Creating a Model of Conceptual Change

By

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DECLARATION

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LIST OF ABBREVIATIONS

PNM	Particulate Nature of Matter
PCP	Personal Construct Psychology
IPM	Information Processing Model
PCA	Principal Component Analysis

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ABSTRACT

This thesis investigates promoting student understanding of the Particulate Nature of Matter (PNM) through Inquiry Based Learning (IBL), visualization and modelling. A Practitioner Action Research methodology was employed and student performance at junior second level school was measured using diagnostic and summative testing. A module on this topic was prepared which included a student workbook and a teaching manual. Student and teacher reflections on the learning issues experienced were obtained through interviews and repertory grid analysis based on Kellyian Personal Construct Psychology (PCP) principles. Summative results show a better comprehension of PNM by the intervention group as opposed to their control group peers. Repertory grid analysis was used to highlight and rate aspects of students' affective and cognitive learning experiences. Furthermore, in conjunction with PCP, student drawings provided as exam answers when they were asked to think critically within a novel problem scenario were investigated. This exploratory approach enabled the systematic metering of student comprehension of chemistry constructs and served to detect the learning gaps in their construct hierarchy. This work represents a considered approach towards the development of an understanding of student answers including alternative conceptions. It integrates PCP with research on explanations and representations of ideas. It attempts to create an assessment instrument that can be used to visualise and comprehend a student's chemistry drawings in a more holistic way than a binary judgement of wrong or right. Furthermore, PCP is employed to extend the focus from the interpretation of student responses to include the consideration of key features of conceptual development. These can be related within a proposed model of learning.

CHAPTER 1: INTRODUCTION

Introduction:

This work was prompted by the possibility of increasing learning among junior second level school students. Specifically, the primary research question aimed to increase understanding of the Particulate Nature of Matter (PNM) using Inquiry Based Learning (IBL) and modelling and visualization tools. This chapter outlines the purpose of this work and the researcher's professional context is then discussed. The content of the subsequent chapters is then described. Later, in Section 1.3, it is apparent that the reflexive nature of the methodology employed allows the research focus to change. The move from an emphasis on the development of materials to improve student understanding (though this process continues) reflects a shift towards the simultaneous creation of a framework of understanding to explain how students learn. A secondary research question then evolves which asks if a proposed model of conceptual change in chemistry understanding may be developed.

1.1 The Purpose of this Study

In this project, the researcher explores the change in his teaching pedagogy from a mainly didactic style to that of an inquiry-based approach, merged with modelling and visualization. This action was prompted by witnessing students' inability to understand and integrate concepts when taught in a style that was curricular-driven and transmissive in nature. Within the transmissive approach, regular formative assessment was not used, nor were strategies employed which might serve to concretise the abstract nature of the subject. The researcher had initially encountered students in the senior stages of school who could not rely on a fundamental chemistry understanding (ideally gained in early second level school) to assist in their progression through various topics in the subject. This phenomenon was compounded by the limited time afforded by the then curriculum to teach any given topic. Ultimately, student performance in Chemistry state examinations was being potentially compromised leading to the possible debasement of its reputation as a subject.

The change in pedagogical approach is made in order to determine if it improves the knowledge of students in the area of the 'particulate nature of matter'. Therefore it focuses on using modelling and visualization to create learning materials in a context that students have found difficult. The effort to pursue an understanding of student learning within this context leads to an attempt to develop an adapted model of conceptual change, using Personal Construct Psychology to inform and manage learning. Thus, it was hoped that the 'considered' <u>action</u> of the researcher within his professional environment would lead to a greater knowledge of how students' understanding of an area pertinent to junior second level school, but critical to their future grasp of chemistry, may be improved. This could then serve to expand his own teaching repertoire and that of his fellow professionals regarding the enhanced PNM learning experience of students. Such an approach permits the inclusion and linking of ideas or techniques acknowledged as promoting conceptual understanding which are cited in the chemistry education literature. It also allows for the examination of the use of heuristics to consider and interpret student understanding.

1.2 Professional Context of the Researcher

This section describes the researcher's work context and the nature of the subject he teaches. The researcher is a graduate of chemistry who teaches Junior Certificate Science, Transition Year Chemistry and Leaving Certificate Chemistry in an urban school. The researcher's school is an all-girls voluntary second level school consisting of over seven hundred and fifty students. The curriculum context lies within the Irish Revised Junior Certificate (Government Publications, 2008) that commenced in 2002 and which consists of Chemistry, Physics and Biology components. Specifically, the area of PNM resides within the Chemistry section of the syllabus and includes both topics of '2A1. Materials' and '2A3. Classification of substances, as elements and compounds'. Hence there is a focus on the various forms of matter and the interactions which enable them to be transformed. These form the chemistry area of the first year science curriculum within the school encountered by 12-13 year old students. The assessment requirements of the student year group in relation to the subject of science are two major summative exams per year. In alignment with the Junior Certificate State examination (undertaken at the end of third year by 14-15 year old students), questions on these exams are designed to suit understanding by rote-memorisation. This is in contrast to questions which seek conceptual understanding (Pickering and Sawrey, 1990). An example is, 'Name the three states of matter and list three properties of each one'.

Within the school, it is apparent that the majority of those who elect to do a science subject at senior level choose Biology. Chemistry and Physics hold less interest for them. This trend also holds at national level. According to the Report by the Chief Examiner of Chemistry (2013), the participation rates for Chemistry dropped slightly over recent years to 15.5% (State Exams Commission, 2013).

Some underlying reasons as to why this is the case are suggested by Pinarbasi and Canpolat (2003) who write that chemistry has been regarded as a difficult subject on grounds such as the abstract nature of many of its concepts. Bunce (2001) and Nahum et al. (2004), also acknowledge the challenge posed by the abstract nature of the subject. They hold the view that since students live and operate in the macroscopic world of matter it can be difficult to follow shifts between the macroscopic (accessible to our senses) and microscopic (inaccessible to our senses) levels. Pinarbasi and Canpolat (2003) also contend that the symbolic level of chemistry is problematic for novices. Johnstone (2000) illustrates that this factor can lead to a high cognitive demand for chemistry students. Snir, Smith and Raz (2003) acknowledge related student difficulties in their attempts to understand PNM. According to Valinides (2000), science educators would agree that an appropriate understanding of PNM is essential to the learning of other chemistry concepts. However, Othman (2008) points to several studies including Nakhleh et al. (2005) which indicate that students' understanding of this model of matter is relatively limited. Ayas et al. (2009) note that it is a key central concept in science education. Indeed, its relevance is reflected in student engagement with science curricula beyond Ireland from the UK [Key-Stage 3] (Department of Education (2013) through Canada [Grade 9] (Ministry of Education (2008), Australia [Years 7-10] (Commonwealth Copyright Administration, 2009), New Zealand [Levels 4 and 5] (Ministry of Education, 1993) to Singapore [Syllabus sections 7 and 8] (Ministry of Education of Singapore, 2012).

It is apparent that, given the deficit in understanding in the area of PNM and its centrality to learning in chemistry, it is worthwhile to use a methodology that complements the professional context of the researcher in an effort to improve the student's learning experience. The methodology chosen in this work is that of Action Research. The form of action research used is Practitioner Action Research.

Carr (2006) points to Kurt Lewin as the devisor of the 'action research method' which he portrayed as a spiral of steps. Each step is based on the results of (the previous) action and often constitutes a cycle of planning, further action and data collection.

Kind and Taber, (2005) capture the realities of using action research as a means of obtaining evidence to inform and improve future practice. Notably, a teacher-practitioner carries out research in a manner that acknowledges:

- The context of their present practice in which a topic has been recently recognised as having the status of being 'problematised'. This differs from deriving the focus of research from the theoretical concerns of academic researchers;
- Their 'ownership' of the research problem. This does not necessarily imply working alone as they may choose to engage departmental colleagues in the work;
- Engaging in 'systematised' research through data collection and evaluation;
- The evidence collected allows the teacher to decide whether to change current practice on the balance of probabilities rather than inevitabilities as they respond to their current reality by action. This echoes the optimistic stance adopted towards student reasoning by PCP, which is later described more fully in Section 3.4.3;
- Abandoning the action research if it does not appear to be working (in contrast to persisting with the work in order to write a convincing report);
- The 'burden of proof' during the work is less than for that of an academic researcher regarding the justification and recommendation of new practices to the profession. However, Tripp (2005) acknowledges that the dissemination and publication of the understanding gained from improving practice may become an important spin-off;
- With the next cycle of planning teaching and evaluation the balance of the evidence may shift, and practice moves forward again.

This final point echoes the nature of the reality that practitioner action research is complex, changeable and cannot be accurately predicted in advance by academic knowledge (Petra, 2007).

The secondary research question in this study evolved as a result of four phases of action research. This is echoed by the nature of the thesis which is working towards an adaptation of a conceptual change model that is revealed at the end.

1.3 Summary Chapter Outline

The thesis document is laid out in 6 main chapters with a final conclusion in Chapter 8. Chapter 2 serves to describe the approach to teaching and the two relevant pedagogical tools that inform the development of the teaching instrument used in this study. It describes the relevance of models and visualizations as pedagogical tools. The various types of models and visualizations are detailed. The potential benefits of student engagement with these, as a means of enhancing the effective learning of chemistry concepts, is described. Some considerations linked to the use of models and visualizations within chemistry education are highlighted. Then, a review of the pedagogical approach into which these tools are embedded i.e. inquiry-based science education, is conducted. An insight into approaches that underpin successful inquiry in terms of their impact on student learning, achievement, and engagement is provided. An analysis of the literature is used to outline the strengths and weaknesses of particular approaches to inquiry in the context of optimising student learning. Learning is the subject of the following chapter.

The focus in Chapter 3 is on how an individual student of science learns conceptually. The learning models and dynamic cognitive processes cited in the literature that promote or hinder the understanding of a topic are described. There is also a brief description of how a teacher may facilitate meaningful learning. Later, the theoretical architecture of Personal Construct Psychology (PCP), which serves as a channel for the convergence of these ideas, is provided. Finally, a framework of learning is proposed that attempts to answer the secondary research question. This serves to illuminate what successful learning in chemistry involves within this study and highlight both the potential benefits for student understanding of chemistry and a teacher's understanding of their students.

