own model of a NaCl-molecule	Scientifically correct Wrong Other	12 44 44	10 36 54	64 36 0
5.1.5 Draw your own model of a NaCl-crystal	Scientifically correct Wrong Other	4 41 56	0 36 64	36 64 0
5.2.3 Draw your own model of a sulphur–molecule	Scientifically correct Wrong Other	4 43 53	3 31 66	7 93 0

A general overview of the table indicates a clear tendency by the two SNSE 111-groups to rather ignore a question than to answer it. The PHSE 111 students answered all the questions although some gave wrong answers. The part of the questionnaire[22] dealing with the NaCl-crystal en Sulphur-molecule was especially difficult for the SNSE-groups to answer. In general, the questions dealing with the verbalisation of concepts were answered very poorly. Students answered the yes-no questions summarised in Table 6.4 more readily than question where they had to do the explaining verbally in their own words.

[22]Annexure A question 5

6.5 Discussion of students' responses

In this section a discussion of each question in the questionnaire[23] will be given. The discussions are based on the answers given by the students summarized in Table 6.5.

1.1 Draw a picture of an atom as seen in your mind

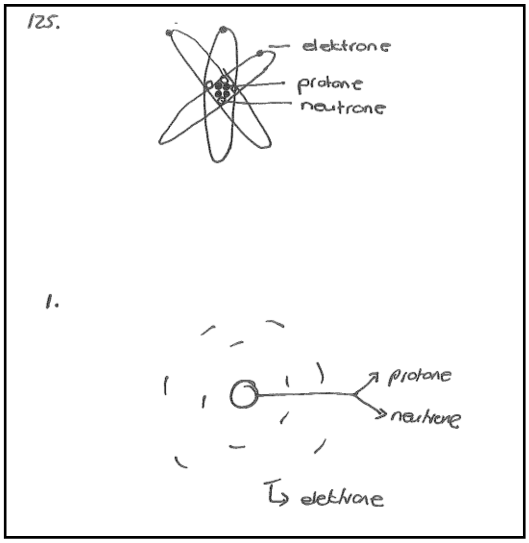
SNSE 2009	**SNSE 2011**	**PHSE 2011**
30% of the students had scientifically correct mental models. 44% had incorrect mental models and 16% of the students didn't attempt to answer the questions.	6% of the students had a scientifically correct mental model of the atom. 69% had an incorrect mental model of the atom. 26% of the students didn't attempt to answer the question.	50% of the students had a correct mental model of the atom as the other half had a wrong mental model. All the students made an attempt to answer the question.

As both grade 10 and grade 11 syllabi put emphasis on the structure of the atom, it is understandable that the SNSE 111 students[24] did not have the same exposure to atomic models than the PHSE 111-group[25]. Although the terms atom, ion and molecule is covered in gr. 8 and 9, it is in a more narrow-minded type of way whilst the detailed atomic models are covered in gr. 10. Some of the 2009 SNSE 111students (30%) had a scientifically correct mental model whereas the 2011 SNSE group (6%) had a very low count of the correct mental model for the atom. The 2011 PHSE 111 group has a 50% grasp of the correct mental model and this is very poor for students who took physical science up to grade 12.

The correct models can be categorized as mainly that of Bohr and a few models looking like that of Thomson. The incorrect models were a mixture of circles, lots of dots grouped together and some amorphous structures resembling plant and animal cell models. As most of the grade 8 and 9 textbooks use a circle to represent a particle, whether it is an atom, molecule or ion, it may explain why most students have a circle as a mental model of the atom.

[23] Annexure A
[24] 5.1.1 Population
[25] 5.1.1 Population

Scanned examples of students' mental models of atoms: (questionnaires 1 and 125)



1.2 Explain the word atom in your own words.

SNSE 2009	SNSE 2011	PHSE 2011
31% of the responses were scientifically correct. 44% had a wrong answer and 24% did not attempt to answer the question.	4% of the responses were scientifically correct. 67% of the answers were wrong. 29% did not make an attempt to answer the question.	50% of the answers were scientifically correct and 50% answered wrong. All the students made an attempt to answer the question.

The correct mental models of atoms and their respective verbal explanations were analysed. From these results it seems that those who can visualize an atom can verbalize it correctly. The fact that textbooks use the word smallest particle, this feature occurred a lot although not in the correct context. These findings concur with those of Mongwaketse (2006) which indicated that there is a serious problem with regard to the concept of atoms and the problem is related to their inability to visualize a mental model of the atom.

1.3 Give an example of an atom.

SNSE 2009	SNSE 2011	PHSE 2011
28% of the students could give an example of an atom. 37% gave wrong answers whereas 25% did not attempt to answer the question.	16% of the students answered correctly while 31% gave wrong answers. 53% did not answer at all.	64% of the students gave scientifically correct answers and 36% gave wrong answers. All the students answered this question.

As this question shows the relationship between microscopic atoms and the macroscopic world, it was a test of this relationship. The relationship is perceived very poor when considering these results. Most of the correct answers used symbols of elements from the periodic table and most of the wrong answers had something to do with the atomic bomb and explosives like dynamite.

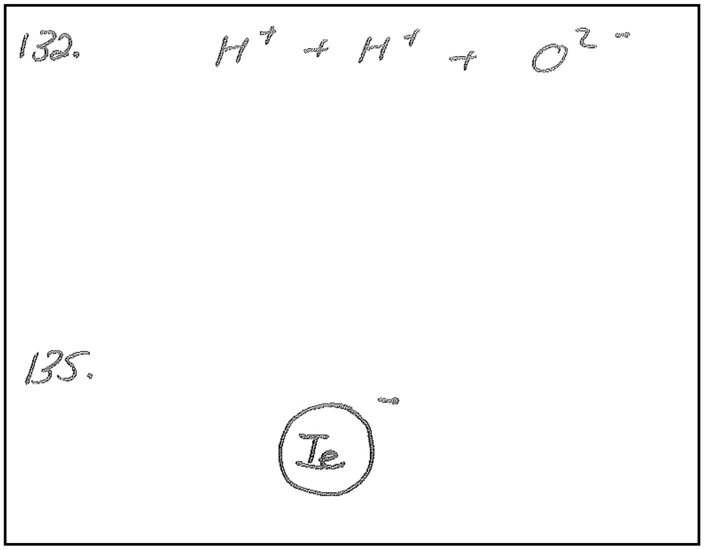
2.1 Draw a picture of an ion as seen in your mind.

SNSE 2009	SNSE 2011	PHSE 2011
Only 2% had a scientifically correct mental model of the ion. 26% had wrong mental models and 72% of the students didn't attempt to answer this question.	4% of the students had a scientifically correct mental model. 13% had the wrong model and 83% did not attempt to answer this question.	50% had scientifically correct mental models of an ion and the other 50% had wrong mental models. All the students answered this question.

This result shows that only a few students had any concept of what an ion is. A few of the wrong answers had some indication of charges. Although the ion is mentioned in grade 8 and 9 syllabi, no clear definition or model of this concept is given. The results of the PHSE 111 group are better but for learners who passed grade 12 with a minimum of 50%[26], this is very poor.

[26] 5.1.1 Population

Scanned examples of students' mental models of ions: (questionnaires 132 and 135)



2.2 Explain the word ion in your own words.

SNSE 2009	SNSE 2011	PHSE 2011
7% of the students could verbalise the concept of the ion scientifically correct. 24% gave wrong answers and 69% did not answer this question.	4% gave a scientifically correct answer. 13% gave wrong answers and 83% did not attempt to answer this question.	29% could verbalise this concept scientifically correct whereas 71% answered wrong. All students answered this question.

About 2% answers indicated iron metal as an ion. Less than 1% of the students responded with answers that include the gain or loss of electrons. The responses to this question reveal a serious problem with the understanding of the ion concept. Once again the responses of the PHSE111 group are very poor when considering that they just wrote grade 12 Physical Science exams, which were only two to three months ago. This concept is not as important to the students' understanding of phase changes as the concept of atoms is, but could facilitate better understanding of chemical bonding and chemical reactions.

2.3 Give an example of an ion.

SNSE 2009	**SNSE 2011**	**PHSE 2011**
7% gave scientifically correct examples of ions. 24% gave wrong answers. 57% did not answer the question.	7% gave a correct answer and 7% gave wrong answers. 86% did not answer this question.	50% gave a scientifically correct answer and 50% gave wrong answers. All the students answered this question.

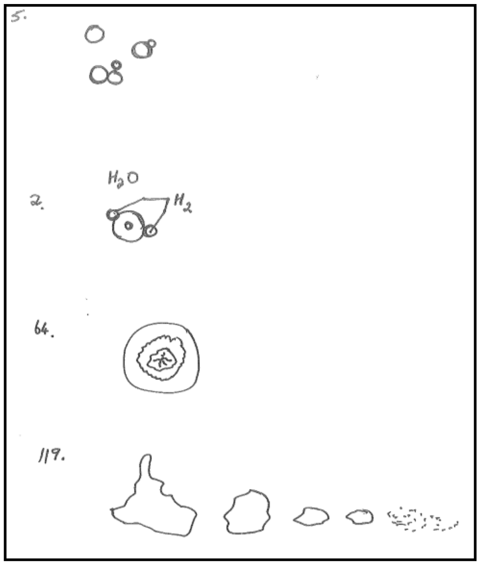
The results from this question support the findings of question 2.2 and clearly show the lack of understanding of the ion concept. From the responses to questions 2.1 and 2.2 it is not surprising that so many students did not even attempt to answer this question.

3.1 Draw a picture of a molecule as seen in your mind

SNSE 2009	**SNSE 2011**	**PHSE 2011**
35% had scientifically correct mental models. Another 35% answered wrong. 30% did not answer the question.	16% had the scientifically correct mental model. 60% had the wrong mental model of the molecule and 24% did not attempt to answer the question.	57% had scientifically correct mental models. 43% answered wrong. All the students answered this question.

The response to this question indicates a lack of understanding of the concept of a molecule. This concept is an integral part of understanding the concept of phase changes. If this concept is not fully understood by students lots of misconceptions regarding the shape and form of the molecule during phase changes can arise. Many of the incorrect responses involved circles and very few students indicated more than one circle or two circles connected to each other. There was however a trend to draw more circles when indicating a molecule than those of atoms or ions. This may be an indication that students do understand that a molecule has more than one atom. Lots of amorphous drawings were made, similar to plant and animal cell structures. This indicates the high level of confusion of the concepts of atoms and cells!

Scanned examples of students' mental models of molecules: (questionnaires 5, 2, 64 and 119)



3.2 Explain the word molecule in your own words.

SNSE 2009	**SNSE 2011**	**PHSE 2011**
11% could correctly verbalise the concept of a molecule. 63% answered the question wrong. 26% did not answer the question.	7% answered this question scientifically correct. 56% answered wrong. 37% did not attempt to answer the question.	71% answered scientifically correct. 29% answered wrong. All the students answered this question.

Although 35% of the 2009 SNSE 111 students, 16% of 2011 SNSE111 students and 57% of the PHSE111 students had scientifically correct mental models of a molecule in question 3.1[27], they could not verbalise it. Fewer students compared to the previous questions[28] did not answer the question; this indicates more confidence on the part of the students in answering this question. More students are familiar with the word molecule but this does not mean that they understand the concept. The students recognise the word from everyday use. Students find this concept easier to grasp than that of an ion although, before an ionic bond can form to construct a molecule, the ion must be created.

[27]Mental model of a molecule
[28] Annexure A questions 1.2 and 2.2 (verbalising the atom and ion)

3.3 Give an example of a molecule

SNSE 2009	SNSE 2011	PHSE 2011
44% of the student gave scientifically correct answers. 22% answered wrong. 33% did not attempt to answer the questions.	33% answered correctly and 20% wrong. 47% did not answer the question.	86% answered scientifically correct and 14% answered wrong. All the students answered the question.

More students gave a scientifically correct example of a molecule than visualizing or verbalising the concept in the previous questions. Most of the students found it difficult to explain the concept of a molecule while higher percentages of students could give an example. This indicates that during teaching more emphasis is placed on examples of molecules such as water, carbon dioxide and nitrogen gas and not on the general description or definitions of a molecule.

4.1 Explain the word "solid" in your own words.

SNSE 2009	SNSE 2011	PHSE 2011
13% gave the scientifically correct answer. 78% answered wrong. Only 9% did not attempt to answer the question.	10% answer the question with a scientifically correct answer. 13% did not answer the question.	36% answered scientifically correct and 64% answered wrong. All the students completed this question.

The low percentage of students that did not attempt to answer this question indicates a confidence in their understanding of this concept. The scientifically correct answers were in the minority though. The most common answer was: "a solid is something that is solid and can be touched". An interesting observation is that many students use sensory perceptions to explain the solid phase of matter. Only a small number of students explained the concept in terms of particles being close together, in terms of little vibration or the low kinetic energy in solids. Even the PHSE students couldn't explain the term solid scientifically correct.

4.2 Give an example of a solid.

SNSE 2009	**SNSE 2011**	**PHSE 2011**
87% correctly answered this question. Only 2% gave wrong answers. 11% did not attempt to answer this question.	86% gave scientifically correct responses. Only 1% gave wrong answers. 13% did not answer the question.	100% gave scientifically correct responses.

The different states of matter are a concept that is predominant in the Natural Science syllabus. Although only a few students could explain the concept they had a very good idea of a solid in real life. This is an example of the disengagement between microscopic and macroscopic properties of matter by students. The students' confidence in answering this question is also very high.

4.3 Explain the word "liquid" in your own words.

SNSE 2009	**SNSE 2011**	**PHSE 2011**
9% answered the question scientifically correct. 83% answered wrong. 7% did not attempt to answer the question.	9% gave scientifically correct answers. 87% answered wrong. Only 4% did not attempt to answer the question.	33% of these students answered scientifically correct. 67% answered wrong. All the students answered this question.

The same inclination is seen here if compared to question 4.2. The confidence of the students is high but they have little or no conceptual understanding of the term "liquid". Common wrong answers were:"it is not a solid and something that can flow". Again there is little or no mention of particle organisation, energy and forces between the particles.

4.4 Give an example of a liquid.

SNSE 2009	SNSE 2011	PHSE 2011
94% gave correct answers to this question. 6% gave wrong answers. All the students answered this question.	96% of the students answered this question correctly. 1% gave a wrong answer and only 3% did not answer this question.	100% of the students gave the correct answer to this question.

The connection between the conceptual understanding and the real life examples is very low. "Liquid" is a general term used in everyday life mostly in connection with drinking, swimming, bathing etc. Almost every student can name an example of a liquid without understanding the micro chemistry of a liquid. This is again an example of the distant relationship between microscopic properties and macroscopic events.

4.5 Explain the word "gas" in your own words.

SNSE 2009	SNSE 2011	PHSE 2011
13% of the students gave scientifically correct answers. 67% gave wrong answers. 11% of the students did not answer the question.	11% gave scientifically correct answers. 74% of the students gave wrong answers. 14% of the students did not attempt to answer the question.	43% gave a scientifically correct answer while 57% answered wrong. All the students answered this question.

A high confidence was detected by the students but they answered the question with little or no knowledge or understanding of the scientific mechanism of gas. Common wrong answers were:"something that cannot be touched or seen". Again, sensory perceptions of the macroscopic world in which they live were used, rather than a microscopic statement that science uses.

4.6 Give an example of a gas.

SNSE 2009	SNSE 2011	PHSE 2011
70% of the students gave scientifically correct answers. 11% gave wrong answers.	66% of the students answered correctly. 16% gave wrong answers. 19% did not answer this question.	100% of the students gave scientifically correct answers.

Gas is a term used widely in everyday life. Although students could not explain the concept of a gas scientifically they could easily name examples of gas. Popular examples were water vapour, carbon dioxide and oxygen. These examples are commonly used by almost everybody as it is found in the atmosphere of the earth. Water vapour is one of the most commonly used examples in textbooks to explain the concept of gas forming from heating water.

4.7.1 Are there spaces between the particles of a solid?

SNSE 2009	SNSE 2011	PHSE 2011
17% answered yes to this question and 74% answered no. 9% of the students did not answer this question.	11% of the students answered yes to this question and 81% answered no. 7% of the students did not answer this question.	29% of the students answer yes to this question and 71% answered no to this question. All the students answer this question.

The response to this question reveals that there is a relatively small group of students who believe that there are no spaces between the particles of a solid. Most models in school textbooks[29] portray the solid phase as circles with tiny spaces between them. Some models[30] make use of an ice cube to explain the concept of a solid. This observable fact may lead to the misconception that there are no spaces between the particles of a solid.

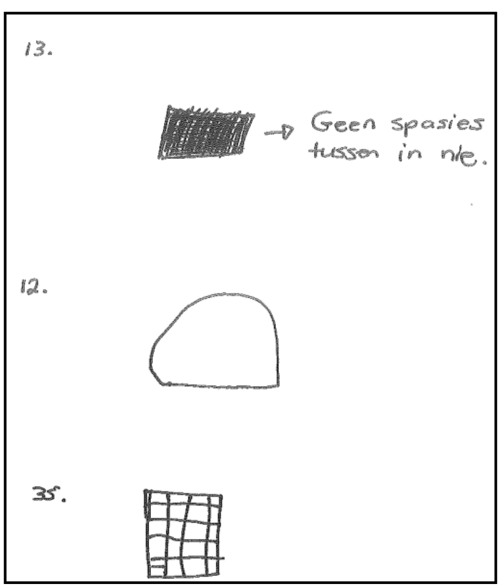
[29] Chapter 4, models no 1,2,6,9,11,12,19 & 20
[30] Chapter 4, models no 7 & 16

4.7.2 Draw a model of a solid's particles.

SNSE 2009	SNSE 2011	PHSE 2011
65% of the students drew scientifically correct models to show the arrangement and form of a solid's particles. 20% drew incorrect models and 15% did not attempt to draw anything.	60% of the students drew scientifically correct models and 27% drew incorrect models. 13% of the students did not draw anything.	100% of the students drew scientifically correct models portraying the particles of a solid.

Although the response to question 4.7.1 indicates that most of the student's answered correctly about the spaces between a solid's particles, a significant percentage (20 – 27%) of students could not visualise it correctly. This question was specifically phrased to include the word "particle" so the students would respond with a visual model presenting particles as part of the model. Most of the wrong answers were just a picture of a block, sometimes coloured in to show that it is a particle. There is no connection between the microscopic and macroscopic properties.

Scanned examples of students' mental models of a solid's particles: (questionnaires 12, 13 and 35)



4.7.3 Are there spaces between the particles of a liquid?

SNSE 2009	SNSE 2011	PHSE 2011
80% answered yes and 17% answered no to this question. 9% of the students did not attempt to answer this question.	74% answered yes to this question and 17% answered no. 13% of the students did not answer this question.	100% of the students answered yes.

A significant percentage (17%) answered this question wrong although the PHSE 111[31] responded with a 100% yes. Grade 10 to 12 models focus more on the energy, movement and spaces between particles whereas the earlier models (gr. 4 – 9) make more use of models without explaining the scientific process in detail.

4.7.4 Draw a model of a liquid's particles.

SNSE 2009	SNSE 2011	PHSE 2011
65% of the students draw scientifically correct models. 20% drew wrong models. 15% did not respond to this question.	66% of the student drew scientifically correct models. 24% of the students drew wrong models. 10 did not respond to the question.	100% of the students drew scientifically correct models.

The response to this question is approximately the same as the response to question 4.7.2. Again a significant percentage (20 -24%) of the students responded with the wrong model as answer. This could again be attributed to models[32] found in grade 4 – 9 textbooks where liquids are not specifically portrayed as a group of particles forming a liquid.

[31] 5.1.1 Population
[32] Chapter 4, models no 7 & 16

4.7.5 Are there spaces between the particles of a gas?

SNSE 2009	SNSE 2011	PHSE 2011
78% of the students answered yes and 7% answered no. 15% of the students did not answer this question.	73% of the students answered yes and 17% answered no. 10% of the student did not answer the question.	100% of the students answered yes to this question.

The correct response to this question was good although one expected to find a more positive answer because students easily named gases in everyday life. A low yet significant percentage of students (10 – 15%) did not have the confidence to answer this question. This percentage is the highest of the questions about the spaces between the particles of all three states of matter.

4.7.6 Draw a model of a gas's particles.

SNSE 2009	SNSE 2011	PHSE 2011
56% of the students drew scientifically correct models. 24% drew wrong models and 20% of the students did not attempt to answer this question.	73% of the students drew scientifically correct models. 23% did not draw acceptable models. 4% did not answer this question.	100% of the students drew scientifically correct models.

In analysing the students' responses, the researcher paid particular attention to the differences between the students' drawings of the three models: solid, liquid and gas. If a student drew a scientifically accepted model of a liquid's particles, and did not increase the distance between the particles of the gas particulate model, it was graded as wrong because the student clearly had no insight into the concept of gas particles moving further apart from each other with smaller forces of attraction between them. The model should distinctly discriminate between the distances between the particles of the different states of matter.

The positive response of the two SNSE111-groups, 56% and 73%, indicated approximately the same understanding of the gas concept than that of solids and liquids[33]. The PHSE 111-group responded with 100% accuracy. The response should be 100% because the particulate nature of matter[34] should be understood 100% correctly because it is the building blocks of more advanced chemistry concepts. Without appreciating this perspective[35], the underlying principle of the molecular model is lost.

4.8.1 When a solid change to a liquid, the spaces between the particles becomes...?

SNSE 2009	**SNSE 2011**	**PHSE 2011**
87% of the students answered greater. 9% answered smaller. 2% answered stays the same and another 2% did not answer the question.	80% of the students answered greater. 7% of the students answered smaller and 4% of the students answered that the spaces stays the same. 9% of the students did not answer this question.	100% of the students answered the spaces become greater.

For the students to answer this question a model from a grade 7 textbook[36] was provided in the questionnaire and the response was mainly that the spaces between the particles increase but 7 to 9% of the students answered that the spaces decrease. Even with the help of a model there were students that did not have the confidence to attempt an answer to this question. This is a significant result because it shows that a small, but not insignificant group of students could not utilize this simple model.

[33] Annexure A questions 4.7.4 and 4.7.2
[34] Paragraph 4.1
[35]Paragraph 4.2
[36] 5.1.2 Questionnaire

4.8.2 When a solid changes to a liquid, the movement of the particles become ….

SNSE 2009	SNSE 2011	PHSE 2011
74% of the students answer faster and 19% of the students answered slower. 6% indicated that the movement stays the same and 2% did not respond at all.	70% answered faster and 17% answered slower. 4% answered that the movement stays the same and 9% of the students did not respond.	86% of the students answered that the movement becomes faster and 7% answered slower. 7% answered that the movement does not change at all. All the students answered this question.

Similar to question 4.8.1 this question probed into students' scientific knowledge about the microscopic events taking place during phase changes. The model provided did not visualise movement and the students needed a deeper knowledge of this event to successfully answer this question. A significant percentage (17-19%) of the students answers the exact opposite to the correct answer, i.e. slower. Clearly there is no understanding of the concept that when energy is applied to change phases, that energy increases movement of the particles.

4.8.3 When a solid changes to a liquid, the force between the particles becomes …

SNSE 2009	SNSE 2011	PHSE 2011
24% of the students answered that the forces become larger and 50% answered that the forces decrease. 19% answered that the forces stay the same and 7% did not answer the question.	26% answered that the forces increased and 56% answered that the forces decreased. 7% answered that the forces between the particles stay the same and 11% did not answer the question.	7% indicated that the forces increased and 93% answered that the forces decreased. All the students answered this question.

Only about half (50-56%) of the SNSE groups agrees that during transition to a liquid the forces between the particles decrease. The forces between the particles are closely linked to the movement which in turn is dependent on the amount of energy applied. The PHSE group clearly has a better scientifically insight into the chemistry of phase changes. The microscopic model given with this question does not present the students with the necessary information to associate the macroscopic events with microscopic mechanism. Models discussed in chapter four[37] display to some extent an increase in movement when a solid transitions into a liquid.

4.8.4 When a solid change into a liquid, does the particles' shape change?

SNSE 2009	**SNSE 2011**	**PHSE 2011**
20% answered yes and 74% no. 6% of the students did not answer this question.	27% answered that the shape of the particles change and 66% answered no. 7% of the students did not answer this question.	7% answered yes and 93% answered no. All the students answered this question.

This question was included into the questionnaire[38] to probe into some misconceptions[39] learners had about the shape of the particles during phase changes. A significant percentage of students (20-27%) answered that the shape of the particles indeed changes during phase changes. The PHSE students did better as only 7% thought the shape of the particles changes. The students' utilization of the given model seems to be very poor as the model clearly shows that the particles stay the same. The instruction was clear: "use the following model to answer the subsequent questions". The shape and size of the particles stay constant during transition from solid to liquid. The group of students (20-27%) could not associate the microscopic model with the macroscopic events. The fact that the appearance of the solid changes and becomes fluid convinced this group that the molecules must change shape as a result of this transformation.

[37] Chapter 4, models 1,4 & 11
[38] Annexure A
[39]Driver 1985

4.8.5 When a solid changes into a liquid, does the particles' shape change? If your answer is yes, explain.

SNSE 2009	SNSE 2011	PHSE 2011
72% of the responses were scientifically correct and 17% of the students answered wrong. 6% of the students did not answer the question.	64% of the responses were scientifically correct and 24% of the students answered wrong. 11% of the students did not answer the question.	93% of the responses were scientifically correct and 7% of the students answered wrong. All the students answered this question.

This question was included so that the students could verbalise the misconceptions they had about the shape change of particles during phase changes. Tables 6.10 to 6.12 give a summary of the explanations that the groups of students gave to explain their answers.

Table 6.6: SNSE 111 (2009) Misconceptions

Explanations
It forms little pieces that break up
It turns from a solid form into a liquid form, thus the form of the item changes
Form changes
They change form and flow away from each other
The shape changes and it becomes a reaction, the shape atom a liquidly shape, if on the floor it will be flat
Solid - melts into liquids Liquid - boiled to evaporation (Gas state) Liquid - frozen into a solid state
They change from a solid to a liquid, from solid to flowing
They move away from each other?
It becomes bigger, the spaces as well as the forces

Table 6.7: SNSE 111 (2011) Misconceptions

Explanations
Break up into smaller pieces
The pieces still have some form but is not packed close to each other and more collisions take place
Their form can change - from small to big and from big to small
In a liquid the particles change form because it is not stable anymore
They are not being pressured anymore
Solids are big forms and liquids are found in smaller pieces
They move away from each other
When there are increases the particles get bigger
The particle becomes a new substance and must takes a new form
It changes form so that the liquid can be formed
It moves away from each other and does not have a specific form and can change into any form
They press against each other and become bigger and expand
It changes form because the particles undergo a phase change
Yes, they expand because there are more spaces between them, so they are not forced into a specific size
It changes from small particles connecting to each other to bigger particles
It changes from a solid to a liquid. This means that the particles become smaller

Table 6.8 PHSE 111(2011) Misconceptions

Explanations
They make contact with other particles from that specific solid and change into another form

One idea that is prevalent with both SNSE-groups[40] was that shape and size of the particle change when the matter changes phases. This is a clear indication that students attribute macroscopic properties to microscopic events[41]. Some students attribute the phase change to the pressure between the particles and this leads to expansion of particles. The only misconception observed from the PHSE 111-group's questionnaires, is that the contact between the particles cause the phase change.

4.8.6 When a solid changes to a liquid, the number of particles becomes …

SNSE 2009	**SNSE 2011**	**PHSE 2011**
13% of the students indicated that the number of particles increases. 43% answered that the number of particles decreases. 39% of the students answered that the number of particles stays constant while 6% of the students did not answer the question.	13% of the students answered that the number of particles increases and 53% of the students indicated that the number of particles decreases during transformation from a solid to a liquid. Only 24% agreed that the number of particles stays constant during phase changes. 10% of the students did not answer this question.	14% answered that the number of particles decrease and 86% of the students agreed that the number of particles stays the same. All the students completed this question.

[40] Paragraph 5.1.1
[41] Table 1.1

This question was included into the questionnaire[42] with the intention to explore the statement of Linsje (1990)[43]. Linsje proposed that a student who cannot distinguish between model and observation makes literal deductions from the models. The model included in the questionnaire[44] is a model used in a grade 8 textbook[45]. This specific model indicates that spaces between the particles increase when the substance changes states from solid to liquid to gas. In this process the blocks in which the states were visualised, stayed the same size. The shape and size of the particles also stayed the same. The only way to fit in the particles were to reduce the number and this gave the students the initiative to decide that the number of particles decreases as the states change from solid to liquid. Only 14% of the PHSE 111 students indicated that the number of particles decrease and this can again be contributed to their higher level of education. The other 86% seems to distinguish between model and observation. The other two groups done considerably worse with this question, only 39 and 24% respectively of the SNSE 2009 and SNSE 2011 students answered this question correctly.

4.9.1 When a liquid changes into a gas, the spaces between the particles become …

SNSE 2009	**SNSE 2011**	**PHSE 2011**
91% of the students answered that the spaces increase and 6% indicated that the spaces decrease. 2% agreed that the spaces stay the same and 2% of the students did not answer the question.	77% of the students answered that the spaces increase and 14% indicated that the spaces decrease. No students answered that the spaces stay the same and 9% of the students did not answer the question.	100% of this students answered that the spaces between the particles increase.

This question was included in the questionnaire for the same reason as that of question 4.8.1 - that was to see if the students could utilise the model in order to answer a simple question about phase changes. The model clearly shows that the spaces between the particles of the gas are bigger than that of the spaces between the particles of a liquid. The response to this question is

[42] Annexure A
[43] 4.5 Models of phase changes in literature
[44] Annexure A page 4 question 4.8
[45] 5.1.2 Questionnaire

better/more in line with the scientific explanation than that of 4.8.1. This could be because the difference in spaces is more prominent in the liquid to gas transition than that of the solid to liquid transition.