Combining the key information from the previous two chapters, Chapter 4 describes the design used to answer the primary research question within a Practitioner Action Research framework. The theoretical basis of the research design is then given. This is done by providing the philosophical rationale for the study's methodology whereby PCP is used as an adjunct to practitioner action research. The chapter describes the research participants, the methods used to collect and analyse data from the participants, and ethical aspect of the study.

Chapter 5 focuses on the practical nature of the development and delivery of a pedagogical instrument, i.e. the workbook, using the methodology described in Chapter 4. It details how this instrument has evolved over the course of the first two of four phases in order to answer the primary research question. The justification for the continued use of the workbook, based on feedback is also provided.

Chapter 6 focuses on the further development and delivery of the pedagogical instrument using a methodological approach identical to that used in the previous chapter. It describes the rationale behind the evolution of this inquiry unit over the course of the third phase and provides some examples of how it has changed. The development of an exploratory evaluation tool to analyse student explanations and understanding in these phases is also detailed. This is done using the lens of PCP.

Chapter 7 describes the development of the final iteration of the pedagogical tool and how it was adapted to serve the students in phase four of the research. Once more, PCP is used to inform the direction of the evolution of the analysis of students' explanations using a further alternative evaluation tool. It also serves to inform the development of a proposed model of conceptual change so that the secondary research question might be answered.

The final chapter presents further analysis of the key outcomes from the work and draws conclusions from these. The learning journey of the Practitioner Action Researcher is summarised. A model of conceptual change is proposed and discussed in the light of the research findings.

CHAPTER 2: PEDAGOGICAL APPROACHES TO ENHANCE CHEMISTRY LEARNING

Introduction

Chapter 1 served to introduce the nature of the research undertaken and how the structure of this work attempts to reflect that. This chapter reviews the importance of visualization and modelling in chemistry education and the pedagogical approach into which it is embedded i.e. inquiry-based science education. The varieties of inquiry based learning are explained. Drawing on the theory and research in the field, insight is provided into the efficacy of particular approaches to inquiry in terms of their impact on student learning, achievement, and engagement. This same body of literature, along with my own analysis, is used to outline the strengths and weaknesses of particular orientations to inquiry.

2.1 What are Models?

This section discusses the meaning of models and their importance in relation to learning in science. The ways in which the use of models may promote understanding of a topic such as the particulate nature of matter (PNM) are acknowledged.

Dilts (1999) points to the claim of media theorist Marshall McLuhan that the medium through which a particular message is *transmitted* has more impact on how that message is received and interpreted than the message itself. Talanquer (2011) suggests that *one* of the theoretical constructs we use in educational environments to convey meaning is that of models. Bridle and Yezierski (2012) suggest that, at the most basic level, learners interpret models as *exact* replicas of reality. Thus, an atom that is represented as a red circle may actually be interpreted as a red circle. An important implication of their work is that part of the instructional process (the medium) must involve exploring and discussing the merits and limitations of a particular model. This is not always an easy task. Due to its potential importance for learning, Hubber and Tytler (2013) note that interest in models as a key characteristic of the knowledge construction processes of science has grown over the last two decades. This is reflected in the argument by Justi and Gilbert (2003) that the introduction of modelling activities into chemical education is an issue that must be the focus of future research.

In terms of the practice of chemistry, Justi and Gilbert (2003) argue that chemists are essentially modellers of substances and of their transformations. Talanquer (2013) highlights the *theoretical models* that chemists have developed to make sense of their world as they interpret it with their senses: for example, rusting is a visible chemical process which may be explained by stating elemental iron reacts with elemental oxygen to produce iron oxide, a chemical compound. He also highlights the competing nature of models e.g. Arrhenius, Brønsted–Lowry and Lewis models of acidity. The model chosen to explain a theory by chemists is usually adopted because it is best adapted for their purposes. Indeed, Justi and Gilbert (2003) posit that modelling is so common in chemistry that it has become "the dominant way of thinking". It is appropriate to consider it as a process very important for students' conceptual development.

In relation to broadly describing what models are, The National Research Council (1996) in the United States describes models as:

> *Tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power. Models help scientists and engineers understand how things work. Models take many forms, including physical objects, plans, mental constructs, mathematical equations and computer simulations* (National Research Council, 1996).

Models are described as being deliberate since they are subject to validation and so can serve an explanatory function. In a study to investigate prospective second level science teachers' understandings of scientific modelling in relation to pedagogy, Crawford and Cullin (2004) state that, "one of the most critical aspects of scientific work is the use of models to explain phenomena in nature". To this end, Hubber and Tytler (2013) cite both Nersessian (2008), who posits that models are created by scientists as systems of inquiry, and Jadrich and Bruxvoort (2011) who conclude that underpinning scientific inquiry is the construction and evaluation of models. Justi and Gilbert (2003) reason that observed phenomena are modelled at both the macroscopic and the submicroscopic levels. In doing so, Crawford and Cullin (2004) assert that models are not only physical objects but represent (explanatory) *ideas*, stemming from the creativity of chemists.

Both Hubber and Tytler (2013) and Crawford and Cullin (2004) illustrate various examples of models, which include:

- concrete models (e.g. scale models);
- pictorial/graphic models (e.g. photographs, diagrams);
- verbal models (e.g. descriptions, directions);
- simulation models (e.g. simulation games);
- symbolic models/semiotic models (e.g. words, numbers, mathematics, figures).

In discussion of classroom learning, Lerman (2003) describes possible physical models as concrete, tangible objects that illustrate chemical structures and processes e.g. Moly-Mod Kits, food items, Play-Doh and role-playing students. Erduran and Duschl (2004) cite Bruner (1966) who describes role-play as being within a classification of enactive modelling. This can entail people translating their experiences into models through action in order to increase their learning. Also, in relation to advancing student knowledge, Akaygün and Jones (2013) note models can be representations given in the textbooks or drawn by instructors. In contrast, Cheng and Gilbert (2009) discuss learner-generated drawings as bringing learning benefits. Ainsworth et al. (2011) explain that the learner can use specific features of models to reason with, and to align with, their observations and measurements of phenomena. The appearance of the drawing is intended to share a physical resemblance with the object(s) being depicted. Thus, learner-generated drawing is goal-directed. Ainsworth et al. (2011) argue that when students *draw* to convey their understandings in science, they are more motivated to learn than by conventional teaching. Ainsworth et al. (2011), Prain and Tytler (2013), and Van Meter and Garner (2005) credit drawing for promoting understanding among students while revealing alternative conceptions. Prain and Tytler (2013) consider that when students make a drawing of a process they are naturally constrained by the physical space available on the page. This requires them to achieve a specificity of detail in order to communicate unambiguously, more-so than with a verbal representation. In turn, drawing helps to force choices upon students and prompt them to consider alternative models to represent their mental model.

In terms of modelling software, Chang et al. (2009), indicate that the results of their study among high-school students on the impact of drawing, indicate that designing animations, coupled with peer evaluation, is effective at improving student learning when instructional animation is employed in classes. The element of "discussion" and its importance is cited by Wu and Krajick (2006) in a study to explore students' learning practices. This was done during an 8-month course unit on water quality, which involved modelling software.

All forms of modelling involve a modelling *process*. According to Greca and Moreira (2000), this process has been understood historically as the learning of a series of steps to identify the main elements of a particular system to be studied by a student.

Erduran and Duschl (2004) posit that a model may be characterized as a representation between a "source and a target" (Figure 2.1) and highlight the centrality of "Mental Models" in relation to "Analogue", "Conceptual" and "Expressed" models Figure 2.2). This is echoed in an earlier study by Coll (1999) on the use of models in chemical bonding.

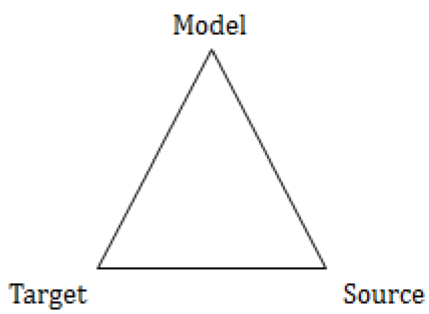


Figure 2.1: The Characterisation of a Model (Coll, 1999)

In summary, Oh and Oh (2011) state a model can be defined as a representation of a target and serves as a "bridge" connecting a theory to a phenomenon with the following characteristics:

- It offers a representation between a source and a target, the target being a phenomenon to be explained;
- It plays the roles of describing, explaining and predicting natural phenomena and communicating scientific ideas to others;
- It can be extended in science to multiple models because (i) scientists may have different ideas about what a target looks like and how it works and (ii) because there are a variety of semiotic resources available for constructing models;

- It can be tested both empirically and conceptually and changed along with the process of developing scientific knowledge;
- It can be used in the science classroom by students and teachers alike as they are engaged in diverse modelling activities.

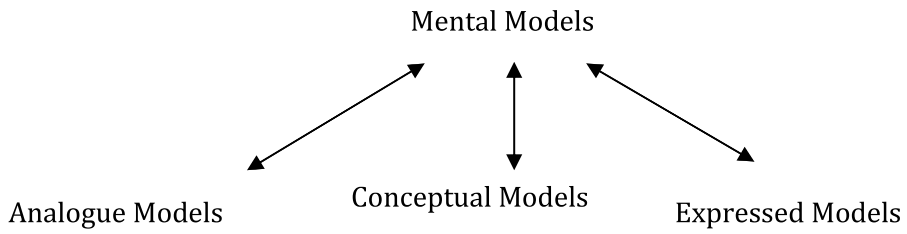


Figure 2.2: The Relationship between Models

Woody (1995) and Erduran and Duschl (2004), drawing on "features of models", cite the importance of the property of compositionality in relation to chemistry and refer to it as the ability to choose the appropriate model in a given situation. They use the example of the topic of "Acids and Bases" in which case a student may need to decide whether to use the Bronsted-Lowry or Arrhenius model of acids and bases in a particular problem scenario.