4.9.2 When a liquid changes into a gas, the movement of the particles becomes …

SNSE 2009	**SNSE 2011**	**PHSE 2011**
72% of the students agreed that the particles move faster and 24% answered that the particles move slower. No students answered that the movement of the particles stays the same and only 4% of the students did not answer the question.	54% of the students answered that the particles move faster when in the gas state and 36% answered that the particles move slower. 1% of the students answered that the movement stays the same and 9% of the students did not answer the question.	79% of the students answered that the movement of the particles accelerates and 14% answered that it becomes slower. 7% answered that the movement stays the same.

As with question 4.9.2 this question probed into the students' scientific knowledge about the microscopic events that take place during phase changes. The model provided did not visualise movement and the students needed a deeper knowledge of this event to successfully answer this question. A significant percentage (24 to 36%) of the students answered the exact opposite; namely slower. This percentage is notably higher than that of question 4.8.2. Clearly there is no understanding of the concept that when energy is applied to change phases, that energy increases movement of the particles.

4.9.3 When a liquid changes into a gas, the force between the particles becomes …

SNSE 2009	**SNSE 2011**	**PHSE 2011**
37% answered that the forces increase and 48% answered that the forces decrease. 9% answered that it stays the same and 6% of the students did not answer the question.	30% answered that the forces increase and 59% answered that the forces decrease. 11% answered that it stays the same and all the students answered the question.	93% answered that the forces decrease. 7% answered that it stays the same and all the students answered this question.

Only about half (48-59%) of the SNSE groups agreed that during transition to a gas the forces between the particles decrease. The forces between the particles are closely linked to the movement which in turn is dependent of the amount of energy applied. The PHSE group clearly had a better scientifically insight into the chemistry of phase changes. This microscopic model provided in order to answer this question clearly does not present the student with the necessary information to associate the macroscopic events with microscopic mechanism. Models discussed in chapter four[46] display to some extent an increase in movement when a solid transitions into a liquid. Another observation made during analysis of this question is that all the students of the SNSE 111 2011 group answered this question. This is the only question this is observed with a 100% correct response.

4.9.4 When a liquid changes into a gas, does the particles' shape change?

SNSE 2009	**SNSE 2011**	**PHSE 2011**
26% of the students answered yes and 69% of the students answered no. 6% of the students did not answer this question.	21% of the students answered yes and 69% of the students answered no. 10% of the students did not answer this question.	14% of the students answered yes and 86% of the students answered no. All the students answered this question.

[46] Chapter 4, models 1,4 & 11

This question was included into the questionnaire[47] to probe into some misconceptions learners had about the shape of the particles during phase changes[48]. A significant percentage of students (21-26%) answered that the shape of the particles indeed changes during phase changes. The PHSE students did better as only 14% thought the shape of the particles changes. The students' utilization of the model provided seems to be very poor as the model clearly shows that the particles stay the same. The instruction was clear: "use the following model to answer the subsequent questions". In the model the shape and size of the particles stay constant during transition from liquid to gas. The group of students (21 to 26%) could not associate the microscopic model with the macroscopic events. When the physical appearance of the liquid changes as it changes into a gas, it is not always visible. This fact convinced this group that the molecules must change shape as a result of this transformation. With this question the response was very similar to that of question 4.8.4. This is thus a confirmation of the findings of question 4.8.4.

4.9.5 When a liquid changes into a gas, does the particles' shape changes? If your answer is yes, explain.

SNSE 2009	**SNSE 2011**	**PHSE 2011**
63% of the responses were scientifically correct and 20% of the students answered wrong. 17% of the students did not answer the question.	79% of the responses were scientifically correct and 10% of the students answered wrong. 11% of the students did not answer the question.	64% of the responses were scientifically correct and 36% of the students answered wrong. All the students answered this question.

This question was included so that the students could verbalise the misconceptions they had regarding the shape change of particles during phase changes. Below is a summary of the explanations students gave to explain their answers.

[47] Annexure A
[48]Driver 1985

Table 6.9: SNSE 111 (2009) Explanations

Explanations
From a liquid to a gas for example vapour (evaporate)
Liquid is heat and evaporate into gases
Water evaporates and becomes a gas
The reaction of evaporation becomes a shape changing aspect. Meaning the liquid will turn into a gas form and accommodate the air
Form changes - liquid form turns into gas e.g., by heating it, it would evaporate
It divides and is distributed into smaller pieces
Liquid moves together, air can move around and not together

Table 6.10: SNSE 111 (2011) Explanations

Explanations
Move around more freely
The size increases significantly
Because the liquid changes to vapour, the particles doesn't have the right look
They pressed against each other and expanded
Yes, they are not visible anymore
They change to form gas
They condensate or are burnt away
It changes from a liquid to a gas
The particles don't have a specific structure anymore, the particles move around freely
They become smaller and are divided into smaller pieces
The blocks in solid to gas have reduced to half

Table 6.11: PHSE 111 (2011) Explanations

Explanations
Yes, it is widely distributed

The students commented on the shape and size of the particles that differ during phase changes. Macroscopic appearances play a large role in the student's explanations of phase changes. This is the same type of misconceptions found in Table 1.1.

The next eight questions were included into the questionnaire to investigate students' mental models about molecules and crystals. No diagrams of models were included for use by the students, only written descriptions such as colour and physical appearance were provided. These questions probed into students' associations between microscopic properties and physical appearance of certain substances like table salt ($NaC\ell$) and sulphur (S_8) powder. Both scientific formulas and names were included as information on the questionnaire[49].

5.1.1 A table salt crystal consists of one molecule.

SNSE 2009	**SNSE 2011**	**PHSE 2011**
22% of the students answered yes and 69% answered no. 9% of the students did not answer the question.	34% of the students answered yes and 54% answered no. 11% of the students did not answer the question.	43% of the students answered yes and 57% answered no. All the students answered this question.

A significant percentage of students answered yes. This item produced a very high percentage of scientifically incorrect responses from the PHSE 111 group. Nearly half of the group gave unacceptable responses. There is clearly an immense problem with this group of students' associations between microscopic structures and macroscopic appearance.

[49] Annexure A

5.1.2 The NaCℓ molecule is white like the crystal.

SNSE 2009	**SNSE 2011**	**PHSE 2011**
67% of the students answered yes and 24% answered no. 9% of the students did not answer the question.	79% of the students answered yes and 14% answered no. 10% of the students did not answer the question.	57% of the students answered yes and 43% answered no. All the students answered this question.

The answers to this question delivered a large number of unacceptable responses. The macroscopic appearance, the colour white, is directly connected to the microscopic structure of the molecule. It was not surprising that learners found it hard to make the association, considering the responses to the questions on the concepts of atoms, ions and molecules. More than half of the PHSE 111 students gave unacceptable responses to the question on the appearance of the NaCℓ molecule.

5.1.3 When a salt crystal dissolves in water, the molecule becomes invisible.

SNSE 2009	**SNSE 2011**	**PHSE 2011**
76% answered yes to this question and 17% answered no to this question. 7% did not answer this question.	79% answered yes to this question and 11% answered no to this question. 10% did not answer this question	71% answered yes to this question and 29% answered no to this question. All the students answered this question.

This question was included to test students' perceptions about the microscopic events when ionic molecules dissolve. The question was asked this way not to test students' knowledge about ionic solutions *per sé*, but to test if they perceive a crystal dissolving as molecules that disappear. In retrospection the researcher thought that this question wasn't phrased correctly and this might have been confusing for the students

5.1.4 Draw your own model of a NaCℓ- molecule.

SNSE 2009	SNSE 2011	PHSE 2011
11% of the students drew scientifically correct models and 44% drew incorrect models. 44% of the students did not attempt to answer this question.	10% of the students drew scientifically correct models and 36% drew incorrect models. 54% of the students did not attempt to answer this question.	64% of the students drew scientifically correct models and 36% of the students gave unacceptable responses.

When this question was analysed the researcher took any model that indicated that there was two atoms bonded to form the molecule as correct. The models did not need to indicate relative sizes or charges etc. When these responses are compared to those of question 2.1[50] there is a slight increase (6 - 8%) at the SNSE 111-groups in scientifically correct answers for this question. A significant percentage (36%) of PHSE 111 gave unacceptable answers. This is alarming because in spite of a 50%+ passing prerequisite for this module this basic question regarding ionic bonding couldn’t be answered. A high incidence of no response to this question is detected. The SNSE 111 students’ confidence were clearly very low in attempting to answer this question. This question was totally out of their knowledge structure.

5.1.5 Draw your own model of a NaCℓ-crystal.

SNSE 2009	SNSE 2011	PHSE 2011
4% of the students drew scientifically correct models and 41% drew wrong models. 56% of the students did not attempt to answer this question.	No students drew scientifically correct models and 36% drew wrong models. 64% of the students did not attempt to answer this question.	36% of the students drew scientifically correct models and 64% of the students gave unacceptable responses.

This question was analysed with the following mind-set: the two models the students drew of the molecule and the crystal should clearly indicate that the crystal is compiled of a collection of molecules. The results of this question clearly indicated that the students did not make this

[50]*Draw a picture of an ion as seen in your mind.*

connection. Less than half (36%) of the PHSE 111 students could make the association between molecule and crystal.

The next three questions involved questions about the physical appearance of sulphur and the model of the sulphur molecule. The physical properties as well as the molecular formula (S_8) were given to the students as information to answer the questions.

5.2.1 The colour of a sulphur atom is yellow.

SNSE 2009	**SNSE 2011**	**PHSE 2011**
69% answered yes to this question and 24% answered no to this question. 7% did not answer this question.	67% answered yes to this question and 23% answered no to this question. 10% did not answer this question	50% answered yes to this question and 50% answered no to this question. All the students answered this question.

The students' confidence in answering this question was not as low as that of questions 5.1.4 and 5.1.5. The response to this question clearly indicated that students make literal deductions from the powder as to what the colour of the atom is. A very high percentage of students, 67-69% for SNSE 111 and 50% for PHSE 111 answered that if the sulphur powder is yellow, the atom should be yellow too.

5.2.2 Sulphur powder (S_8) consists of eight sulphur atoms.

SNSE 2009	**SNSE 2011**	**PHSE 2011**
69% answered yes to this question and 20% answered no to this question. 11% did not answer this question.	71% answered yes to this question and 19% answered no to this question. 10% did not answer this question	79% answered yes to this question and 21% answered no to this question. All the students answered this question.

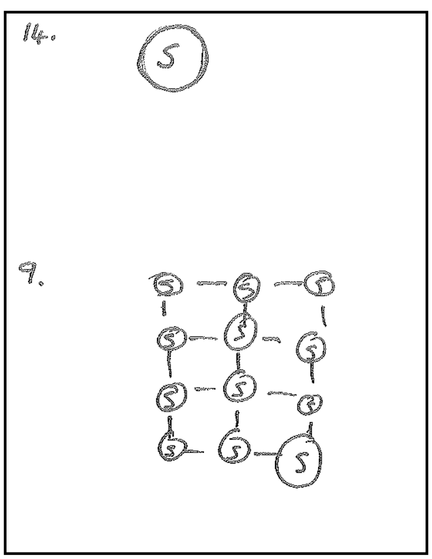
This question was included into the questionnaire[51] to investigate if students could make the deduction from a chemical formula as to how many atoms were involved. This question was very basic with the use of only one kind of atom. The response was exceedingly positive. Only about one fifth (19 - 21%) could not make the correct deduction from the formula.

5.2.3 Draw your own model of a sulphur molecule

SNSE 2009	**SNSE 2011**	**PHSE 2011**
4% of the students drew acceptable models and 43% drew wrong models. 53% of the students did not attempt to answer this question.	3% of the students drew acceptable correct models and 31% drew wrong models. 66% of the students did not attempt to answer this question.	7% of the students drew acceptable models and 93% of the students gave unacceptable responses.

This question was analysed with the approach that if a student demonstrate in any way that eight particles were bonded together, it was considered an acceptable answer. Only a very low percentage (3 - 7%) of the students responded with acceptable models. There is little or no association between the formulas (S_8) and the mental models students form when only given only written information. The response from the PHSE 111 students is disappointing as S_8 is part of the Inorganic chemistry syllabi.

Scanned examples of students' mental models of the S_8 molecule: (questionnaires 9 and 14)



[51] Annexure A

6.6 Results from interviews

Six questionnaires[52] were selected for interviews. The first questionnaire was selected because most of this student's[53] responses to the questions were correct. The other five questionnaires were selected because of the many wrong interpretations the students[54] made of the concepts tested in the questionnaires. The ATLAS.ti6.2 program was used to analyse these interviews. The students were asked five open ended questions[55] and the responses of the students were coded with the codes explained in Table 6.12. The text were analysed as proposed by Miles and Huberman (1994)[56].

Table 6.12: Explanation of codes

CODES	EXPLANATION
Define by distance	The student explains the phase changes in terms of the distance between the particles
Define by energy	The student explains the phase changes in terms of the energy of the particles
Define by forces	The student explains the phase changes in terms of the forces between the particles
Define by form	The student explain the phase changes in terms of the shape and appearance of the particles
Define by movement	The student explains the phase changes in terms of the movement of the particles, slow or fast
Example used	Type of material used to explain phase changes
Literal deduction from model	When a student makes a literal deduction from the model e.g. number of particles etc.
Microscopic characteristics same as macroscopic	When a student gives the microscopic particles the same features as the macroscopic view of the material
Misconceptions	Different misconceptions about phase changes in general
Model confuses student	Student does not understand the purpose of the model
No connection to model	Student explains the phase changes viewed during the experiment[57] without any connection to the model[58] shown earlier
Phases correct	The student named the three phases: solid, liquid, gas
Unsure answer	The student is not sure if the answer is correct or not
Use model to explain phase changes	The student uses the model[59] to explain the phase changes seen during experiment[60]
Wrong scientific terminology	The student used wrong terminology to explain scientific phenomena e.g. hydrogen instead of gas

52 Annexure A
53 PHSE 111 student
54 SNSE 111 students
55 Annexure B
56 Paragraph 5.2.2
57 An ice cube is heated in a beaker to form water and then water vapour
58 Annexure B question 4
59 Annexure B question 4
60 An ice cube is heated in a beaker to form water and then water vapour

The six interviews[61] were done by the researcher and each participant was interviewed individually. The verbal transcripts and coding linked to certain phrases are tabulated in Tables 6.13- 6.18. This coding was used to analyse the data and a graph of this analysis was drawn[62] along with the verbal analysis of the text.

Table 6.13: Interview 1

Questions(Q) and answers(A)	Coding
Q: Goed, kan jy vir my sê wat is die drie fases van materie?	
A: Dis vastestof-, vloeistof- en gasvorm.	Phases correct
Q: Goed, dankie. En wat is die drie hoofverskille tussen die drie fases?	
A: Ok wel, uh, die vastestof is die deeltjies baie naby aan mekaar, die aantrekkingskragte is groot en daarom is hulle baie naby aan mekaar.	Define by distance
Vloeistof is die aantrekkingskrag nie so groot nie, deeltjies is meer beweeglik. Uhm, daar is meer botsings. En dan in die gasvorm, daar is	Define by forces
die aantrekkingskragte glad nie. Deeltjies is baie ver uit mekaar uit. Enne	Define by forces
ja, botsings kom dan nie meer, kom dan meer voor, uhm dis hoekom dit so verspreid is.	Define by distance
Q: Ok, dankie, die derde vragie: wat gebeur met die deeltjies as die stof van fase verander? Verduidelik vir my met `n voorbeeld.	
A: Ok, eh, wel, die deeltjies raak meer beweeglik, die bot, botsings raak meer. Eh, om `n voorbeeld te noem, seker van `n vloeistof na, `n	Define by movement
vastestof, ys na water. Eh, hitte, hitte laat die deeltjies dan, uhm, versprei, so is die deeltjies nie meer so kompak soos wat dit in ysvorm as wat dit in water sou wees nie.	Define by distance
Q: Goed. As jy nou na die sketsie kyk, hierdie een wat ek vir jou wys, kan jy vir my sê wat gebeur met die deeltjies, van die een fase na die ander, in terme van. vorm, hoeveelheid, grootte, dalk energie ..?	
A: Ok as ek kyk na die vastevorm na die vloeistofvorm, is die deeltjies, lyk of daar minder is, uhm, hulle is meer verspreid, uh, die aantrekkingskragte is dan minder. Ek dink nie die deeltjies grootte verskil so nie.	Literal deduction from model
Eh, dan van vloeistof na gas, is die deeltjies ook meer uitmekaar uit. Aantrekkingskragte is nou weer eens nie so sterk nie. Meer vrylik, beweeglik. Eh, ek dink daar is die van-der-wahls-kragte, dis ook nie meer so sterk nie. Dis ook, dit kom neer op die, op die aantrekkingskragte. Ja,	Unsure answer / Define by forces

[61]Annexure B
[62]Figure 6.1

die deelties is glad nie meer so kompak soos wat dit sou wees in `n vastestof nie, daarom kom ook die deeltjies nie so bymekaar voor nie. Dit	Define by forces
sal oralster gevind word, inne, in da die, in die vorm waarin dit geplaas is. Soos in die gasvorm sal dit oralster voorkom waar die vloeistof, waar die	Define by forces
vastestofvorm sal bymekaar voorkom, waar gas sal die hele ruimte vul. Ja. Q: Goed. Dankie. As ek nou vir jou hierdie voorbeeld wys, dis `n ysblokkie wat ek nou daar insit wat besig is om te smelt ... A: Ok. Q: ...goed, kan jy vir my verduidelik, wat gebeur met hierdie deeltjies? A: Ok die deeltjies.. Q: Van vastestof na vloeistof na gas. A: Ok die deeltjies raak nou relatief, deur daardie kragte raak nou minder tussen hulle, dis hoekom hulle versprei in die glasfles val, so die deeltjies is nie meer so kompak soos wat dit sou wees in die ysvorm nie, waar in	Define by distance
die vloeistofvorm is dit bietjie meer uitmekaar uit die, die kragte is nie meer so sterk maar hou nog steeds, daar is nog steeds kragte tussenin. En as dit nou weer weer eens verhit sal die die hitte sou nou weer, uhm,	Define by forces
aanleiding gee tot vinniger beweging van die deeltjies. Dit sou dan nou dit	Define by distance Define by forces
heeltemal oplos, en dan die hele ruimte van die glasfles vul. So hitte sou, die hitte gee aanleiding tot vinniger en meer botsings. Q: As ek, nou byvoorbeeld in die ysblokkie is 500 deeltjies het, hoeveel deeltjies sal in die vloeistof wees, en hoeveel sal in die gasfase wees.	Misconception
A: Ek dink nie die deeltjies sal verander nie, ek dink daar sal nog steeds	No connection to model
500 in die vloeistof en die gasvorm wees. Dit sal net meer verspreid wees. Q: Verspreid wees, daar's hy, baie dankie. A: Reg.	Unsure answer

Table 6.14: Interview 2

Questions(Q) and answers(A)	Coding
Q: Goed, ek gaan nou net vir jou vyf vragies vra. Antwoord vir my, net soos jy dink. Die eerste een is: Kan jy vir my die drie fases van materie opnoem?	
A: Eh, dis `n vastestof, `n vloeistof en `n gas.	Phases correct
Q: Dis reg, dankie. Wat is die hoofverskille tussen die drie fases?	
A: Ek dink dis die vorm, seker maar, waarin hulle voorkom.	Define by form
Q: Ja.	
A: En eh, voorkoms. En eh, ja die derde een is ek nie seker nie.	Unsure answer
Q: Goed. Net soos, jy kan vir my net noem, soveel soos jy weet. Goed.Wat gebeur met die deeltjies, waneer `n stof van fase verander? Eh noem vir my `n voorbeeld.	
A: Uhm as ek vat water...	
Q: Ja...	Example used
A: ...wat `n vloeistof is, verhit dit dan, vorm dit uh dan waterdamp...	Phases correct
Q: Ja...	
A: ...wat dit dan in `n gas insit..	
Q: Ja...	
A: Sover ek weet, dan beweeg dit op.	Define by movement
Q: Ja..	
A: En eh ja, so dit, as `n mens dit verhit dan verander dit in of in `n blokkie ys, wat `n vastestof en verhit dit dan verander dit in `n vloeistof.	Unsure answer
Q: Goed. Kan jy vir my sê, wat word, hoe verander die deeltjies self of weet jy nie...?	
A: Nee, glad nie.	
Q: Weet jy glad nie? Goed. Nou, as jy nou na die sketsie kyk wat ek jou wys, kan jy vir my sê as jy nou na die sketsie kyk, wat gebeur met die deeltjies as hulle van fase verander?	
A: Ja, wat is dit nou?	
Q: Dis `n vastestof, dis `n vloeistof en dis `n gas.	
A: Hulle word, as ek na die skets kyk word hulle, uh minder, verder uit mekaar uit.	Literal deduction from model
Q: Dis goed.	
A: Dis soos dit afgelei word.	Literal deduction from model
Q: Goed, as jy nou vir my sê van vloeistof na gas toe, sê jy die deeltjies gaan verder uit mekaar uit?	

A: Ja	Literal deduction from model
Q...en hulle word minder?	
A: Ja.	Literal deduction from model
Q: Goed. Nou as ons nou kyk na die ysblokkie in die water, as die ysblokkie smelt, as hy van fase verander, wat gebeur dan?	
A: Uhm, van die deeltjies gaan seker ook verder uit mekaar uit.	Use model to explain phase changes
Q: …daar's hy.	
A: Word dit ook damp ...word dit ook minder..soos die prentjie wys.	Literal deduction from model
Q: Goed. Uhm, as ek vir jou sê dat in die ysblokkie is daar 500 deeltjies, hoeveel deeltjies, sal jy sê is in die water, en dan in die waterdamp?	
A: Dit gaan seker maar met die helfte verminder. Sê maar 250 deeltjies in die water, en dan..	Literal deduction from model/ Use model to explain phase changes
Q: Kan jy, kan jy vir my sê wat word van die deeltjies?	
A: Uhm, as hulle nou in gas verander?	
Q: Ja, sê nou maar van ys af na water toe..?	
A: Uhm	
Q: Jy sê vir my dit word minder..	
A: Ja..	
Q: Weet jy hoekom word hulle minder?	
A: Nee, ek weet nie hoekom nie, ek weet net dit behoort op te beweeg, boontoe..soos dit ..	Unsure answer
Q: Soos dit gas word..	
A: …soos dit gas word, Ja.	
Q: Goed daar's hy...	
A: Dis al wat ek weet.	
Q: ...dis reg so, baie dankie hoor.	

Table 6.15: Interview 3

Questions(Q) and answers(A)	Coding
Q: Goed, jy kan maar net vir my hard en duidelik praat hoor.Kan jy vir my die drie fases van materie opnoem?	
A: Nee, ek kan nie onthou nie.	Unsure answer
Q: Kan jy nie onthou nie?	
A: Nee, nee..	
Q:As ek vir jou sê, dink aan water ..	
A: O, uhm vastest, vastestof.	
Q: ..Vastestof..	
A: Uhm, vastestof, vloeistof en gas.	Phases correct
Q: Dis reg..	
A: (verleë laggie)	
Q: Daar's hy, dankie hoor. Wat is die hoofverskille tussen die drie fases?	
A: Vastestof is die, is, is`n stof wat solied is en dan vloeistof is soos water wat kan vloei en gas is soos gas wat jy in die lug kry.	Microscopic same characteristics as macroscopic
Q: Goed. Kan jy vir my sê, deur `n voorbeeld te gebruik, wat gebeur met die deeltjies as jy van `n vastestof na `n vloeistof na `n gas toegaan.	Example used
A: Uhm, vastestof is soos ys kan ek sê..	
Q: Ja..	
A: dan smelt dit, dan word dit vloeistof. En gas kan verdamp.	Microscopic same characteristics as macroscopic
Q: Ja en goed en as jy nou dink aan die deeltjies waaruit water bestaan...?	
A: Soos materie, of wat?	
Q: Ja,.	
A: Ja.	
Q: Ja die deeltjies waaruit water bestaan. Het jy enige idee in jou kop oor wat gebeur as dit van `n vastestof na `n vloeistof toe gaan, byvoorbeeld?	
A: Uhmmm, word dit nie soos in die spasie tussenin groter nie?	Define by distance/ Unsure answer
Q: Dis. Dis reg, dis reg, goed, die spasies word groter. Goed, as ek nou vir jou hierdie diagram wys, kan jy vir my verduidelik wat gebeur van vastestof, vloeistof na gas toe, in terme van die deeltjies, die, die,die grootte van die deeltjies, die hoeveelheid van die deeltjies, die beweging van die deeltjies.	
A: Uhm, ek dink dat ...	
Q: Ja..	
A: ...vastestof is hulle baie naby aan mekaar,	Define by distance

Q: Ja.. A: Want hy moet solied wees. Dan vloeistof, as hy, gis, as die ys byvoorbeeld smelt, dan word die deeltjies, dan gaan hulle verder uit mekaar uit en beweging is vinniger, dink ek, en dan gas, is hulle, ver, van die vloeistof na die gas word gaan hulle nog verder.	Define by distance Define by movement
Q: Goed, as ek nou vir jou sê, die, die, die vastestof het 500 deeltjies ... A: Ja .... Q: Hoeveel deeltjies gaan daar wees in die vloeistof en hoeveel deeltjies gaan daar wees in die gas? A: Uh, a, dit gaan minder wees, dit ..	Literal deduction from model
Q: Goed, hoekom sê jy dit gaan minder wees, wat word van die deeltjies? A: Ek dink omdat die spasie verder uit mekaar uit is, daarom is daar nie meer so baie plek nie.	Misconception
Q: Goed. Goed. nou kyk jy na die blokkie ys wat ek vir jou hier neergesit het, A: Uhhmm.. Q: Nou wil ek weer soos wat jy nou met die diagram verduidelik het, wil ek hê jy moet vir my verduidelik, wat gebeur met die ysblokkie se deeltjies, soos wat dit van fase verander. As dit nou klaar gesmelt het, dan steek ons hom aan die brand, dan word hy warm. A: Ja Q: Goed, so ek kan dit solank doen, jy kan solank vir my verduidelik wat gebeur as hy as hy van die ysblokkie af na water toe oorgaan. A: Uhm.. die ysblokkie is al die materie deeltjies baie naby aan mekaar. So wanneer hy smelt, en hy word `n vloeistof, gaan hulle nou verder uitmekaar uit beweeg.	Define by distance Define by distance
Q: Goed. Ja.. A: Moet ek .. gas .. Q: Kan jy aangaan.Nou gaan kyk jy, as ons hom ... Uhg, nou is hy nie aan die brand nie. A: Oeps. Q: Stink dit nou na die gas. As, as ons hom nou ... Dis, dis as hom verder verhit, dit weer probeer, A: Laggie.. Q: Goed, nou kan ons sien wat gebeur nou as ons dit verder verhit kan jy weer vir my verduidelik wat gebeur, A: Ja die ysies die smelt maybe, vastestof smelt, so al die molekules	Unsure answer Define by distance

beweeg nou verder uitmekaar uit as dit ‘n vloeistof word, en dan die gas dan beweeg hulle nog verder uitmekaar uit want dan word daar nou nie so baie plek, hulle word minder, Q: Goed dankie	Define by distance Literal deduction from model Misconception

Table 6.16: Interview 4

Questions(Q) and answers(A)	Coding
Q: Ek gaan net vir jou 5 vragies vra. Die eerste vragie is: kan jy vir my die drie fases van materie opnoem? A: Vastestof, vloeistof en gas. Q: Goed. Wat is die hoofverskille tussen die drie fases? A: Moet ek in terme van kinetiese...? Q: In terme van wat jy wil ... A: Vastestof is die deeltjies bymekaar en hulle vibreer op die plek. Uhm, en hulle het `n lae kinetiese energie. En vloeistowwe se deeltjies is `n bietjie verder uit mekaar uit. Daar is genoeg spasie tussen mekaar, lat hulle deurmekaar kan vloei, maar hulle is nog nie vry verspreid nie, en hulle kinetiese energie is bietjie hoër, en hulle beweeg bietjie vinniger as wat vastestowwe doen. Q: Ja ... A: ..en vloeistowwe ... gasse, die deeltjies is baie verspreid. Hulle vul die hele houer. So hulle het nie `n vaste volume nie. Ook nie `n vaste vorm nie. En ... die kinetiese energie is baie hoog, Q: Daar’s hy, baie dankie. A: ..en hulle beweeg baie vinnig, skies ek praat weer, Q: Nee, jy kan, jy kan praat en beduie net soos jy wil. A: Dis lekker, goed. Is dit reg? Q: Dis doodreg Goed, die derde vragie: Wat gebeur met die deeltjies wanneer `n stof van fase verander? Jy kan in terme van vorm, grootte, afstand, verduidelik vir my met `n voorbeeld. A: Soos water? Q: Dis hy. A: Ok, as jy water vries, vries is dit `n vastestof. Juffrou moet net sê of ek reg is? Q:Goed A: en dan, soos ek gesê het vastestof het mo, uhm, hy beweeg nie vinnig	Phases correct Define by energy, distance, movement Define by energy Define by distance Define by distance Define by energy Define by form, distance Misconception Define by energy Define by movement Example used

nie, vibreer in dieselfde posisie, en dan as jy bietjie hitte bysit, dan raak die kinetiese energie al hoe meer. En dan..., naderhand breek dit, dis hoe ek dit verstaan. Q: Ja. A: en dan breek dit, dan gaan dit oor na `n vloeistof fase toe. En dan ... verhit jy dit nog so bietjie meer, en dan vibreer nog vinniger en dan gaan dit nog verder van mekaar af. Die interne molekulêre kragte raak swak. Q: Dis hy, vastestof.. A: ... vastestof Q: Ja A: Van vastestof na vloeistof. A: na gas Q: Goed, dankie. As ek nou vir jou hierdie prentjie hierso, dis `n model. Ek wil hê jy moet vir my kommentaar lewer, verduidelik: wat verstaan jy onder hierdie model. In terme van die deeltjies, hulle grootte, hulle hoeveelheid, hulle vorm...as jy nou vir my moet verduidelik volgens hierdie model. Wat sal jy sien? A: Die deeltjies bly dieselfde grootte. Q: Ja.. A: Ehm..., dis eintlik maar dieselfde as al die antwoorde, die ander antwoorde, dink ek. Q: Sê vir my ... A: Ok, die deeltjies bly dieselfde grootte, hulle is naby mekaar, vibreer op die plek met vastestowwe. Uhm, moet ek dan sy vloeistof doen? Q: Ja. Dis die vloeistof en dan's dit gas. A: Ok, sterk aantrekkingskrag, vastestowwe. Q: Goed.. Q: Ek wil, ek wil meer weet in terme van hoeveelheid molekules, hoeveelheid deeltjies... A: Al beweeg ons van vastestof na vloeistof na gas toe, dit bly dieselfde hoeveelheid deeltjies en hulle bly dieselfde grootte. Dis net die spasies tussen hulle wat gaan vergroot of verkein. Q: Goed, dankie, dis wat ek wil weet. A: Ok. Q: En dan, wil ek weer dieselfde hê, moet jy vir my verduidelik wat gebeur met die fase verandering van ys na water na waterdamp. Wat gebeur as jy dit fisies so sien ?	Define by movement Define by energy Misconception Unsure answer Misconception / Unsure answer Define by movement Define by forces / distance Wrong scientific terminology Unsure answer Define by form / distance Define by movement Define by forces No connection to model Literal deduction from model