2.2 Why Model in Chemistry?

If a central objective is to enable young scientists move their behaviour towards that of real scientists, Penner et al. (1997) suggest that it is important to remember that the work of professional scientists is underpinned by the building and testing of mental models in a quest for chemical knowledge. In this regard, Coll et al. (2005) see modelling as a vehicle for "authentic science education" whereby students can engage in becoming practitioners of the general chemistry community. The understanding of chemical ideas in this way, as creative products of scientific work, should help students make sense of how chemists modified concepts over time. One example of this is oxidation in terms of oxygen or electrons (Taber, 2012). The above assertions allow Harrison and Treagust (1998) to give modelling their fullest endorsement by claiming that modern chemistry cannot be taught without it. Meanwhile, Erduran and Duschl (2004) write that modelling encapsulates some of the "fundamental concepts of chemistry". In this regard they argue there is a need to manifest what chemists do which is to model the structure and function of matter. Interestingly, they address the phenomena of atoms and molecules, which they argue are models to begin with, in terms of their related concepts.

When learning about chemistry at the atomic level, it is necessary to use an extensive range of symbolic representations such as models and analogies to benefit student knowledge. This idea is echoed by Cook et al. (2008) who assert that novices depend heavily on observable entities such as models to construct understandings.

The researcher is adopting the position that models may promote the visualization of key chemical concepts in the area of PNM. Simultaneously, they can enhance conceptual understanding by readily providing a cognitive focus for groupwork while also allowing for social engagement, such as peer to peer debate, to occur.

2.3 What is Visualization?

The following section indicates how visualizations relate to models and their importance in improving conceptual understanding in chemistry where concepts of an abstract nature frequently occur. Some criticisms of visualization follow.

Tasker and Dalton (2006) cite that Conlon (2002) explains that, ranging from a word for an object to a diagram for an arrangement of things, a representation is simply "*a structure that stands for something else*". Michalchik et al. (2008) further describe representations as symbols (written or drawn), diagrams or drawn indices. They assert that, while not objects themselves, they "stand for" or "refer to" other objects, and are characterized by relationships between the objects. Prain and Tytler (2013) argue that these representational tools of science are crucial resources for speculating, reasoning, constructing and contesting explanations, theory-building, and communicating. Research on learning with representations has shown that when learners can interact with an *appropriate* representation their performance is enhanced (Ainsworth, 2006). Notably, Justi et al. (2009) emphasize that one of the major aspirations of science education is that students' internal representations of a given model will be very nearly the same as the corresponding external representation. The exercise of visualization may support this.

2.3.1 Visualizations

Talanquer (2011) refers to visualizations as chemical symbols and formulae, particulate drawings, mathematical equations, animations, simulations, physical models, etc., used to visually represent core components of a theoretical model. Although it is common for people to refer to visualizations as 'models', most theoretical models used in chemistry have different levels such as symbolic, macroscopic and submicroscopic that are difficult to capture by a single visualization.

Justi et al. (2009) state that a mental model is initially produced in a person's mind by means of a visualization. In terms of enhancing mental models of students, Cheng and Gilbert (2009) contend that a visualization is an external representation in a *visual* mode and is regarded as more than a tool for learning by students. Rather, it enables learners to make meanings and internalize representations or express their ideas. In this way, Talanquer (2011) argues that visualizations facilitate reasoning and communication about both experiences and models.

Jones (2013) refers to visualizations of models of molecules and their interactions as helping to form understandings of the submicroscopic level. This is of particular relevance to the area of PNM. These visualizations that allow interpretation of the functions of molecular models can be physical or computer-generated. Davidowitz and Chittleborough (2009) insist that visualization of the sub-microscopic level is the key to developing mental models of that level. This can also benefit the formation of mental images of symbolic representations. Özmen (2013) extends the understanding of abstract concepts in chemistry to require three-dimensional thinking. Indeed, Davidowitz and Chittleborough (2009), Cheng and Gilbert (2009) and Justi et al. (2009) perceive the role of visualization as important in learning about the linkages involved between macro, symbolic and particulate levels (as represented by Johnstone's (2000) triplet in chemistry). This echoes Jones et al. (2005) who state that "some chemical phenomena are not obvious without the use of visualizations", especially in the area of molecular systems. At this representational level, José and Williamson (2005) explain that the use of visualization in the classroom led to student gains in academic achievement.

While, in parts of the literature, visualization and modelling are almost synonymous, it becomes clear (see below) that visualization and modelling are distinct constructs that can support one another. Waldrip et al. (2006) found *appropriate* visualization techniques to include the static pictorial viz. written text, diagrams, cartoons, images, photographs and models and the dynamic pictorial viz. computer programs, drama and acting out a process. Nakhleh and Postek (2008) use the concept of the role of time to distinguish between static and dynamic representations. It may be contended that both static and dynamic forms are valuable and can be used to complement each other (Davidowitz and Chittleborough, 2009).

Finally, a skill that visualization can develop in a student is "metavisualization". Gilbert (2005) refers to *metavisualization* as "metacognition in respect of visualization". He describes it as the ability of interpreting and translating from one diagram (at one level) to another (usually on another level). A more specific view is expressed by Cheng and Gilbert (2009) who posit that it involves the capability to demonstrate an *understanding* of the "convention" for different levels (i.e. macroscopic, submicroscopic and symbolic) and dimensionality (3D, 2D and 1D) of representations. Davidowitz and Chittleborough (2009) conflate metavisualization with having a fluent capability in visualization in respect to all of three levels. Justi et al. (2009) echo this view of the coherency of understanding by describing metavisualization as a capacity to mentally translate a given model between the modes.

Kozma and Russell (2005) recommend the use of visualization resources for learning chemistry. Two popular forms of dynamic visualization are discussed below, i.e. multiple representations and simulations.

2.3.2 Multiple Representations

Cook et al. (2008) argue that multiple representations may be used when a single representation cannot convey all parts of the model required to advance learners' knowledge. Talanquer (2011) points out that in chemistry, most theoretical models are multi-faceted and are therefore difficult to capture by a single visualization. The view of Ainsworth (2008) is that when people are learning complicated scientific concepts and interacting with multiple forms of representation such as diagrams, graphs and equations can bring unique benefits. Specifically, Nakhleh and Postek (2008), are aware that learning benefits accrued in relation to PNM via multiple external representations (MERs) and cite Sanger et al. (2001) and Williamson and Abraham (1995) in this regard. Sanger (2000) finds that MERs all have one thing in common: they don't just provide a single visualization. Ainsworth (2006) posits that MER systems employ at least two representations, but commonly many more are available, either simultaneously or at some point during a learner's interaction with a system. Gilbert (2008) notes that the use of MERs implies not only the use of many external representations but also their presentation in a variety of *ways* e.g. by means of video, traditional 2D and 3D materials, computer modelling software etc. Ainsworth (1999) proposes that the functions of multiple representations fall into three broad classes including:

- Supporting learning by allowing for complementary computational processes or information. In this regard Ainsworth and VanLabeke (2004) claim that when multiple representations complement each other they do so because they differ either in the information each expresses or in the processes each supports;
- The use of representations so that one representation constrains interpretations of another. Ainsworth (1999) notes that this goal tends to be achieved by employing a familiar representation to support the interpretation of a less familiar one. For example, in this way, when textual and graphical representations are presented together, interpretation of the textual (ambiguous) representation may be constrained by the graphical (specific) representation;
- The construction of deeper understanding when learners observe and relate representations to identify what are "shared invariant features" of a domain and what are distinct properties of individual representations. Ainsworth (1999) argues that the increased level of understanding gained in this case may be difficult to achieve with only a single representation. This is particularly true if two or more representations have perceptually salient (e.g. one representation is 2-D while another is 3-D) but conceptually irrelevant differences in the appearance of any specific instance.

Ainsworth (2006), adds that using MERs can encourage learners to try different *strategies* when problem solving. Specifically, by switching between representations (and comparing them), learners can compensate for weaknesses in their strategy by finding a better alternative approach to a learning goal.

Briefly, there are three noteworthy design features that pertain to MER's from Ainsworth (2006). *Seductive details* are textual representations that are interesting but conceptually irrelevant. This may cause a student engaging with an MER to activate inappropriate prior knowledge and integrate it with new knowledge. Systems can also be partially *redundant*, so that some of the information is constant across (some of) the representations. Finally, *computational offloading* is the extent to which different external representations reduce the amount of cognitive effort required to solve equivalent problems. An example of a focal point used in attempting to achieve this phenomenon, albeit with regard to a pen and paper approach, was the model of the atom illustrated in the respective workbooks. As the pedagogical instrument evolved over four phases, an attempt was made to use a consistent atomic model based on the one encountered in PhET simulations i.e. a hard-ball sphere imprinted with a symbol from the periodic table. This reflected a shift from sometimes representing atoms of 'different elements' using circles of various styles in phase 1 and 2 to the afore mentioned singular style in phases 3 and 4. This model was viewed by the author as a 'safe' starting point for neophyte scientists as it would be similar to that encountered in potential future studies of areas such as gas kinetics and rates of reaction. However, it is important for students to be constantly aware during their learning experience that models may evolve and are not representations of reality. Hence, drawing from the Bridle and Yezierski (2012) acknowledgement that the instructional process must involve exploring the merits of various models, questions involving best representations within an array of 'molecular' models were posed in phase 3 and 4 of the workbook.

2.3.3 Simulations

Gabel (2003) describes computer simulations as a way of representing real-world situations by simulating what is happening on the particulate level. Moore et al. (2013) extends the range of application to include linking macroscopic, microscopic and symbolic levels and describes the following benefits:

- Simulations can provide students with the opportunity to interact with dynamic visualizations and thereby allow for focused exploratory inquiry.
- They usually entail rapid feedback cycles whereby cause-and-effect relationships are made explicit.

It is the view of Ainsworth and VanLabeke (2004) that learners often acquire a deep knowledge using the multiple dynamic representations employed within a simulation. Learners are allowed to construct their own knowledge by interacting with Sim environments in such ways as conducting experiments and observing the effects of these experiments. Moore et al. (2013) analyse the use of supports provided, such as PhET simulations, which allow students to experience learning through self-directed exploration and development of science concepts. Hence, the epistemological framing of the learning experience shifts from passive to active.

Indeed, within the PhET simulation "Build Molecules", there is employment of the idea Sanger (2000) describes as manipulating perceptual processes by *grouping relevant information together* in order to make search and recognition (of atoms) easier. The notion of employing *tables to make information explicit* is also used. The same PhET Sim also utilizes a design feature involving *emphasising empty cells* (of molecules) in order to highlight patterns between co-efficient symbols and the number of molecules built by the student (Sanger, 2000)**.**

Moore et al. (2013) describe a further design element in-built to the same PhET simulation that is related to hard scaffolding and is known as *implicit scaffolding*. It results in students being guided without feeling guided, by scaffolding. Thus there is a subtle shift from an explicit source of guidance, such as a set of written instructions, to an implicit one, whereby guidance is in the form of affordances and constraints featured in the simulation. A specific example of such implicit scaffolding in the aforementioned simulation is the appearance of an arrow on the screen directing the student to drag a molecule to a box when they build the *initial* molecule of a particular family e.g. O_2.