A: Dis `n vastestof..	
Q: Ja..	
A: En ... moet ek weer dieselfde van die prentjie?	
Q: Nee, nee, jy gaan nou , vergeet nou eers van die prentjie.	
A: OK	
Q: Verduidelik vir my wat jy nou, wat nou daar gebeur met hierdie praktiese demonstrasie.	
A: Ok, dis `n vastestof..	
Q: Ja ..	
A: Van sterk interne kragte.	Define by forces
Q: Ja ..	
A: Beweeg op die plek.	
Q: nou goed, ek gaan hom nou verhit ..	Define by movement
A: Dit vibreer op die plek, die deeltjies. En dan .. as dit verhit word... Wanneer hitte bygevoeg word, begin die deeltjies al hoe vinniger beweeg. Endan, op `n sekere stadium, ek kan nie onthou wat noem mens dit nie, maar toemaar...	Define by movement
Q:Goed	
A: Op `n sekere stadium is die kragte, die interne molekulêre kragte, swakker as wat die kragte is waarmee hulle beweeg, die kinetiese  krag, so dan gaan dit oor na `n vloeistof toe. En dan met gas.... is dit ook juffrou, voeg jy hitte by, en dan beweeg dit alhoe vinniger, en dan raak die kragte weer, die interne kragte weer swakker, en die kinetiese krag, en of die kinetiese energie is dan baie vinnig, en dan beweeg dit, die gas deeltjies.	Define by forces Wrong scientific terminology Define by movement Define by movement Define by forces Define by forces Wrong scientific terminology
Q: Daar's hy. Dis al wat ek wou weet.	
A: Ok.	

Table 6.17: Interview 5

Questions(Q) and answers(A)	Coding
Q: Heel eerste wil ek hê jy moet vir my verduidelik wat verstaan jy onder die drie fases van materie?	
A: Daar is mos nou drie fases, wil mevrou verstaan nou ..	
Q: Ja ek wil weet, noem hulle vir my op.	
A: Dis die, die vastestof..	Phases correct
Q: Ja	
A: ...dan is al die molekules teenaanmekaar.	Define by distance
Q: Ja	
A: So, en dan kry jy die, die vloeistof...	
Q: Ja	
A: ... waar die molekules bietjie verder van mekaar af is. En dan kry jy die gas waar die molekules heeltemal uitmekaar uit is.	Define by distance Define by distance
Q: Goed	
A: Soos in verspreid is.	
Q: Dankie, dis wat ek wou weet. Wat is die drie hoofverskille tussen die drie fases. Jy het dit al amper begin beantwoord in die eerste vraag.	
A: Dis die molekules wat verder weg van mekaar af is dat daar meer spasies tussen in, ruimtes tussen in is.	Define by distance
Q: Wat gebeur met die deeltjies as `n stof van fase verander, sê dan maar van vaste stof na vloeistof of van vloeistof na gas? Ek wil hê jy moet vir my `n voorbeeld gee.	
A: Ok, dit kan verdamp. Is dit soos wat...	
Q: Ja	
A: Dit kan verdamp, die deeltjies wat dan soos uitsit, soos van die kan verdamp, dan word die stof minder, of so.	Microscopic same characteristics as macroscopic Misconception
Q: Ja..	
A: En dan's dit net, hulle skuif maar net verder. Hulle, vat ruimte.	Define by distance
Q: En dan, goed. En dan skuif hulle verder uit mekaar uit.As ek vir jou hierdie diagram wys ... ek wil hê jy moet vir my sê: Wat gebeur met die deeltjies in hierdie diagram, beide spasies en hoeveelheid. En alles as hulle van fase verander.	
A: As ons soos `n vastestof soos in almal bymekaar sit ...	
Q: Ja	
A: .... is al die deeltjies as `n mens dit so kan sê: nou vasgevang. En soos wat dit `n vloeistof raak, dan	Microscopic same characteristics as macroscopic

Neem dit mos ruimte in, en so aan..	Define by distance
Q: Ja	
A: .. so dit word versprei oor die hele plek, so deeltjies word minder in daai sekere area waar as dit soos `n vastestof was.	Define by distance
Q: Ja	
A: En dan’s ons by die gas, dan gaan dit half in die lug op en dan’s dit soos heeltemal in die hele lug versprei. En dan word die deeltjies minder want die spasies is groter.	Define by distance
Q: Goed, die hoeveelheid deeltjies in die vastestof, ..	
A: Ja.	
Q: ... wat is die vergelyking met die hoeveelheid deeltjies in die vloeistof en die hoeveelheid deeltjies in die gas?	
A: Wil mevrou, ok dis net soos drie, die vloeistof is soos in baie	Literal deduction from model
Q: Ja	
A: ...en dan’s die gas is omtrent soos, as ek net vinnig kyk net in `n derde byvoorbeeld daarvan.	Literal deduction from model
Q: Goed.	
A: Dis baie baie minder.	Literal deduction from model
Q: Goed. Dankie. Nou die laaste vragie: hier het ek nou, ek gaan nou vir jou `n praktiese demonstrasie gee, die blokkie ys gaan smelt, en dan wil ek hê jy moet vir my sê wat gebeur, verduidelik weer vir my, in terme van deeltjies,	
A: Reg	
Q: .. soos jy nou die sketsie gebruik het. Wat gebeur met die blokkie ys as hy smelt. Goed ek kan hom, ek kan hom laat staan, as jy hom laat smelt, wat gebeur dan?	
A: Dan begin hy klaar smelt. Soos wat hy nou staan?	
Q: Ja, dis hy..	
A: Hy begin klaar smelt, dit is nie meer die koue temperatuur waarin hy in is nie. Die, die kamer temperatuur laat hom smelt, en so, want hy bereik nou `n hoër temperatuur.	
Q: Goed. Nou gaan ek die vlammetjie aansteek, dat hy vinniger smelt. En dan wil ek weer weet wat gebeur met die deeltjies? Die water se deeltjies of die water se molekules, as hy smelt.	
A: Ok, as gevolg van die hitte verdamp van die molekules. En dan dit, word mos nou die spasies word groter tussen in.	Define by distance
Q: Ja	

A: Alles is mos nou vasgevries in `n klein spasie. Q: Ja A: En soos dit nou warmer word, versprei die deeltjies mos nou van mekaar af. Q: Ja A: Dan word daar lugruimtes tussenin geskep. Q: Ja A: Daarom maak dit hom nou vloeibaar. Q: Goed, en as hy nou vloeibaar is...? Daar, daar's reeds `n bietjie water. As hy, vloeibaar is ...? Die volgende faseverandering? A: Dis die gas, soos wat mens daar kan sien. Soos in `n mens kan soos half sien daar gaan gas in die lug op soos wat daai deeltjies nou nog verder uit mekaar uit gaan. Q: ...uit gaan. Goed, uhm, as ek vir jou sê ek het 500 deeltjies in die ysblokkie, .. A: Ja Q: .. Hoeveel deeltjies het ek in die vloeistof en hoeveel deeltjies het ek in die gas? A: Sê nou maar jy gaan 300 in die vloeistof hê, en net soos in 100 in die gas hê. Q: Goed. A: Ja. Q: Goed. Baie dankie. A: Dis reg so. Q: Dis al wat ek wil, wou weet, dankie. A: Dis `n plesier.	Define by distance Define by distance Misconception Misconception Define by distance Literal deduction from model

Table 6.18: Interview 6

Questions(Q) and answers(A)	Coding
Q: Kan jy vir my die drie fases van materie opnoem? A: Vaste stof vloeistof en waterstof – nee – vastestof, vloeistof en gas. Q: daar's hy, dankie. Wat is die hoof verskille tussen die drie fases? Die grootste verskille tussen die drie fases? A: Kyk vastestof is eh soliede stowwe. Vloeistowwe is wat waterig is, tannie, dit kom in `n vorm in en hy vat die vatsoen van hom en gas is wat soos waterstof, dit is nie sienbaar nie, dit verdamp vinnig. Dit kan in `n fatsoen gesit word, dit omvat die hele vatsoen, maar dit is nie `n vaste ding wat jy kan optel en rondskuif nie. Q: Goed dankie. Wat gebeur met die deeltjies wanneer `n stof van fase verander? Probeer vir my verduidelik deur `n voorbeeld te gebruik. A: Ok, van vaste stof na voeistof is wanneer die stof , uhm, ten minste, is al die deeltjies naby mekaar.. Q: Ja A: en dan skuif skuif die deeltjies meer weg van mekaar sodat dit meer vloeibaar .. Q: Ja ... A: minder hanteerbaar. Ok dan van vloeistof na gas, is as die deeltjies nog verder van mekaar af weg gaan. Die deeltjies word al hoe kleiner en dit word half nie meer as een deeltjie nie, meer soos waterstof nie, dit word drie molekules, wat al hoe verder van mekaar af weg gaan. Q: Goed, dankie. Kan jy vir my, in in hierdie diagram, dit is `n diagram wat uit `n skoolhandboek uit kom, ek wil hê jy moet na die diagram kyk en vir my sê wat gebeur met die deeltjies, in die diagram. A: Wat gebeur met die deeltjies in die diagram? Q: Ja. A: Ok, wat gebeur het of hoe dit is eintlik, die deeltjies is baie na aan mekaar, .. Q: Ja, ja, ja, dis wat ek wil hê jy moet vir my sê wat gaan hier aan in die diagram. A: Ok, soliede vaste stowwe is baie naby aan mekaar, almal is half rakend aan mekaar. Vloeistowwe is verder van mekaar af weg en gasse is baie ver van mekaar af weg. Dit het amper geen aanraking nie, heeltemal geen. Q: Ok goed en sê vir my: die hoeveelheid deeltjies, kan jy vir my	Phases correct Unsure answer Microscopic same characteristics as macroscopic Microscopic same characteristics as macroscopic Microscopic same characteristics as macroscopic Define by distance Microscopic same characteristics as macroscopic Define by form / distance Misconception Define by distance Misconception Define by distance Literal deduction from model Define by distance Literal deduction from model Define by distance Unsure answer

kommentaar gee daaroor? A: Dit is nie, soos reliable nie want solied is amper daar soos byvoorbeeld 20 deeltjies .. Q: Ja.. A: en dan, liquid is daar amper die helfte; en dan is daar in gas gas, nog die helfte van die helfte. So jy weet nie regtig hoe vêr hulle alles van mekaar af is nie want dis nie dieselfde hoeveelheid nie. Q: Goed, dankie. Kan ek net vinnig vir jou `n demostrasietjie en vir my ook net jou kommentaar gee. Goed, ek wil net hê jy moet vir my soos die die faseveranderings plaasvind net sê wat gebeur, in terme van die deeltjies A: Ok Q: en hoeveelheid A: Ok Q: Verstaan jy? A: Ja Q: Goed. Q: Goed dis nou ... A: Resultate Q: Ja. Dit is nou `n blokkie ys wat gaan smelt. A: Uhum Q: So jy kan vir my kommentaar gee soos wat jy sien wat gebeur. A: Ok soos dit gebeur sal dit van vloei.Van vaste stof af nou warmer word, so dan gaan die deeltjies oplos of so verder van mekaar af weg beweeg. So dit gaan `n vloeistof word en na dit dan klaar `n vloeistof, nou ok dit gebeur nog nie, nadat dit `n vloeistof gaan wees, ok wasem, so wasem beteken dit gaan in waterstof in, en dit is dan `n gas. So dit is van vloeistof.. vstestof na vloeistof na gas toe deur ... Q: goed. A: ....deur die proses van warmte. Q: Kan jy vir my sê die hoeveelheid deeltjies wat in die ysblokkie is? A: Nee ek kan dit nie doen nie ... Q: Nee, nee, nee, ek wil nie weet hoeveel dit is nie, A: Ok .... Q: Ek wil weet as hy nou van vloeistof af gaan, ag van vastestof af gaan na vloeistof toe, A: Ja ..	Model confuses student Model confuses student Microscopic same characteristics as macroscopic Misconception Microscopic same characteristics as macroscopic Misconception Wrong scientific terminology

Q: .. en daarna na gas toe, wat is die .... A: Dit gaan minder word want die vastestof is al die deeltjies saam en nou kom daar gla klaar die deeltjies klaar weg nou word dit met water, met die vloeist, deur gas weg gaan. Dit gaan uit.. Q: Goed A: Dit raak al minder, die deeltjies word al hoe minder. Later as jy dit so gaan los, gaan dit heeltemal weg wees. Q: OK goed. En eh sou die deeljies nie gas word nie, kyk hy word nou vinnig gas ... A: Ja, ja Q: ...omdat hy smelt. A: As hy nie is nie, sal die hoeveelheid dieselfde bly. Q: Gaan dit dn dieselfde bly? Goed. A: tensy dit nie verdamp of goed nie. Q: Goed, jy sê dit verdamp en dis hoekom die deeltjies minder word? A: Ja, want dit verander in gas. Van vastestof na gas. Q: Goed daar's hy, baie dankie. A: Dis `n plesier.	Literal deduction from model Microscopic same characteristics as macroscopic Misconception Literal deduction from model Misconception Microscopic same characteristics as macroscopic

In Table 6.19 a summary is made of the prevalence of all the different codes assigned to phrases in the text. It is a summary of all the codes and the number of times each interviewee used quotations linked to a specific code. Interviews are abbreviated as **"In"** for the purpose of the table.