There is a further (more subtle) implicit scaffold characteristic that features in relation to the same idea. When a subsequent molecule of the *same type* has been constructed, the perimeter of the appropriate box pulses a blue colour briefly to signal the appropriate box for deposition. Ainsworth (2006) wrote about the design feature of *dyna-linking* in relation to animations but in the author's experience, it is also true of particular simulations and is therefore included in this section. Ainsworth (2006) describes dyna-linking as referring to learners acting on one representation and seeing the results of those actions in another because of the live connection between them.

Another learning benefit that can accrue in terms of interactive computer simulations is the capacity of students to visualise complex systems (Talanquer, 2010). It is argued by Yezierski and Birk (2006) that research points to conceptual gains in terms of particle behaviour when simulations are used. As they construct knowledge, the multiple representation dimension of a simulation may lead to what Gobert et al. (2011) refer to as students engaging in content-rich conversations during their interaction with material on the screen. While doing so, Seery and McDonnell (2013) acknowledge the potential for students to fact-make in an environment of self-regulated learning.

2.3.4 Criticisms of Visualizations

According to Greca and Moreira (2000) students sometimes fail to understand that conceptual models are *not* actually reality. For example, Gabel (2003) recognises that alternative conceptions based on perceptions can arise due to simulations which might convince students that atoms are hard, coloured balls. Also, alluding to this tendency for students to rely on the inherent properties of a representation, Ainsworth (2008) gives a slightly extreme example of the possibility of a student understanding that Newton's laws are only true for motorcycles with yellow stripes being ridden by men in red. More generally, and with a higher risk of occurrence amongst students, Nakhleh and Postek (2008) conclude that students who viewed static visuals formed static mental models that provided an incomplete understanding of the dynamic character of the PNM. Regarding dynamic forms of visualization, Ainsworth and VanLabeke (2004) argue that representations almost never be presented in isolation, but are combined with textual description. Sanger (2000) asserts learners can pay a cognitive price as they may become overwhelmed with many learning demands. This is described by Ainsworth (2006) in terms of the possibility of "processing loads" becoming too high for students to obtain the anticipated benefits of such "apparently" simple representations. In order not to be led astray during visualization activities, Özmen (2011) recommends that students should be accompanied with oral and written exercises to enhance learning. Ainsworth (2006) recommends that when using animations or simulations as learning tools, the minimum number of representations consistent with the pedagogical function of the system be employed. Often the person who is best placed to make decisions regarding the (in) appropriate nature of a representation for their students is the teacher.

As the teacher co-ordinating this action research study, it is my view that in order for appropriate visual encounters of the PNM to occur (which may successfully lead to developing the skill of meta-visualization among learners), one must be acutely aware of the potential for student working memory overload. This idea (further discussed in Section 3.1), can readily occur when students employ simulations involving multiple representations as learning tools. However, if this danger is acknowledged, students may be able to use simulations such as PhET to integrate macroscopic, symbolic and submicroscopic representations.

2.4. What is IBL as a Pedagogical Action?

This section describes the meaning of the term IBL and the potential benefits it holds for student knowledge if facilitated appropriately by a teacher. An evaluation of IBL is also described.

Furtak (2006) contends that scientific inquiry teaching originated with efforts to align students' thinking processes and activities with those of real scientists since their knowledge will be deeper if they find answers on their own rather than being told by their teacher.

2.4.1 Inquiry Education in Terms of the Learner

The National Science Education Standards (NSES) (National Research Council, 1996) describe scientific inquiry as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work".

The European Commission (2007) observe that the "bottom up" or student centred, inductive approach to teaching science is now mostly referred to as Inquiry-Based Science Education. They cite Linn et al. (2004) in describing Inquiry-Based Science Education (IBSE) as:

> *... the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments*.

Anderson (2002) argues that what is essential is to raise a fundamental question for students that requires them to become conscious of possible deficiencies in their thinking and, at the same time, provides a basis for the development of a greater scientific understanding on their part. The provision of simple experiments or demonstrations to elicit (and subsequently abandon) their alternative conceptions is a good pedagogical approach in this regard.

Llewellyn (2005) provides further detail and lists five essential features of classroom inquiry:

- Learners are engaged by scientifically-orientated questions;
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically-orientated questions;
- Learners formulate explanations from evidence to address scientifically-orientated questions;
- Learners evaluate their experiences in the light of alternative explanations;
- Learners communicate and justify their proposed explanations.

Gyllenpalm et al. (2010) divide the student experience of inquiry into two parts:

- Acquiring a skills set that enables students engage with science;
- Accessing scientific knowledge through the art of hypothesising, reasoning, critical thinking, controlling variables and correlating data (to forge deep learning around learning outcomes).

Abd-El-Khalick et al. (2004) describe the first part as "Inquiry as a means" where its science content is an instructional outcome, and refer to the second as "Inquiry as an ends", where inquiry skills and epistemological understandings about how science knowledge is developed are an instructional outcome.

Capps et al. (2012) add a third dimension to inquiry to include its use as a classroom teaching strategy. Crawford (2007) acknowledges that all three descriptions of inquiry guide her own research regarding teachers' beliefs in relation to IBL.

Minner et al.(2010) describe this division as:

- how students learn (e.g. epistemic practices involving actively inquiring through thinking, discourse and modelling and, argumentation (Sandoval , 2014);
- what scientists do (e.g. understanding about inquiry by conducting investigations using scientific methods used by research scientists);
- pedagogical approach that teachers employ (e.g. designing or using curricula that allow for extended investigations).

In terms of acquiring a skills set (or a content understanding) to engage with science, Hofstein et al. (2005) suggest the provision of opportunities for students to reflect on findings, clarify their understanding (and alternative understandings) with peers, and consult a range of resources, which include peers, the teacher, and books and materials. Hofstein et al. (2005) believe that this provision will facilitate the development of knowledge constructs for the students. Hmelo-Silver et al. (2007) refer to this idea as "sense making". Sadeh and Zion (2009) also view IBL's main purpose as the guidance of students to construct their own knowledge with their acknowledgement that they must consent to take risks to solve the problem with which they are confronted. With this in mind, Wolf and Fraser (2008) recognise that during inquiry, while student social interaction is high, students must be able to work in a non-threatening environment. This type of collaboration would help to foster what the European Commission (2007) cite as critical thinking amongst students. It would often be accompanied by hands-on / minds-on activities, reflection and written and verbal expression. Grandy and Duschl (2007) describe critical thinking in relation to evidence and understanding arising from criticisms from others, of others, of self-explanations and the reflection on alternative explanations that do not have a unique resolution. A critical thinker can then argue the merits of alternative models and theories (Friesen and Scott, 2013). Indeed, Grandy and Duschl (2007) indicate that at the core of what it means to conduct scientific inquiry is to allow for learning and reasoning to get beyond conceptual learning goals and to develop important epistemic and social dimensions of learning such as arguing, modelling, explaining, questioning, evaluating and modelling.

2.4.2 Inquiry Education in Terms of the Teacher

Friesen and Scott (2013) list a number of ideas, which they see as underpinning a successful teaching approach to IBL in a mutual way. These include:

- Formative Assessment;
- Questioning;
- Scaffolding.

They are described in more detail below.

Formative Assessment:

Confrey (2006) describes the process of engaging in formative assessments as creating a "set of landmarks" that can help to guide them along a "conceptual corridor". It may take the form of students engaged in expressing and communicating their understanding and skills through dialogue in an effort to improve their work. Descriptive feedback can clarify goals and prompt reflection on how learning gaps are bridged. More specifically, Black and Wiliam (1998) who conducted an empirical review of classroom assessment reveal that formative assessment conclusively improves learning considerably. Furthermore evidence in many studies in their work indicates that emphasis on formative assessment is of particular benefit to the so-called low-attaining learners.

Questioning:

Friesen and Scott (2013) argue that guiding questions help focus the inquiry around links to formative assessment in that it helps to clarify learning goals.

Oliveira (2010) contends that the aim of questioning is twofold in terms of facilitating knowledge construction amongst learners:

- elicit students' individual experiences;
- encourage students to derive more refined meanings from their own individual experiences.

To this end, Oliveira (2010) calls for the use of questions that are:

- descriptive - motivate students to describe their work;
- challenging - encourage students to explore further;
- connecting - questions that help students link their exploratory work to prior knowledge in order to avoid fragmentation;

- probing - questions which prompt students to expand, clarify or justify their own answers;
- redirecting - questions that require students to expand, clarify or justify answers provided by another student.

Scaffolding:

Wilson et al. (2010) point out that inquiry learning requires far from minimal guidance and is dependent upon sufficient scaffolding to guide student learning. Hmelo-Silver et al. (2007a) reflect that IBL employs scaffolding extensively. Friesen and Scott (2013) view scaffolding as having positively impacted upon problem solving and knowledge attainment amongst students. They note that effective scaffolding involves “bracketing” out elements of a task *initially* beyond the learner’s capability in a way that allows the learner to concentrate upon and complete only those elements that are within their range of understanding. Criswell (2012) argues that the learner should get assistance regarding demands on both content acquisition and scientific reasoning which can be faded as the student becomes more proficient and can problem-solve in an “unassisted” way. While Friesen and Scott (2013) argue that it is sometimes ambiguous as to what precisely constitutes a scaffolding activity, it generally involves tools, strategies, and guides.

Simons and Klein (2007) echo the importance of the use of hard and soft scaffolding that is useful in an inquiry context discussed earlier in relation to PhET simulations. The benefits of scaffolding as a metacognitive strategy when used by teachers is discussed in Chapter 3.

If these approaches to teaching are acknowledged, learning benefits to students can accrue. In a meta-analysis of one hundred and thirty-eight science education studies, a definite trend favouring inquiry-based instructional practices, particularly those that emphasize student active thinking and drawing conclusions from data was evident regarding the attainment of increased conceptual knowledge (Minner et al., 2010) .