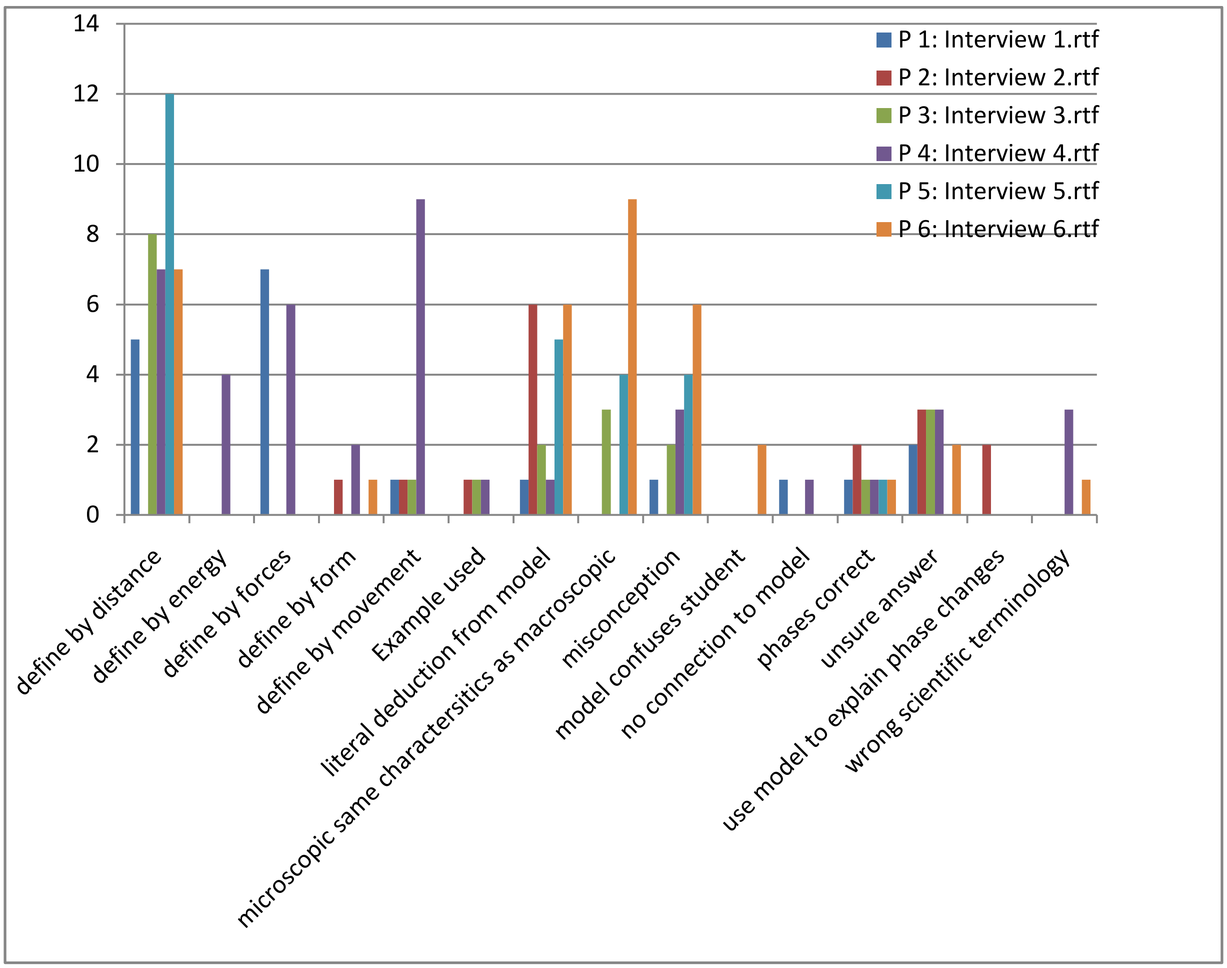
Table 6.19: Codes Table

CODES	In 1	In 2	In 3	In 4	In 5	In 6	TOTALS
Define by distance	5	0	8	7	12	7	39
Define by energy	0	0	0	4	0	0	4
Define by forces	7	0	0	6	0	0	13
Define by form	0	1	0	2	0	1	4
Define by movement	1	1	1	9	0	0	12
Example used	0	1	1	1	0	0	3

Literal deduction from model	1	6	2	1	5	6	21
Microscopic characteristics same as macroscopic	0	0	3	0	4	9	16
Misconceptions	1	0	2	3	4	6	16
Model confuses student	0	0	0	0	0	2	2
No connection to model	1	0	0	1	0	0	2
Phases correct	1	2	1	1	1	1	7
Unsure answer	2	3	3	3	0	2	13
Use model to explain phase changes	0	2	0	0	0	0	2
Wrong scientific terminology	0	0	0	3	0	1	4
TOTALS	19	16	21	41	26	35	158

In Figure 6.1 the data from Table 6.22 is displayed as a graph.

Figure 6.1: Graphical presentation of interview results



6.7 Discussion of interview results

The interviews took place after the students completed the SNSE 111 and PHSE 111 modules. This has the implication that all the students that participated in this study already had a formal lesson about phase changes. The motivation behind this was a matter of time and availability of the students. The chemistry section of SNSE111 is first in line at the beginning of the first year of SNSE 111. The questionnaires were completed during the first few periods the SNSE 111 students attended class. There was therefore not enough time to analyse the questionnaires before students received instruction about the phases of matter. The SNSE 111 module only covered the basics and the PHSE 111 module did a more in depth study of matter and phase changes.

All the students, except for one who could answer the question with a little help, knew the three phases, solid, liquid and gas without ado. All the students, except for one, defined phase changes by the distance between the particles. The distance is described as increasing from solid to liquid and eventually to gas. Only one student mentioned the difference in energy between the three different stages. Some of the students mentioned the heat that is applied to facilitate a phase change but did not connect it to kinetic energy.

Two students mentioned the forces between the particles in connection to the different phases. No mention was made that this is forces of attraction between the particles and that the kinetic energy coming from the heat, supplies the particles with the energy to sever the forces of attraction.

Three students define the phase changes by the shape or appearance of the particles. This connects with another code, misconceptions. The misconceptions are mainly because the students attribute macroscopic properties to microscopic events. The particle takes the appearance of the water when ice turns to liquid. Three students also endorsed macroscopic properties to the microscopic events taking place during phase changes. For instance, if the phase changes to water, the particles become runny as well. One student[63] commented that if the matter is left indefinitely, all the particles will disappear eventually. This student ignored the principle of conservation of matter.

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[63] Interview 6

Four students defined the phase changes by the movement of the particles. There is a definite tendency by the students to explain the phase changes from solid to liquid and gas with an increasing mobility of the particles. When all the different ways that students define phase changes by, is compared, it seems that phase changes are most commonly defined by the distance between the particles followed by the forces and movement of the particles.

Half of the students spontaneously selected water to explain phase changes. This can be attributed to the everyday use of water as an example in school textbooks to explain phase changes. The student who was unsure of the three phase changes, immediately connected water to the phases when the interviewer mentioned water as an example.

The entire group made at one stage or the other literal deductions from the model[64] used during the interviews. Three students literally deduct that the number of particles decreases as the matter changes from solid to liquid to gas. This result is important in the light of the negligence of the textbooks[65] to adhere to the principle of conservation of matter in their sketches of the models. Some students commented on the shape or size of the particles. One student was very confused about the number of particles as the model was very confusing according to her. She commented that not all the particles were visible so she couldn't comment on the number.

Just one student answered the question about the experiment[66] without any reference to the deductions made from the model[67] used in the previous question. Literal deductions are made about the number of particles left after a phase changes. This leads to misconceptions about the disappearance of particles during phase changes. The literal deduction about the distance between the particles does not lead to misconceptions as the distance between the particles does expand as the matter change from solid to liquid to gas.

Just one student was confident about all the answers he/she gave. The rest of the students were somewhat doubtful about their answers and made remarks like "I think" or "is that right?".

[64] Annexure B question 4
[65] Chapter 4 paragraph 4.5
[66] An ice cube is heated in a beaker to form water and then water vapour.
[67] Annexure B question 4

Wrong scientific terminology was used to explain phase changes. A term like "hydrogen" instead of "gas" is an example of this.

Conclusions can firstly be drawn from the results of the questionnaire[68]:

- The students have a very poor understanding of the basic concepts of atoms, ions and molecules. Learners had a problem visualizing and verbalising atoms, ions and molecules. As atoms are the basic building blocks of matter, they need to understand what atoms are. If this basic knowledge is not understood well, phase changes and the particulate nature of matter will be misunderstood as well.
- Students make literal deductions from models representing phase changes For example they count the number of particles in the model and deduct that particles get lost when matter changes phases.
- Students treat models as true pictures of non-observable phenomena and this makes it difficult for students to visualize their own models.
- Macroscopic characteristics of matter such as colour and shape are transferred to microscopic units.
- Various misconceptions exist about phase changes and the particulate nature of matter. These misconceptions need to be identified and corrected for students to acquire a better understanding of the basic concepts of atoms, ions and models.

Secondly the interviews provide the following conclusions:

- Students are familiar with the three phases of matter.
- Phase changes are defined primarily by movement of the particles, distance between particles and the forces between particles.
- Students make literal deductions from models representing phase changes.
- Macroscopic properties are transferred to microscopic events during phase changes.

The students' scientific vocabulary about phase changes is not always on standard for first year students.

[68] Annexure A

6.8 Summary

Firstly this chapter dealt with students' responses to the items in the questionnaire[69]. It gave an indication of the students' ability to visualise and verbalise concepts like atoms, ions and molecules[70]. Students' knowledge of physical changes was also tested[71]. The questions about physical changes incorporated a model[72] commonly found in school textbooks. This question was included to test if the students made literal deductions from the model. The last few questions[73] in the questionnaire dealt with students' perceptions regarding microscopic events and their tendency to attribute macroscopic features to microscopic events.

From the results it was evident that the students who participated in the study did not grasp the concepts of atoms, ions and molecules very well. This is understandable for the SNSE 111 students, as they did not have the reinforcing of these concepts as the PHSE 111 students had in grade 10, 11 and 12. The data shows that students make literal deductions from models and attribute macroscopic properties to microscopic events. Students do not apply the principle of conservation of matter to the phase changes. They literally count the amount of particles in each block of the sketch[74] and thus deduct that particles disappear when changing phase for example from solid to liquid.

Secondly the results of the interviews[75] are reported and analysed seperately[76]. From the interviews a lot of misconceptions were identified. Students made literal deductions from the model[77] used during the interviews. A tendency to present macroscopic properties to microscopic events was also detected, as in the questionnaire. Phase changes were mostly defined by the distance between particles as well as the forces between and movement of the particles. This corresponds with the models used in textbooks[78] discussed in chapter 4. Characteristics like energy and the shape and contour didn't feature prominently in their

[69] Annexure A
[70] Annexure A questions 1-3
[71] Annexure A question 4
[72] Annexure A question 4.8
[73] Annexure A question 5
[74] Annexure A question 4.8
[75] Chapter 6.6
[76] Paragraph 6.4
[77] Annexure B question 4
[78] Paragraph 4.5

explanations of differences between the phases. The principle of conservation of matter never featured in any explanation given by any student concerning phase changes.

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

Chapter 7 Conclusions and Recommendations

This chapter provides a brief summary of all the chapters as well as conclusions and recommendations. The conclusions and recommendations are based on the results of the empirical study that aimed to investigate first year natural science education students' association between microscopic models and macroscopic processes such as phase changes in chemistry.

7.1 Summary of chapters

Chapter 1 serves as an orientation to the research problem, the rationale and the research process. A short review of the relevant literature is done to position the research aim, namely to investigate first year natural science education students' association between microscopic models and macroscopic events such as physical and chemical change, in context. The literature refers to the use of different types of models in chemistry education as well as the educational framework within chemistry education and research takes place.

Chapter 2 provides a literature review of the role of models in chemistry and chemistry education. Different types of models are discussed and the history and philosophy of models are briefly attended to. This chapter also provides teaching and learning perspective on micro-macro relationships in chemistry. The roles as well as the types of general misconceptions about the particulate nature of matter as well as phase changes are discussed. The importance of identifying these misconceptions amongst students in order to improve chemistry education is emphasised.

In **Chapter 3** the relationship between constructivism and chemistry research and education is presented as a theoretical framework. The theoretical framework is considered an instrument in chemistry research. The theoretical perspectives in chemistry education are grouped into categories of constructivism, hermeneutics, and critical theory. For the purpose of this study constructivism is discussed extensively in the following subsections: symbolic interactionism, models and modelling and pedagogical content knowledge. Hermeneutics and critical theory are only mentioned to orientate constructivism with respect to the theoretical framework.

Models are used in chemistry to explain the particulate nature of matter and phase changes. In **Chapter 4** the literature, school textbooks as well as chemistry textbooks, are evaluated and the researcher takes a look at different types of models used to explain phase changes and the particulate nature of matter. One such model, presented by Linsje (1990) led to the conclusion that students make literal deductions from models. This was the rationale for the model used in the questionnaire[79] and the model[80] used for the interviews. The particulate nature of matter and phase changes is discussed along with the principle of conservation of matter. In the literature study, many models came to the fore that can lead to misconceptions and confusion for learners and students.

Chapter 5 describes the research methodology used in this study. The composition of the population is explained. Two year groups of SNSE 111 students as well as a small group, PHSE 111, students serve as population. The composition of the questionnaire[81] is discussed as well as the approach to the analysis of the questionnaires. In order to analyse the qualitative part of the study, the interviews, a short summary of how to analyse and utilise interviews are prepared. It is important to conduct interviews so that reliable and valid results can be collected.

Chapter 6 reported the results of this study and the analysis thereof. The results of the questionnaires are reported and analysed question by question. The interviews are analysed with the use of the ATLAS.ti6.2 program.

7.2 Discussion of results in the framework of the literature study

Some observations that Norman (1983) made on mental models led him to make a few generalisations about mental models[82], namely:

- Mental models are not complete
- People's abilities to use their own mental models are severely limited
- Mental models are "unscientific",

[79] Annexure A question 4.8
[80] Annexure B question 4
[81] Annexure A
[82] Paragraph 2.4.1

The results of this empirical study are in line with the observations that Norman (1983) made. The students who participated have incomplete, severely limited and unscientific mental models[83].

Students live and function in the macroscopic world of matter but unfortunately they often do not recognise chemistry as part of their surroundings and do not easily link the microscopic and macroscopic (Levy Nahum *et al.,* 2004). The participants in this study connected the microscopic events directly with the macroscopic world we live in[84]e.g. when attributing macroscopic properties to microscopic events.

Learning problems arise because a student cannot understand the phenomenology and laws of chemistry (Ben-Zvi *et al.,* 1990). To facilitate proper understanding, students should be able to function on all descriptive levels. One of these levels is:

- the macro level where the student needs to know the difference between liquid and gas properties[85].

The participants of this study clearly don’t function on the macro level because there is not an optimal understanding of these concepts. Students fail to distinguish between the different properties of the phases of matter[86].

According to Ben-Zvi *et al*. (1990) students have difficulties in understanding macro-micro relationships. These difficulties can, however, be overcome by appropriate attention to teaching methods. An important feature of a constructivist classroom is the fact that learners are often presented with a concept which is in conflict to their life world experience. The educator should be aware of such alternative conceptions and address these issues effectively[87]. This study provides the researcher with a lot of useful data which gives the teacher insight into the conceptual thinking and misconceptions of the population[88].