2.4.3 Spectrum of Inquiry Teaching

Furtak (2006) suggests that it may be useful to think about scientific inquiry as one side of a continuum of different methods of science teaching. At one pole of the continuum is traditional didactic teaching while at the opposite pole, is teaching to an open inquiry approach. This is reflected in Figure 2.3.

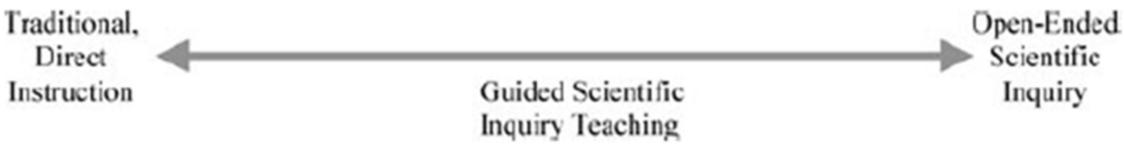


Figure 2.3: Continuum Representing Forms of Science Instruction (Furtak, 2006)

This architectural vision of IBL based on the degree of independence that students have in the inquiry process, is echoed by Windschitl (2003) and by Sadeh and Zion (2009). In addition, Gyllenpalm et al. (2010) state that frameworks of Structured Inquiry to Open Inquiry Instruction all include, as their central characteristic, being driven by an initial question for which an answer cannot readily be found in a textbook. A brief overview of the types of inquiry in relation to this work is now described.

2.4.3.1 Structured Inquiry

Windschitl (2003) and Crawford (2007) regard this form of instruction as being one where students are given both a question and a procedure by their teacher. They receive complete instruction at each stage and their aim is to find out the answer to the question from their inquiry. Sadeh and Zion (2009) compared the structured inquiry approach to working by a recipe toward a desired outcome. Banchi and Bell (2008) note students follow the directions for doing the experiment, recording their data, and analysing their results. In turn, students generate an explanation supported by the evidence they have collected. While it is regarded as a low-level inquiry, it is important because it enables students to gradually develop their abilities to conduct more open-ended inquiry.

2.4.3.2 Guided Inquiry

Gyllenpalm et al. (2010) consider this method of instruction to be teacher initiated, by the posing of a question. Students are then guided by multiple teacher questions, through a process of scientific investigation, to particular answers that are likely to be known to the teacher. Windschitl (2003) notes that, in a guided inquiry approach, the teacher does *not* provide a method for the students to follow. According to Banchi and Bell (2008), it is the students who design the procedure (method) to test their question and generate the resulting explanations. Just because students are designing their own procedures does not mean that the teacher's role is passive. The teacher may provide models, verbal guidance and other supports needed to investigate the question and help them ascertain if their plans make sense. Sadeh and Zion (2009) view guided inquiry as a form of instruction where the teacher likely has a good idea of what results to expect but where the students actually lead the inquiry process, thus empowering them to draw their own conclusions. Hence there is a requirement on the students to use their prior knowledge to incorporate new learning by thinking critically about the situation that is presented. Because this kind of inquiry is more involved than structured inquiry, it is most successful when students have had numerous opportunities to learn and practise different ways to plan experiments and record data.

Demir and Abell (2010) claim that the defining feature of guided inquiry is asking students to think through problems (e.g. giving evidence, explanation or justification).

The author employs an approach in the development of the pedagogical instrument in this study that is a mixture of both 'Structured' and 'Guided' inquiry. While it is seen as desirable to move away from 'Structured' inquiry in as far as possible, the hybrid nature of these styles reflect:

- The abstract nature of the area of PNM;
- The lack of familiarity of students with IBL;
- The time constraints of the curriculum.

The relative level of each style may vary during actual teaching and learning that occurs using the workbook on any given day making it difficult to accurately indicate at which point it lies along the continuum in Figure 2.3. However, it is possible to say that this approach <u>does</u> involve an increased level of teacher facilitation both verbally and in terms of the appropriate sequencing of topics within the workbook in class. This is further elaborated in Chapter 4 where development of the workbook is discussed.

2.4.4 Inquiry Cycles

The National Research Council (1996) proposed the term "integrated instructional units" to describe the sequence of science instruction connecting laboratory activities with other science learning activities. In this sequence students engage in "framing research questions, making observations, designing and executing experiments, gathering and analysing data, and constructing scientific arguments and explanations". Bybee et al. (2006) report that, The Biological Sciences Curriculum Study, a curriculum developer in the United States, currently uses the 5E Instructional model as an example of a model, which is a specific case of integrated instructional units. Llewellyn (2005) attributes that its first use to Atkin and Karplus (1962) Curriculum Improvement Study. It is a constructivist teaching strategy and its five stages are aligned with cognitive theories on how learning occurs. Goldston et al. (2010) argue that the learning cycle is grounded specifically in Piagetian theory. Llewellyn (2005) explains these stages which are paraphrased below:

(i) Engagement – The teacher sets the stage for learning, which is accomplished by stating the purpose of the lesson and often the learning outcomes. The teacher creates ways to "hook" students into learning by creating what Palmer (2009) refers to as situational interest, via a demonstration or counterintuitive display which can be used in turn to elicit questions from the students. The teacher may assess student prior knowledge at this point and allow students share their experiences about the topic.

(ii) Exploration – If using structured or guided inquiry, this can be an appropriate time to engage students with a teacher initiated question. This leads students to ask questions, develop hypotheses around the question and work within their co-operative groups, without direct instruction from the teacher. Bunce (2001) notes that the process of asking questions has the advantage, for the teacher, of reflecting student understanding in an overt fashion rather than trying to guess where the students are in terms of their learning.

(iii) Explanation –The teacher facilitates the discussion of findings or information collected and may provide vocabulary and definitions to students to help them assimilate their understanding in terms of a scientific explanation. Alternative conceptions unearthed from the initial two stages are addressed.

(iv) Elaboration / Extension – The teacher uses the application of the key concepts involved to real world situations to consolidate understanding.

(v) Evaluation – Here the teacher can compare the prior knowledge elicited in the first two phases with the newly formed understanding gained from the lesson. Metacognition can be elicited and/or assessed via concept maps. The teacher may also ask higher order and application questions. Finally, students may be helped towards summarizing relationships between concepts and variables encountered during the lesson.

2.4.5 Evaluation of IBL

Capps et al. (2012) argue that, although science education reform efforts highlight the importance of inquiry-based instruction, it appears that little has changed regarding how science is taught in the majority of US classrooms. Some reasons as to why this may be the case are described below.

The findings of research conducted on inquiry learning experiences for students appear inconclusive in terms of which part of the inquiry spectrum yields better results. Sadeh and Zion (2009) propose that, as students move along the spectrum of inquiry learning from structured inquiry to guided inquiry, they transform their data much more into complex and abstract forms, such as graphs and concept maps, while Sadeh and Zion (2009) contend that open inquiry demands the most from students in terms of high-order thinking. They also argue that guided inquiry students developed poorer procedural understanding than open inquiry students. The latter had a better chance to develop procedural understanding because of the need to handle difficulties and problems that arose during the inquiry process. However, Kirschner et al. (2006) draw from results of studies by Mayer (2001) that guided inquiry instruction not only produced more immediate recall of facts than unguided approaches, but also longer term knowledge transfer and problem-solving skills.

Sadeh and Zion (2009) report that those science educators who claim that the open inquiry experience may deepen student's understanding of the nature of science have called for further investigation of open-inquiry learning practices. Palmer (2009) writes with regard to student motivation and asserts that from a constructivist viewpoint, learning may be interpreted as an active process which requires effort on the part of the learner. Thus, it follows that students need to be motivated to make that effort or no meaningful learning will occur. Crawford (2007) concurs with this view.

Kirschner et al. (2006) argue, using evidence gathered from empirical research over the last 50 years, that minimal-guidance (open inquiry) instruction appears to proceed without reference or acknowledgement of working memory, long-term memory, or the dynamic relationship between them. They stress the unhelpful nature of this oversight in a learning context where novel information is presented to the student, given that working memory is limited in terms of its capacity. In this sense, Capps et al. (2012) argue that this form of classroom inquiry will never reach the level of sophistication involved in authentic scientific inquiry.

Abd-El-Khalick et al. (2004) refer to high-stakes assessments as an important feature of educational systems internationally. Thus, teachers may lack the incentive to change their teaching because from a time-efficacy perspective, they may view an inquiry approach as requiring "additional" instructional time which results in poorer coverage of the curriculum.

Crawford (2007) considers local factors, such as students who may be resistant to IBL due to their fear of being wrong or unwilling to engage in thinking, in a learning environment where there is an element of uncertainty in lessons. This scenario may appear unfamiliar and less appealing to students than writing notes from the board or learning definitions from the textbook.

Finally, in terms of chemistry and the area of PNM in particular, Snir et al. (2003) agree that a pure inquiry-oriented approach is naive. With this point in mind, the author commits to an IBL approach that is a hybrid of 'Structured' and 'Guided' driven by his desire to optimise his students' opportunities for learning in which they are given choices and are forced to make decisions. It is underpinned by the steer drawn from Minner et al. (2010) where learning is considered to be inquiry-based if it (i) instructed students via some part of the inquiry cycle in relation to scientific phenomena and (ii) used pedagogical practices that emphasised, to some extent, student responsibility for learning or active thinking. It also seeks to blend IBL with regular formative assessment, considered teacher questioning and scaffolding so that working memory overwhelm is avoided and deep thinking (as opposed to surface thinking) is allowed.

2.5 Conclusion

This chapter has examined the meanings of models that might be considered in science education. It has also pointed to the specific reasons why modelling is of use in understanding chemistry concepts as well as the criticisms of modelling that exist and the factors that need to be considered around it. Michalchik et al. (2008) view the science education research community, as being at the initial stages of understanding of the processes through which use of visual representations in classroom practice can contribute to student learning. However, this chapter sought to outline what visualization is and the benefits it can bring to student learning. Some cognitive aspects of visualization were described in tandem with visualization processes in order to suggest how it might function in an optimum sense as a teaching tool. The area of Inquiry Based Learning (IBL) was then detailed in terms of what it can mean to a teacher and to a student of chemistry. Two forms of IBL were then described and its importance as a pedagogical style is stressed. Some criticisms of IBL are then offered.