[83] Paragraph 6.7
[84] Paragraph 6.5 analysis of questions 5.1.2, 5.1.3, and 5.2.1. 5.2.2, and paragraph 6.7
[85] Paragraph 2.5
[86]Paragraph 6.5 analysis of question 4
[87]Paragraph 3.6.5
[88] Paragraph 5.1.1

Van Rooyen and de Beer (2006) summarised constructivism in the classroom as follows:

- The best way to understand constructivism is to see actual examples, speak to others and try it in the classroom.

- When learners question themselves and their learning strategies constantly, they become more efficient and reflective learners. The teacher fulfils the role of facilitator to facilitate the reflection process.

- Constructivist classrooms demand a highly motivated educator in terms of preparation and supervising teaching-learning activities.

- As learners gain knowledge they start to feel more empowered and this create increasingly stronger abilities to integrate and internalise new information.

Implementing the above mentioned principles summarised by Van Rooyen and de Beer (2006) can improve the participants understanding of concepts like phase changes and the particulate nature of matter. In the context of the SNSE 111 and PHSE 111 modules, a highly motivated lecturer leads to a highly motivated and reflective student teacher. As the Natural and Physical Science teachers are so scarce, the application of constructivism is of the utmost importance to these modules. The use of constructivism in the classroom ultimately improves the PCK[89] of the students leading to more effective educators.

Anderson (1990:28) had the following criticism regarding textbooks for chemistry:

- Atoms and molecules are seldom perceived in the hypothetico-decductive sense.

- Students are required to learn facts about chemistry the same way they learn facts about the observable world

- Too many different atomic models are used.

- No clear distinction is made between atoms, molecules and substances.

[89] Paragraph 3.5.2.2

The questionnaire included a model from a current grade 8 textbook (Van Aswegen & Van Aswegen, 2005, p76). This model depicts the number of particles becoming less and less during each phase change. This model was included to further explore the findings[90] of Linsje (1990). In accordance with the findings of Linsje (1990), the results of this study indicate that students made literal deductions from the model used. Models with the same number of particles in each phase should be used in the introductory level so that misconceptions like "there is less particles in the gas phase than the liquid phase"[91], could be prevented. The conservation of mass is a very essential and fundamental idea in chemistry. Its application is yet again tied directly to the particle ideas (Taber, 2002a). The original mass of a fixed number of particles is the same as the sum of all the constituents it is divided into.

Two key instruction points during phase changes are:

- the same number of "particles" are present at the beginning and the end, and
- the total mass stays the same.

The model[92] used in this study leads to a lot of confusion about the principle of conservation of mass to students and ultimately provides an incorrect base to the understanding of more difficult concepts in chemistry.

7.3 Conclusions

Before any conclusions can be drawn, it should be stated clearly that the findings from this study is only applicable to the group tested and cannot be considered as a standard for all first year students at this university.

In chapter one the following two research questions were asked:

- What is the state of first year natural science education students' mental models regarding phase changes in chemistry?
- What are their prior knowledge and understanding of models and representations of basic chemistry concepts such as atoms, ions and molecules?

[90] A student who cannot distinguish between model and observation makes literal deductions from models.
[91] Paragraph 6.7
[92] Grade 8 textbook (Van Aswegen & Van Aswegen, 2005, p76.)

The conclusion the researcher can deduct from the analysis of the data is that:

- Firstly, the state of the students' mental models regarding phase changes is very poor even after instruction on this topic. The students had severe difficulties in reproducing their own mental models both by sketching and especially verbalising it.
- Secondly, students have a very poor prior knowledge of the basic concepts of atoms, ions and molecules. Students have almost no knowledge about ions in particular. There was a distinctive difference between the SNSE 111 and PHSE 111 groups in terms of prior knowledge. The PHSE 111 students have a better prior knowledge but it is not satisfactory at all considering that they completed grade 12 Physical Science successfully.

7.4 Recommendations

The results of this study indicate that students have difficulty with the basic concepts, atoms, ions and molecules and the understanding and representing of phase changes. The following is recommended for chemistry teaching in this regard:

- Educators should use teaching and learning strategies that firstly ensure the capture of basic concepts, atoms, ions and molecules and secondly include the use and construction of these concepts. Constructivism can be used beneficially to discredit misconceptions and establish scientific correct concepts.
- Basic explanations of phase changes should include kinetic energy as well as forces of attraction as definitive vocabulary. Conservation of mass should always be emphasized.
- Students should master the visualization of these basic concepts and then the visualization of more complex concepts, like phase changes, should be easier.
- Models used to explain phase changes should include all particles in the three phases. One model in chapter 4 (Akoojee *et al.,* 2000, p 124.) is a better explanatory model to use when teaching phase changes. It should be stated that chemistry should not be taught without the use of models. The importance of models is outlined in chapter 2.
- Students should be encouraged to become modellers themselves and in this way learn to interpret and use models more effectively.
- Students should be exposed to different types of models, this way they acquire a better perspective of a certain concept.

7.5 Short comings of this study

In order to make the result of a study like this more widely applicable, the following can be done:

- This is a study done locally at the North West University and only a portion[93] of the first year students was used. More usable results could be generated if all the first year Educational Study students were used for this study.
- Secondly a better image of first year students could be achieved if a reliable sample of all the first year students was done.
- The interviews should have been done before the students received any instruction on the topics.
- An intervention can be staged with the help of a model[94] where the particles are in the right proportion and number to determine whether it is a helpful tool.

7.6 Concluding remark

During this study I became aware of the intensely important role models and modelling, in collaboration with constructivism plays in chemistry education. Educators who utilise models to the fullest can get better results and thus ease South Africa's burden, the immense shortage of Science Educators.

[93] SNSE 111 & PHSE 111
[94] Chapter 4 (Akoojee *et al.,* 2000, p 124)

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ANNEXURE A: Questionnaire

Studente Vraelys oor Materie

Naam:..Studentenommer.............................   **Jaar matriek geskryf:.................   Geslag: ....**   **Fisiese Wetenskap (Natuur-en Skeikunde) geneem tot graad:................**

Antwoord asseblief al die vrae op die vraelys deur die korrekte blokkie of die korrekte antwoord met 'n kruisie te merk.

1. Atome

1.1 Teken die prentjie van 'n atoom soos jy dit in jou gedagtes sien in die spasie voorsien.

1.2 Verduidelik in jou eie woorde wat 'n atoom is
....
....
....
....

1.3 Gee 'n voorbeeld van 'n atoom
....
....
....

2. Ione

2.1 Teken die prentjie van 'n ioon soos jy dit in jou gedagtes sien in die spasie voorsien.

2.2 Verduidelik in jou eie woorde wat ‘n ioon is

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

2.3 Gee ‘n voorbeeld van ‘n ioon

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

3. Molekule

3.1 Teken die prentjie van ‘n molekule soos jy dit in jou gedagtes sien in die spasie voorsien.

3.2 Verduidelik in jou eie woorde wat ‘n molekule is

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

3.3 Gee ’n voorbeeld van ’n molekule

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

4. Fisiese veranderinge

4.1 Verduidelik die term “**vastestof**” in jou eie woorde

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

4.2 Gee ‘n voorbeeld van ‘n vastestof

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

4.3 Verduidelik die term “**vloeistof**” in jou eie woorde

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

4.4 Gee ‘n voorbeeld van ‘n vloeistof

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

4.5 Verduidelik die term “**gas**” in jou eie woorde

....

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

4.6 Gee 'n voorbeeld van 'n gas
....
....
....

4.7.1 Is daar spasies tussen die deeltjies van 'n vastestof?

JA	**1**
NEE	**2**

4.7.2 Teken 'n model van 'n vastestof se deeltjies.

4.7.3 Is daar spasies tussen die deeltjies van 'n vloeistof?

JA	**1**
NEE	**2**

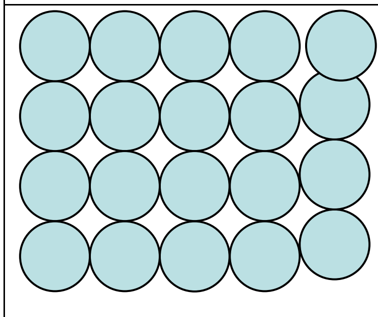
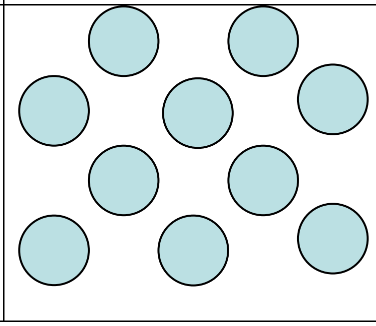
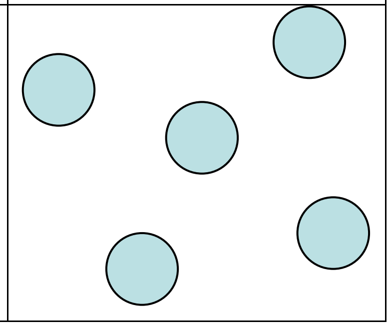
4.7.4 Teken 'n model van 'n vloeistof se deeltjies.

4.7.5 Is daar spasies tussen die deeltjies van 'n gas?

JA	**1**
NEE	**2**

4.7.6 Teken 'n model van 'n gas se deeltjies.

4.8 Maak gebruik van die onderstaande model uit 'n graad sewe leerdershandboek om die volgende vrae te beantwoord:

Vastestof	Vloeistof	Gas
		

4.8 Wanneer die <u>vastestof na vloeistof</u> verander:

4.8.1 word die spasies tussen die deeltjies

groter	1
kleiner	2
of bly dieselfde	3

4.8.2 word die beweging van die deeltjies

vinniger	1
stadiger	2
of bly dieselfde	3

4.8.3 word die kragte tussen die deeltjies

groter	1
kleiner	2
of bly dieselfde	3

4.8.4 Verander die deeltjies van vorm?

JA	1
NEE	2

4.8.5 Indien jou antwoord <u>**ja**</u> is, beskryf hoe die deeltjies verander het.
………
………
………
………
………………

4.8.6 Word die aantal deeltjies gedurende die faseverandering

meer	1
minder	2
bly dieselfde	3

4.9 Wanneer die vloeistof na gas verander:

4.9.1 word die spasies tussen die deeltjies

groter	1
kleiner	2
of bly dieselfde	3

4.9.2 word die beweging van die deeltjies

vinniger	1
stadiger	2
of bly dieselfde	3

4.9.3 word die kragte tussen die deeltjies

groter	1
kleiner	2
of bly dieselfde	3

4.9.4 Verander die deeltjies van vorm?

JA	1
NEE	2

4.9.5 Indien jou antwoord **ja** is, beskryf hoe die deeltjies verander het

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

4.9.6 Word die aantal deeltjies gedurende die faseverandering

meer	1
minder	2
bly dieselfde	3

5. Mikroskopiese eienskappe

5.1 Tafelsout (**NaCl**) is saamgestel uit natriumione en chloorione. NaCl se voorkoms is klein wit kristalle. Kies die korrekte antwoord by die volgende vrae:

5.1.1 ‘n Tafelsoutkristal bestaan uit een molekule

JA	**1**
NEE	**2**

5.1.2 Die NaCl- molekule is wit soos die kristal

JA	**1**
NEE	**2**

5.1.3 Wanneer 'n soutkristal in water opgelos word, word die molekule onsigbaar

JA	**1**
NEE	**2**

5.1.4 Teken jou eie model van 'n **NaCl-molekule**

5.1.5 Teken jou eie model van 'n **NaCl-kristal**

5.2 Swawelpoeier ($\mathbf{S_8}$) is 'n fyn geel poeier. Antwoord die volgende vrae deur die korrekte blokkie te merk:

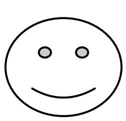
5.2.1 Die kleur van die swawelatome is geel

JA	**1**
NEE	**2**

5.2.2 Swawelpoeier ($\mathbf{S_8}$) bestaan uit 8 swawelatome

JA	**1**
NEE	**2**

5.2.3 Teken jou eie model van die swawelmolekule



BAIE DANKIE VIR JOU DEELNAME!

ANNEXURE B: Interview Questions

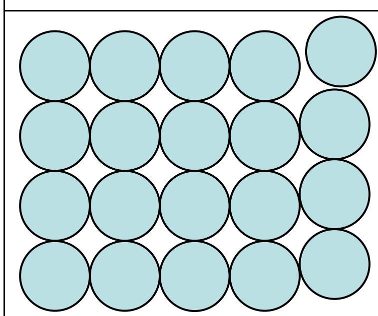
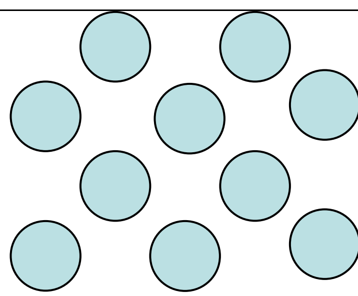
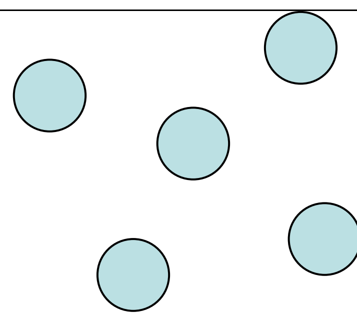
Questions posed to students during semi-structured interviews:

1. Can you name the three states of matter?

2. What are the main differences between these states?

3. What happens to particles when a substance changes from one state to another? Explain with the use of an example.

4. Please explain what happens to the particles in this diagram. Why do you say so?

SOLID	**LIQUID**	**GAS**
		

5. Explain what happens to the particles in this practical demonstration[95] of the phase changes water undergoes from ice to water to water vapour. Why do you say so?

[95] An ice cube is heated in a beaker to form water and then water vapour.

ANNEXURE C: Summarised results of questionnaires

TABLE 1: Biographical Information SNSE 111 2009: 54 Participants

SEX

Response	Number	Percentage
Male	9	17
Female	41	76
Not responded	4	7
Total	54	100

PHYSICAL SCIENCE AS SUBJECT TO SCHOOL GRADE:

Grade	Number	Percentage
9	33	61
10	6	11
11	4	7
12	8	15
Not responding	3	6
Total	54	100

SCHOOLYEAR MATRIC:

Year	Number	Percentage
2003	1	2
2004	1	2
2005	1	2
2006	2	4
2007	16	28
2008	29	54
2009	2	4
Not responding	2	4
Total	54	100

TABLE 2: Biographical Information SNSE 111 2011: 70 Participants

SEX

Response	Number	Percentage
Male	18	26
Female	47	67
Not responding	5	7
Total	70	100

PHYSICAL SCIENCE AS SUBJECT TO SCHOOL GRADE:

Grade	Number	Percentage
9	51	73
10	6	9
11	1	1
12	4	6
Not responding	8	11
Total	70	100

SCHOOL YEAR MATRIC:

Year	Number	Percentage
1998	1	1
2000	1	1
2002	1	1
2004	2	3
2006	2	3
2007	5	7
2008	3	4
2009	16	23
2010	39	57
Total	70	100

TABLE 3: Biographical Information PHSE 111 2011: 14 Participants

SEX

Response	Number	Percentage
Male	4	29
Female	10	71
Total	14	100

PHYSICAL SCIENCE AS SUBJECT TO SCHOOL GRADE:

Grade	Number	Percentage
12	14	100
Total	14	100

SCHOOL YEAR MATRIC:

Year	Number	Percentage
2008	1	7
2010	13	93
Total	14	100

TABLE 4: Summary of responses SNSE 11 2009

Question	**Analysis**	**Number students**	**% students**
4.7.1 are there spaces between the particles of a solid?	Yes No No Answer	9 40 5	17 74 9
4.7.3 Are there spaces between the particles of a liquid?	Yes No No Answer	43 9 2	80 17 4
4.7.5 Are there spaces between the particles of a gas?	Yes No No answer	42 4 8	78 7 15

4.8.1 When a solid changes to a liquid, the spaces between the particles become	Bigger Smaller Stay the same No Answer	47 5 1 1	87 9 2 2
4.8.2 When a solid changes to a liquid, the movement of the particles becomes	Faster Slower Stays the same No Answer	40 10 3 1	74 19 6 2
4.8.3 When a solid changes to a liquid, the force between the particles becomes	Bigger Smaller Stays the same No answer	13 27 10 4	24 50 19 7
4.8.4 When a solid changes to a liquid, does the particles' shape change?	Yes No No Answer	11 40 3	20 74 6
4.8.6 When a solid changes to a liquid, the number of particles becomes	Bigger Smaller Stays the same No Answer	7 23 21 3	13 43 39 6
4.9.1 When a liquid changes into a gas, the spaces between the particles become	Bigger Smaller Stay the same No Answer	49 3 1 1	91 6 2 2
4.9.2 When a liquid changes into a gas, the movement of the particles becomes	Faster Slower Stays the same No Answer	39 13 0 2	72 24 0 4
4.9.3 When a liquid changes into a gas, the force between the particles becomes	Bigger Smaller Stays the same No answer	20 26 5 3	37 48 9 6

4.9.4 When a liquid changes into a gas, does the particles' shape change?	Yes No No Answer	14 37 3	26 69 6
4.9.6 When a liquid changes into a gas, the number of particles becomes	Bigger Smaller Stays the same No answer	8 25 17 4	15 46 31 7
5.1.1 A table salt crystal consists of one molecule	Yes No No Answer	12 37 5	22 69 9
5.1.2 The NaCl molecule is white like the crystal	Yes No No Answer	36 13 5	67 24 9
5.1.3 When a salt crystal dissolves in water, the molecule becomes invisible	Yes No No Answer	41 9 4	76 17 7
5.2.1 The colour of a sulphur atom is yellow	Yes No No Answer	37 13 4	69 24 7
5.2.2 Sulphur powder (S_8) consists of 8 sulphur atoms	Yes No No answer	37 11 6	69 20 11

TABLE 5: Summary of responses SNSE 111 2011

Question	**Analysis**	**Number of students**	**% students**
4.7.1 Are there spaces between the particles of a solid?	Yes No No Answer	8 57 5	11 81 7

4.7.3 Are there spaces between the particles of a liquid?	Yes No No Answer	52 9 9	74 13 13
4.7.5 Are there spaces between the particles of a gas?	Yes No No Answer	51 12 7	73 17 10
4.8.1 When a solid changes to a liquid, the spaces between the particles become	Bigger Smaller Stay the same No Answer	56 5 3 4	80 7 4 9
4.8.2 When a solid changes to a liquid, the movement of the particles becomes	Faster Slower Stays the same No Answer	49 12 3 6	70 17 4 9
4.8.3 When a solid changes to a liquid, the force between the particles becomes	Bigger Smaller Stays the same No Answer	18 39 5 8	26 56 7 11
4.8.4 When a solid changes to a liquid, does the particles' shape change?	Yes No No Answer	19 46 5	27 66 7
4.8.6 When a solid changes to a liquid, the number of particles becomes	Bigger Smaller Stays the same No Answer	9 37 17 7	13 53 24 10
4.9.1 When a liquid changes into a gas, the spaces between the particles become	Bigger Smaller Stay the same No Answer	54 10 0 6	77 14 0 9
4.9.2 When a liquid changes into a gas, the movement of the particles becomes	Faster Slower Stays the same No Answer	38 25 1 6	54 36 1 9

4.9.3 When a liquid changes into a gas, the force between the particles becomes	Bigger Smaller Stays the same No Answer	34 67 12	30 59 11
4.9.4 When a liquid changes into a gas, does the particles' shape change?	Yes No No Answer	15 48 7	21 69 10
4.9.6 When a liquid changes into a gas, the number of particles becomes	Bigger Smaller Stays the same No Answer	11 40 13 6	16 57 19 9
5.1.1 A table salt crystal consists of one molecule	Yes No No Answer	24 38 8	34 54 11
5.1.2 The NaCl molecule is white like the crystal	Yes No No Answer	53 10 7	76 14 10
5.1.3 When a salt crystal dissolves in water, the molecule becomes invisible	Yes No No Answer	55 8 7	79 11 10
5.2.1 The colour of a sulphur atom is yellow	Yes No No Answer	47 16 7	67 23 10
5.2.2 Sulphur powder (S_8) consists of 8 sulphur atoms	Yes No No answer	50 13 7	71 19 10

TABLE 6: Summary of responses PHSE 111 2011

Question	Analysis	Number students	% students
4.7.1 Are there spaces between the particles of a solid?	Yes No No answer	4 10	29 71
4.7.3 Are there spaces between the particles of a liquid?	Yes No No Answer	14	100
4.7.5 Are there spaces between the particles of a gas?	Yes No No Answer	14	100
4.8.1 When a solid changes to a liquid, the spaces between the particles become	Bigger Smaller Stay the same No Answer	14	100
4.8.2 When a solid changes to a liquid, the movement of the particles becomes	Faster Slower Stays the same No Answer	12 1 1	86 7 7
4.8.3 When a solid changes to a liquid, the force between the particles becomes	Bigger Smaller Stays the same No Answer	1 13	7 93
4.8.4 When a solid changes to a liquid, does the particles' shape change?	Yes No No Answer	1 13	7 93
4.8.6 When a solid changes to a liquid, the number of particles becomes	Bigger Smaller Stays the same No Answer	 2 12	 14 86

4.9.1 When a liquid changes into a gas, the spaces between the particles become	Bigger Smaller Stay the same No Answer	14	100
4.9.2 When a liquid changes into a gas, the movement of the particles becomes	Faster Slower Stays the same No Answer	11 2 1	79 14 7
4.9.3 When a liquid changes into a gas, the force between the particles becomes	Bigger Smaller Stays the same No Answer	 13 1	 93 7
4.9.4 When a liquid changes into a gas, does the particles' shape change?	Yes No No Answer	2 12	14 86
4.9.6 When a liquid changes into a gas, the number of particles becomes	Bigger Smaller Stays the same No Answer	1 2 11	7 14 79
5.1.1 A table salt crystal consists of one molecule	Yes No No Answer	6 8	43 57
5.1.2 The NaCl molecule is white like the crystal	Yes No No Answer	8 6	57 43
5.1.3 When a salt crystal dissolves in water, the molecule becomes invisible	Yes No No Answer	10 4	71 29
5.2.1 The colour of a sulphur atom is yellow	Yes No No Answer	7 7	50 50

5.2.2 Sulphur powder (S_8) consists of 8 sulphur atoms	Yes No No Answer	11 3	79 21

TABLE 7: Summary of responses to qualitative questions SNSE 111(2009)

Question	Analysis	Number of students	% students
1.1 Draw a picture of an atom as seen in your mind	Scientifically correct Wrong Other	16 24 14	30 44 26
1.2 Explain the word atom in your own words	Scientifically correct Wrong Other	17 24 13	31 44 24
1.3 Give an example of an atom	Scientifically correct Wrong Other	15 20 19	28 37 25
2.1 Draw a picture of ion as seen in your mind	Scientifically correct Wrong Other	1 14 39	2 26 72
2.2 Explain the word ion in your own words	Scientifically correct Wrong Other	4 13 37	7 24 69

2.3 Give an example of a ion	Scientifically correct Wrong Other	4 19 31	7 35 57
3.1 Draw a picture of a molecule as seen in your mind	Scientifically correct Wrong Other	19 19 16	35 35 30
3.2 Explain the word molecule in your own words	Scientifically correct Wrong Other	6 34 14	11 63 26
3.3 Give an example of a molecule	Scientifically correct Wrong Other	24 12 18	44 22 33
4.1 Explain the word "solid" in your own words	Scientifically correct Wrong Other	7 42 5	13 78 9
4.2 Give an example of a solid	Scientifically correct Wrong Other	47 1 6	87 2 11
4.3 Explain the word "liquid" in your own words	Scientifically correct Wrong Other	5 45 4	9 83 7

4.4 Give an example of a liquid	Scientifically correct	51	94
	Wrong	3	6
	Other	0	0
4.5 Explain the word “gas” in your own words	Scientifically correct	7	13
	Wrong	36	67
	Other	11	20
4.6 Give an example of a gas	Scientifically correct	38	70
	Wrong	6	11
	Other	10	19
4.7.2 Draw a model of a solid’s particles	Scientifically correct	35	65
	Wrong	11	20
	Other	8	15
4.7.4 Draw a model of a liquid’s particles	Scientifically correct	35	65
	Wrong	11	20
	Other	8	15
4.7.6 Draw a model of a gas’s particles	Scientifically correct	30	56
	Wrong	13	24
	Other	11	20
4.8.5 When a solid changes into a liquid: If your answer is yes, explain how the particles changed	Scientifically correct	42	78
	Wrong	9	17
	Other	3	6
4.9.5 When a liquid changes into a gas: If your answer is yes, explain how the particles changed	Scientifically correct	34	63
	Wrong	11	20
	Other	9	17

5.1.4 Draw your own model of a NaCl-molecule	Scientifically correct Wrong Other	6 24 24	11 44 44
5.1.5 Draw your own model of a NaCl-crystal	Scientifically correct Wrong Other	2 22 30	4 41 56
5.2.3 Draw your own model of a sulphur - molecule	Scientifically correct Wrong Other	2 23 29	4 43 53

TABLE 8: Summary of responses to qualitative questions SNSE 111(2011)

Question	**Analysis**	**Number of students**	**% students**
1.1 Draw a picture of an atom as seen in your mind	Scientifically correct Wrong Other	4 48 18	6 69 26
1.2 Explain the word atom in your own words	Scientifically correct Wrong Other	3 47 20	4 67 29
1.3 Give an example of an atom	Scientifically correct Wrong Other	11 22 37	16 31 53

2.1 Draw a picture of ion as seen in your mind	Scientifically correct Wrong Other	3 9 58	4 13 83
2.2 Explain the word ion in your own words	Scientifically correct Wrong Other	3 9 58	4 13 83
2.3 Give an example of a ion	Scientifically correct Wrong Other	5 5 60	7 7 86
3.1 Draw a picture of a molecule as seen in your mind	Scientifically correct Wrong Other	11 42 17	16 60 24
3.2 Explain the word molecule in your own words	Scientifically correct Wrong Other	5 39 26	7 56 37
3.3 Give an example of a molecule	Scientifically correct Wrong Other	23 14 33	33 20 47
4.1 Explain the word “solid” in your own words	Scientifically correct Wrong Other	7 54 9	10 77 13
4.2 Give an example of a solid	Scientifically correct Wrong Other	60 1 9	86 1 13

4.3 Explain the word “liquid” in your own words	Scientifically correct Wrong Other	6 61 3	9 87 4
4.4 Give an example of a liquid	Scientifically correct Wrong Other	67 1 2	96 1 3
4.5 Explain the word “gas” in your own words	Scientifically correct Wrong Other	8 52 10	11 74 14
4.6 Give an example of a gas	Scientifically correct Wrong Other	46 11 13	66 16 19
4.7.2 Draw a model of a solid’s particles	Scientifically correct Wrong Other	42 19 9	60 27 13
4.7.4 Draw a model of a liquid’s particles	Scientifically correct Wrong Other	46 17 7	66 24 10
4.7.6 Draw a model of a gas’s particles	Scientifically correct Wrong Other	51 16 3	73 23 4
4.8.5 When a solid changes into a liquid: If your answer is yes, explain how the particles changed	Scientifically correct Wrong Other	45 17 8	64 24 11

4.9.5 When a liquid changes into a gas: If your answer is yes, explain how the particles changed	Scientifically correct Wrong Other	55 7 8	79 10 11
5.1.4 Draw your own model of a NaCl-molecule	Scientifically correct Wrong Other	7 25 38	10 36 54
5.1.5 Draw your own model of a NaCl-crystal	Scientifically correct Wrong Other	0 25 45	0 36 64
5.2.3 Draw your own model of a sulphur - molecule	Scientifically correct Wrong Other	2 22 46	3 31 66

TABLE 9: Summary of responses to qualitative questions SNSE 111(2011)

Question	**Analysis**	**Number of students**	**% students**
1.1 Draw a picture of an atom as seen in your mind	Scientifically correct Wrong Other	7 7 0	50 50
1.2 Explain the word atom in your own words	Scientifically correct Wrong Other	7 7 0	50 50

1.3 Give an example of an atom	Scientifically correct Wrong Other	9 5 0	64 36
2.1 Draw a picture of ion as seen in your mind	Scientifically correct Wrong Other	7 7 0	50 50
2.2 Explain the word ion in your own words	Scientifically correct Wrong Other	4 10 0	29 71
2.3 Give an example of a ion	Scientifically correct Wrong Other	7 7 0	50 50
3.1 Draw a picture of a molecule as seen in your mind	Scientifically correct Wrong Other	8 6 0	57 43
3.2 Explain the word molecule in your own words	Scientifically correct Wrong Other	10 4 0	71 29
3.3 Give an example of a molecule	Scientifically correct Wrong Other	12 2 0	86 14
4.1 Explain the word “solid” in your own words	Scientifically correct Wrong Other	5 9 0	36 64

4.2 Give an example of a solid	Scientifically correct Wrong Other	14 0 0	100
4.3 Explain the word "liquid" in your own words	Scientifically correct Wrong Other	5 9 0	36 67
4.4 Give an example of a liquid	Scientifically correct Wrong Other	14 0 0	100
4.5 Explain the word "gas" in your own words	Scientifically correct Wrong Other	6 8 0	43 57
4.6 Give an example of a gas	Scientifically correct Wrong Other	14 0 0	100
4.7.2 Draw a model of a solid's particles	Scientifically correct Wrong Other	14 0 0	100
4.7.4 Draw a model of a liquid's particles	Scientifically correct Wrong Other	14 0 0	100
4.7.6 Draw a model of a gas's particles	Scientifically correct Wrong Other	14 0 0	100

4.8.5 When a solid changes into a liquid: If your answer is yes, explain how the particles changed	Scientifically correct Wrong Other	13 1 0	93 7
4.9.5 When a liquid changes into a gas: If your answer is yes, explain how the particles changed	Scientifically correct Wrong Other	13 1 0	93 7
5.1.4 Draw your own model of a NaCl-molecule	Scientifically correct Wrong Other	9 5 0	64 36
5.1.5 Draw your own model of a NaCl-crystal	Scientifically correct Wrong Other	5 9 0	36 64
5.2.3 Draw your own model of a sulphur - molecule	Scientifically correct Wrong Other	1 13	7 93