As IBL is the type of pedagogy employed in this work to develop units of a workbook on PNM to facilitate conceptual development, it is important to explore the meaning of successful learning. This is undertaken in the next chapter in which IBL is framed within the 'experience' of learning, which may be promoted or hindered by cognitive processes. In doing so, the researcher is allowing the study to rest on a foundation based on Kelly's Fundamental Postulate (Kelly, 1955 / 1991) which views the student as moving from the known to the unknown as they learn. This has the advantage of being able to gauge the student's level of success while doing so. It also confers the researcher with the freedom to consider the possibility of the invocation of useful 'constructs of transitions' such as Kellyian Aggression by students. Such constructs are used as individuals attempt to elaborate their understanding in the zone of cognitive transition which involves varying degrees of uncertainty. Hence, Kelly's 'Personal Construct Psychology' is employed to assist in the author's attempt to make sense of his students' explanations and consider the nature of their cognitive frameworks whether they are fragmented on one hand or organised and integrated on the other. Student sense-making activities are contained within a workbook and are underpinned by visualizations, with the aim of developing learners' mental models. This feature is coupled with an approach of 'structured' and 'guided' inquiry based learning which serve to direct learning activities and the development of the workbook itself.

CHAPTER 3: HOW AN INDIVIDUAL LEARNS CHEMISTRY

Introduction

The previous chapter outlined the importance of modelling and visualization as tools for learning in the science classroom. Their use was considered from a pedagogical view so that they might function to promote, as opposed to obstruct learning. One of the teaching settings in which these tools may be used is IBL. The nature of IBL and its possible associated learning benefits were described. Finally, some views of it as a teaching approach were offered. This chapter focuses on how an individual student of science learns conceptually. The learning models and dynamic cognitive processes cited in the literature that promote or hinder the understanding of a topic are described. There is also a brief description of how a teacher may facilitate meaningful learning. Later, the theoretical architecture of PCP, which serves as a channel for the convergence of these ideas, is provided. Finally, a framework of learning is proposed that may be applied to answering the secondary research question. This serves to illuminate what successful learning in chemistry involves within this study.

3.1 Knowledge in Chemistry

This section describes the features of chemistry that a learner must contend with in order to learn successfully. In addition, their influence on the components of students' memory which are critical to successful knowledge acquisition in areas such as PNM is outlined. Finally, the implication of memory capacity for the effective use of visualization tools in order to help students reflect on their thinking is provided.

3.1.1 The Nature of Knowledge in Chemistry

Nersessian (2008) argues that the functioning human cognitive apparatus is capable of mental modelling, analogy-making, abstraction, visualization, and simulative imagining. These are resources that can help students develop an expanded set of skills that are moving to centre stage in the classroom, and which, according to Yenawine (2012), include: reasoning clearly, listening constructively and thinking critically. Critical thinking involves internalizing knowledge and redeploying it appropriately to speculate and consider alternatives. However, Cracolice et al. (2008) argue that a very low percentage of students in junior second level school have sufficient reasoning skills to become successful conceptual problem solvers where genuine understanding is required. Unfortunately, this situation does not improve greatly upon entry to university even though Sere (1985) contend that from the age of about 11, students begin reasoning in more abstract ways. Gabel (1999) views the nature of this problem in terms of the *information processing model* of learning which highlights impediments to successful knowledge acquisition in this chemistry and reasoning skills. This includes the threefold representation of matter, meeting unfamiliar materials and their potential effect on working memory space.

Nahum et al. (2004) suggest that a large portion of the challenge posed by the abstract nature of chemistry may be due to the fact that students live and operate in the macroscopic world of matter and highlight that they do not easily follow shifts between the macroscopic (real and accessible to our senses) and microscopic (real but inaccessible to our senses) levels. She cites Johnstone (1991), Gabel (1996), Tsaparlis (1997), and Robinson (2003) for further evidence in support of her thesis. Coll (1999) describes the nature of this shift as the "*constant interplay between the <u>macroscopic</u> and <u>microscopic</u> levels of thought*" and it is this aspect of chemistry learning that represents a significant challenge to novices. Newman (2012) gives an example of the difficulty linking levels: a fundamental alternative conception in chemistry appears to arise from learner-beginners thinking of microscopic chemical entities as themselves having the very same 'macro' properties that we observe through the senses (e.g. colour). This idea is evident in the earlier work of Taber (2001) on how research into a learner's ideas and difficulties in chemistry might inform teaching practice.

Johnstone (2000) points to the high cognitive demand on chemistry students due to the highly *symbolic* nature of chemistry. Jacob (2001) explains some aspects of chemical symbolism. Chemical symbolism consists of an alphabet, a particular syntax and a set of semantic rules. It includes more than 110 symbols representing the known chemical elements (e.g. Na, Cl). Elemental symbols can be combined in order to form a chemical formula (e.g. NaCl) and reaction equations (e.g. $2Na + Cl_2 \rightarrow 2NaCl$). Chemical syntax is the formal set of rules which allow the combination of symbols and covers empirical rules regarding valency, oxidation state, electronegativity, affinity etc. Gabel (1999) regards the use of strings of letters to represent unfamiliar chemical materials as simply serving to be "non-interpretable symbols" and mentions that, even <u>when</u> interpretable, symbols can be used in several ways. This is illustrated through her use of the example of "Fe" where she poses the ambiguous but common question that a student might ask: "Does the symbol Fe stand for one atom of iron or for a sheet of iron?" Nahum et al. (2004) contextualize this difficulty: *"The instructor writes symbols, which <u>represent</u> a physical reality. Very often, students write letters, numbers, and lines, which have no physical meaning to them.*" Ball and stick models are further examples of symbols used to represent molecules.

While acknowledging that chemistry operates at an interpretative level that is symbolic (in order to explain chemical relationships), Johnstone (2000) emphasizes that chemistry also operates at two other related interpretative levels which are the sub-micro and the macro. Based on a Slovenian study of students' capacity to understand these levels of interpretation, Devetak et al. (2004) posits that chemical thinking requires knowledge about how to connect macroscopic findings (such as experiences and experiments) with the explanations at the submicroscopic level (such as electrons, atoms, ions and molecules) and their recordings at a symbolic level. He argues that unless this is achieved, chemical education results only in 'fragmentary knowledge', which is quickly forgotten. Williamson (2014) gives a context to the way in which chemistry was traditionally taught, by arguing that symbolic representations were first presented to students (the chemical formulae and mathematics concerning a phenomenon). Subsequently, students would work on problems and conduct a verification laboratory activity (macroscopic representation). The rationale for this approach lay in the assumption that conceptual understanding of the particulate level would follow. Chittleborough (2014) explains that while the submicroscopic level is as real as the macroscopic level (it is only the scale that distinguishes it), the fact that the submicroscopic level is invisible makes it hard to accept as real.

In summary, Johnstone (2006) represents the linkages between the three levels graphically in Figure 3.1.

Figure 3.1: The Three Conceptual Levels of Chemistry (Johnstone, 2006)

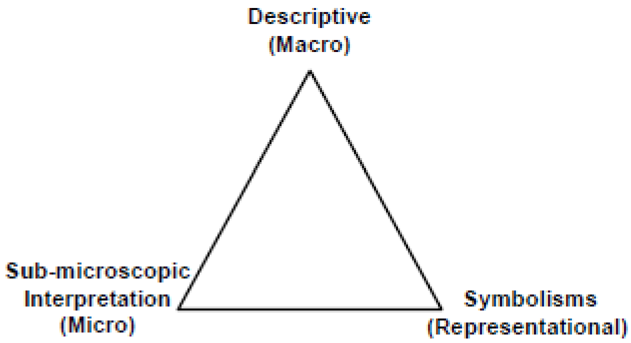


Figure 3.1: The Three Conceptual Levels of Chemistry (Johnstone, 2006)

Taber (2013a) explains that this triplet relationship is the most significant to the learning of chemistry for the pupil and the teacher. In terms of managing cognitive demands for learners, Chittleborough (2014) cites Johnstone (1997) as advocating the gradual development of the three interconnected levels instead of introducing all three levels *simultaneously* (to novice learners). Otherwise the 'working space' of their brains would be overloaded.

3.1.2 Memory and Knowledge Processing

In some instances, the working memory capacity of the novice learner may be overwhelmed. Hussein and Reid (2009) explain how this phenomenon occurs; "*cognitive load is dependent on* <u>*working memory capacity*</u> *which is described as a psychological space, where incoming information is held temporarily*". Schneider and Stern (2010) posit that due to its limited capacity, working memory is a *bottleneck* for the <u>transfer of knowledge</u> to long- term memory.

Johnstone (2006) argues that a further function of this limited space is to <u>operate upon</u> this information in order to make 'sense' of it and prepare it for some response and/or to try to integrate it with prior knowledge in Long Term Memory. It is the location where the learner thinks, solves problems and understands. If information is moved from working space memory to long-term memory, it leaves working space memory free for further tasks. Specifically, Taber (2013a) points out that a learner's working memory is considered to have a very limited number of 'slots' for data: typically it is 7 ± 2. Most people therefore can 'keep in mind' from

5 to 9 distinct new pieces of information at a time. This may lead to the problem for learners of 'too much to hold in mind at once' as they attempt to complete the task.

Kirschner et al. (2006) underline the importance of working memory by stating that it influences our audio-visual senses. Furthermore, Johnstone (2006) indicates that external stimuli such as those presented in teaching and learning experiences, are perceived by our senses and filtered. The learner attends to what is familiar, stimulating, interesting, surprising or exciting. In order to do this, the filter is subject to the control of what is already held in Long Term Memory. The information admitted through the filter enters the conscious processing part of the mind, the Working Memory Space. New information cannot be assigned meaning unless it is compared with some previous experience. Thus, what is held in the Long Term Memory store is crucial for this perception stage. Tsaparlis (2014) views the information embedded in long-term memory as being (potentially) a powerful tool for looking at the world. Johnstone's Information Processing Model is shown in Figure 3.2.

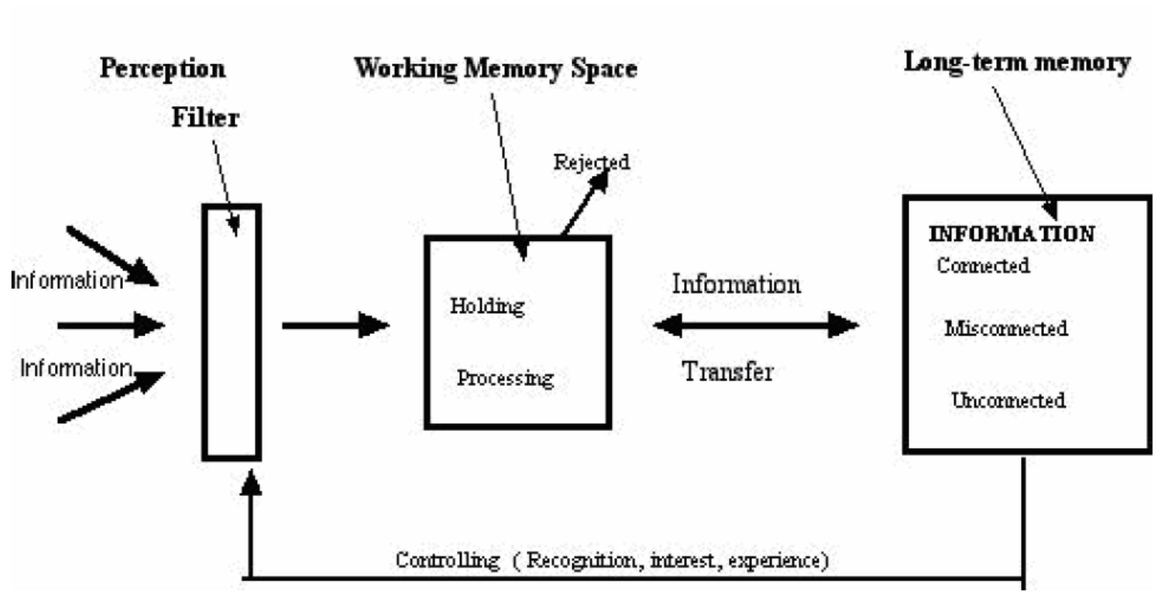


Figure 3.2: Information Processing Model (Johnstone 1991)

In the view of Gabel (1999), if something does exist to which the new concept can be related, then learning occurs and the information is stored in Long Term

Memory beside prior knowledge. If there is nothing in Long-Term Memory to which a new concept can be related, then it will either not be stored, or it will be stored as a single entity ('fragmentary knowledge'). She notes that, although it is possible for isolated information to be added to Long-Term Memory (via rote learning, for example), more *effective learning* occurs when new information is linked to information that is already stored there. Existing concept networks are then expanded and a person can *make sense* of their world.

Johnstone (2000) warns however that if 'sense' is achieved by a faulty attachment, then, so-called "knowledge" becomes static and it is very difficult to reverse. Wink (2001) also reminds us that learning is made more difficult if students enter the classroom with "incomplete or distorted prior knowledge". According to Pinarbarsi and Canpolat (2003) this type of prior knowledge, leading to incomplete and incorrect ideas, may have serious effects on subsequent learning and chemistry becomes more difficult to study. One of the areas he cites as frequently problematic is that relating to the PNM.
Table 3.1 summarizes the types of knowledge considered in the Information Processing Model (IPM).

Table 3.1: Summary of Knowledge Considered in IPM

Relation with Long Term Memory	Acquisition Status	Attachment to Prior Knowledge	Usable for Further Learning	Ease of Recall
Can relate to	Knowledge stored	Good link	Yes	Easy
Can relate to	Knowledge wrongly stored	Faulty link	No	Easy
Cannot relate to	Knowledge not stored	No link	No	No
Cannot relate to	Stored as 'fragmentary knowledge'	No link	Yes	Difficult

Unless it is rejected, filtered material is admitted into the conscious part of our mind (Working Space) and processed where it may be matched with things we know or modified into a meaningful form (of knowledge) where we are *satisfied* with our thinking or problem-solving. A decision is then taken, consciously or otherwise, to store or reject the information. A related reason, in terms of successful filtration, is 'chunking' and this is discussed later in this chapter in Section 3.2. The next section considers the implications of how students process information for visualization strategies.

3.1.3 Visualization Software Considerations for Knowledge Acquisition

The effectiveness of using computer animations of chemical processes at the particulate-level, according to Rosenthal and Sanger (2013) is based on Mayer's (2001) cognitive theory of multimedia learning. This was derived from Paivio's dual-coding theory (Paivio, 1986) and Baddeley's model of working memory (Baddeley, 1986).

In the conclusion to a review of the use of animations at the beginning of this century, Mayer and Moreno (2003) advocate its potential to enhance meaningful learning based on how students interpret ideas from verbal and pictorial communications (media). They present a cognitive theory of multi-media learning, hinging on three basic assumptions from which they derive a model (Figure 3.3).

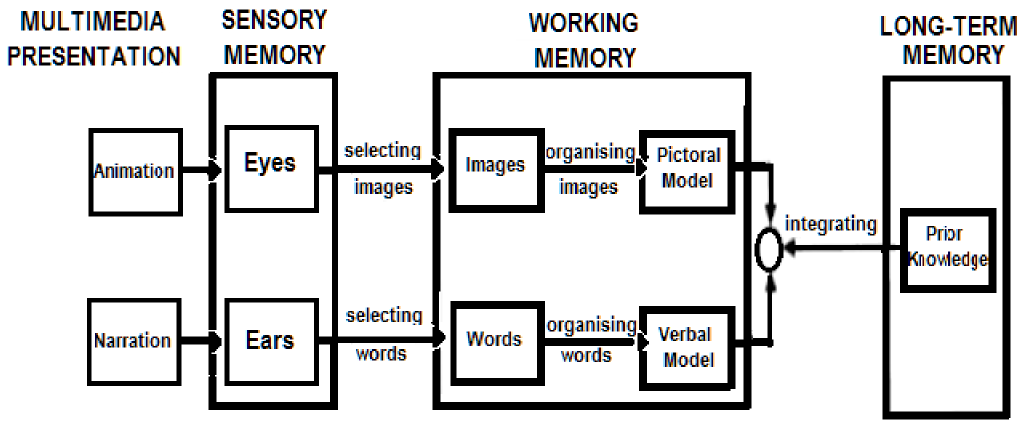


Figure 3.3: A Cognitive Theory of Multi-Media Learning (Mayer and Moreno, 2003)

The cognitive theory of multi-media learning assumes:

- learners possess separate cognitive channels for processing visual (pictorial) and auditory (verbal) information;
- have limited processing capabilities (Working Memory) in each channel;
- engage in active learning by attending to relevant information, organising this information into a mental schema, and integrating this new knowledge.

This model is similar to the Information Processing Model (IPM) of Johnstone (2006) in that it acknowledges incoming information, working memory and long-term memory and the relationships between them. Mayer and Moreno (2003) refer to the label 'organising words' as the building of a *coherent* verbal representation of new words. The label 'organising images' refers to a parallel process involving the completion of a coherent pictorial representation. While Reid (2009) in considering IPM, refers to meaningful learning as that which involves the application of knowledge to new situations, Mayer and Moreno (2003) view it in terms of being able to construct coherent representations of mental models. Summarizing its importance for student learning, Davidowitz and Chittleborough (2009) argue that students learn by active selection, organisation and integration of information from auditory and/or visual inputs. Mayer and Moreno (2003) developed eight principles of multimedia learning based on Cognitive Theory and Design Principles. Two of these are relevant to the topic of chemical diagrams: *Multimedia principle,* which states a combination of words and pictures is more effective in promoting deeper learning than the use of words alone; *Coherence principle,* which states that extraneous words, sound or pictures can distract the learner and should be excluded in order to facilitate deeper learning.

Having derived a mental model using their senses, students can employ them by putting them into operation. This process is known as metacognition (Taskin and Bernholt, 2014). Hewson (1992) points to the context for metacognition arising when students are encouraged to "step back" from ideas held by themselves and/or others in order to think about them and express an opinion. During this process, students may reflect on whether a new conception is meaningful using the following parameters:

- *Intelligible:* A conception that is sensible and non-contradictory relative to other conceptions. Its meaning is understood by the student;
- *Plausible:* Means that the words of the conception must be understandable and make sense. In addition, it must fit in with other ideas or concepts the student knows about. Therefore the conception is believable;
- *Fruitful:* This is a characteristic bestowed upon a conception if it is useful and so may help the student solve problems directly or suggest new directions to

research them.

Dolan and Grady (2010) note that students get the opportunity to engage in metacognition when asking scientifically-oriented questions, giving priority to evidence in response to questions, formulating explanations from evidence and, communicating and justifying explanations. Cheung (2015) gives other examples of metacognitive control strategies used to make one conscious of how we use our knowledge as including goal-setting and self-testing. A potential benefit for learning relating to students who engage in metacognition is the capacity to perform intelligently rather than mechanically (Machamer, 2007).

3.2 Conceptual Change

This section discusses how mental models developed by students following activities such as visualization are features of conceptual change. In addition, conceptual change is considered from an epistemological and ontological perspective.

Nersessian (2008) acknowledges that, though the level of *reflection* they engage in may be different, sense making involves constructing and manipulating a model in working memory for scientists, learners, and developing children. Keil and Newman (2008) posit that resultant conceptual change is not always synonymous with cognitive development. They suggest that true conceptual change occurs under one of two conditions: either a concept's internal structure changes (sets of features, properties and their interrelations) or its relations to other concepts change in ways that are central to its 'meaning'. Clement (2008) refers to Thagard (1992) who views a conceptual change as structural or relational in character rather than a change in *surface* features.

Duit and Treagust (1998) and Treagust and Duit (2008) note that in discussion of conceptual change, improvement is more far-reaching than simply extinguishing and replacing old ideas that are deemed unfit for purpose. Previously and similarly, Hewson (1992) explained that change should not mean 'exchange' (i.e. replacement) but rather a *change of status* given to conceptions. He noted that this dynamic involving the attribution of a new status to (rather than the extinction of) a new or old idea, could best describe how students *meaningfully integrate* their prior knowledge with newly constructed knowledge and experiences. Thus a conceptual extension is allowed to take place.

Treagust and Duit (2008) maintain that old ideas stay alive in particular contexts. If a learner was dissatisfied with his/her prior conception *and* an available replacement conception was intelligible, plausible and/or fruitful, then accommodation of the new conception may follow. However, if such a conception's status is intelligible, plausible or fruitful, two conceptual events may happen. If the new conception conflicts with a prior rival conception, it may lead to the status of the old conception becoming lowered. In this way, accommodation of the new idea may occur. However, if the old conception retains a higher status, conceptual 'exchange of status' will not proceed (for the time being). Treagust and Duit (2008) indicate that the replaced conception is not forgotten as the learner may wholly or partly reinstate it at a later date. Therefore, rather than the *exchange* of one conception for another, there may be *increased use* of the rival conception that makes better sense. Treagust and Duit (2008) report that in a study on genetics, students moved continuously back and forth between fundamental and advanced conceptual positions for the duration of the course. Hewson (1992) interprets conceptual change as meaning 'extension'. This view of learning also involves recognising the interaction between new and existing conceptions (which can act as points of inference).

In terms of how conceptual change may take place visually, Van Meter and Garner (2005) extend the range of this dynamic by alluding to the necessary conditions for integration of new concepts. These involve the generation of referential connections to link *both* internal verbal and nonverbal representations (e.g. images). When these 'associative' connections between internal concepts are activated, a mental model is constructed. As a result, the learner stores a mental model of target content in which both *verbal* and *non-verbal* representations can be integrated. Gilbert (2008) extends this idea further: once (multiple) internal representations have been visualised, they may be recombined to form a novel internal representation that is capable of external expression. He explains that this is the essence of creativity. Earlier, Gilbert (2005) referred to the capacity to carry out the act of 'metacognition in respect of visualization' as *metavisualization*. He argues that this term needs to be considered in relation to pedagogical approaches as both students' visualization skills and meta-visual capacity impact are relevant. This is especially true when students are required to navigate through multiple representations in order to interpret and evaluate images.

As previously stated, students learn by making connections to what they already know and in so doing, reconcile their present views with what they learn. Treagust and Duit (2008) acknowledge that conceptual changes may be permanent, temporary or barely detectable in nature. It may be useful to interpret current status (visually) as a bipolar construct with a 'concept congruous to one's knowledge system' at one end and 'a concept incongruous to one's knowledge system' at the other, such as in in Figure 3.4.

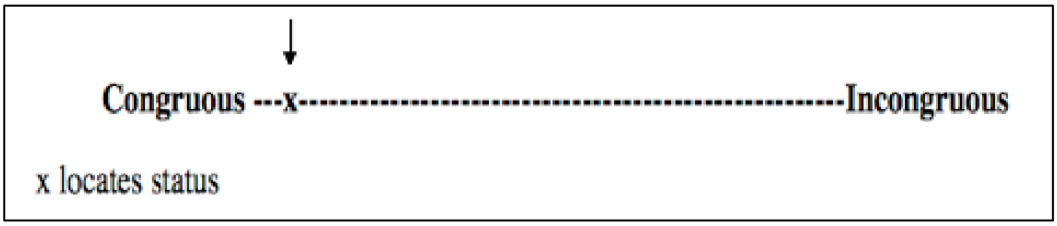


Figure 3.4: **Conceptual Status Using a Construct Based on Intelligibility, Plausibility and Fruitfulness**

The status of the concept (x) in Figure 3.4 is likely to be *satisfactory* and lead to its meaningful integration into a learner's knowledge system. Therefore, it is likely to be applied to new problems more frequently than a concept with a lower conceptual status.

In summary, learning is the construction of new conceptions. This implicitly involves change. Notably, Duit (1996) refers to "conceptual change" as learning and claims it only occurs when the *learner, rather than the teacher*, chooses to believe that the necessary conditions of knowledge integration have been satisfied. This is in harmony with constructivist learning theory and is echoed by Taber (2015). Talanquer (2009) notes that at this point (of conceptual change / reconstruction), a revision and modification of an individual's (naïve) theories and mental models may result.

3.2.1 Conceptual Change from an Epistemological and Ontological Perspective

Using Hewson's metaphor for conceptual change as *status* change (e.g. high or low), it is possible to extend the range of related categories through which we can see the learning of chemistry. Miyake (2008) describes conceptual change involving the interaction among the *inner* and *outer* resources of a learner. The inner is the accumulated and structured knowledge reflecting their mental model while the outer is the physical and social environments which influence it. Treagust and Duit (2008) envisage two forms of conceptual change. The first is viewed through the lens of epistemology and the second from an ontological perspective. These encompass both sources considered by Mikaye (2008).

<u>Epistemological Perspective</u>:

Driver et al. (1996) describe epistemology as the branch of philosophy dealing with theories of knowledge. It probes the distinctions between *believing* something to be the case, and *knowing* that it is. It is concerned with relationship between methods of inquiry and the knowledge they produce. For example, they cite Songer and Linn (1991) who report that students who view science knowledge as revisable (dynamic) rather than fixed (static) were less likely to believe that learning science depended on memorisation. This resulted in a more integrated understanding of the topic of study. Willison and Taylor (2006) argue that each epistemology provides a different focus for learning and a different *means of engaging* in the process of learning. Treagust and Duit (2008) deem epistemology as the nature of <u>how</u> students learn concepts. Its *focus is on viewing knowledge as being constructed* (this is contrary to a transmission model of learning).

An epistemological feature they describe as leading to knowledge coherence for learners is the capacity to remain open to alternative ways of 'knowing' a topic. This may serve to increase the efficiency of students' predictions and hypotheses.

This characteristic goes towards explaining Kelly's (1955/1991) metaphor of 'the person as scientist' (the focus of this metaphor is on the sense-making activity within the mind of the individual student). Kelly is the founder of Personal Construct Psychology (PCP), a theory that will be explained later in this chapter.

Kelly (1955/1991) would claim that a chemistry teacher, considering their epistemological position, might ask *how* they can best go developing the understanding of their students. While considering this process of increasing knowledge, it is possible to take an epistemological stance by adopting Kelly's (1955/1991) 'credulous listener' approach to chemistry learners. This is to identify them as 'active meaning-seeking individuals, whose views of the world are valued' (Pope and DeNicolo, 2001).

Ontological Perspective:
In alignment with (Taber, 2013a), this work uses constructivism as an ontological model of human cognition. It also shares the view held by PCP theory that learning is a *process* rather than a final *product*. At the end of the process, a teacher can ask, what is the range of convenience/application of the acquired knowledge of the learners in their care? Treagust and Duit (2008) state that, from an ontological perspective, chemistry teaching involves considering how students learn scientific concepts in terms of the nature of (their perceived) reality. Barria et al. (2016) argue that many scientific concepts have come to be understood because of ontological interrogation. This has involved connecting concepts to reality using ontological categories such as entities, properties or processes. While not the focus of this work, it is worth noting that Chi (2008) offers a very comprehensive description of ontological phenomena using these categories.

3.2.2 Knowledge Structure - Novice to Expert

This section discusses the process of 'chunking' and its association with novice-expert knowledge elements including heuristics. Differences in knowledge between novices and experts from a cognitive perspective are also considered.

Duit (1996) acknowledges an architecture of learning which may be viewed in terms of students' pathways from parts of their *already existing* conceptual structure towards accepted science conceptions. In principle, two alternative pathways may result from this constructivist perspective: one smoothly causes enrichment (or structural enlargement) via *minor* revisions and the other a traumatic modification due to *major* restructuring. Nersessian (2008) holds that reasoning involves the construction and manipulation of a model in working memory. Reese and Gilbert (2008) signal that novices and experts within a discipline actually 'think' *differently* due to varying levels of experience which can serve to develop a deeper and more highly-organised hierarchical knowledge (structure). Talanquer (2013) frames *experience* as the empirical knowledge about chemical substances or processes that are gathered through the senses. Consequently, more experienced learners can gain a *perception* that is <u>more sensitive</u> to information patterns which allows them to "chunk" information. This may be explained by Taber (2015) who writes that when *new memories* are first represented, they are initially linked to a network of more established memories through *a temporary mechanism*. There are <u>automatic (neural) processes</u> in the brain that can supplement (and in time replace) these fragile interim links with more established *permanent linkages.* More established links grow following (sufficient) stimuli to cause the <u>activation</u> of a group of relevant/related knowledge representations. Thus, in keeping with Constructivist theory, after a time that can take weeks/months, knowledge becomes more robust and can serve as a dependable platform of support for further, more complex, learning. At this point it can be chunked in working memory with information encountered in new learning experiences so that the learner can efficiently *coordinate it with new material* presented in teaching. This automatic mechanism is an accurate and efficient way of gaining further knowledge for experienced learners. However, it may prove faulty for novices with perceptions that are less sensitive to the nature of the new knowledge being encountered.

Talanquer (2013) claims that (for experts) advantages due to chunking, such as easier information analysis, retrieval and knowledge application, may accrue. 'Chunking' is the ability to group several variables, facts or ideas together into a meaningful unit so that working memory space is not overloaded as it attempts to 'make sense' using *automatic strategies* (Taber, 2013a). These strategies are based on sequences of steps, each of which is individually manageable within working memory. Therefore, information which has become closely associated by previous cognitive activity can be manipulated.

An everyday example illustrated by attempts to remember a telephone number is provided by Schneider and Stern (2010) who describe it as the *hierarchical* *structuring* of knowledge. Someone who tries to remember the number 01202009 has to hold 8 digits in working memory but might be able to *subsume* the number directly. Others may categorise it under the superordinate label 'date of President Obama's first inauguration'. Hence, all digits can then be recalled by storing one label in working memory. Thus, working memory limitations can be overcome. Taber (2013b) uses the hierarchical structure of knowledge to differentiate between a novice and expert learner by explaining that the expert learner often has relevant, highly-organised, prior learning that enables recognition of how teaching can be related to what they already know.

Thus, a task that is *initially* unfamiliar and complex becomes manageable as its components can be efficiently chunked. In this way, 'recognition' may become *'re-cognition'* whereby representations are free to be used and manipulated for learning purposes.

In relation to knowledge retrieval, Taber and Bricheno (2009) posit that when there is extensive consolidation of knowledge at the base of a (cognitive) structure, many concepts are accessible (to working memory). This can lead to the *accurate automation* of the process of declaring knowledge by experts. In this case, patterns are treated as *singular units* and sequences of cognitive actions are treated as one process. In contrast and in connection to learning with multiple representations, Ainsworth (2006) argues that novices tend to characterise problem representations by their *surface* features. In the absence of deeper, more integrated knowledge, Davidowitz and Chittleborough (2009) indicate an important aspect of the capacity to successfully problem-solve in chemistry is missing. Cook et al. (2008) claim that novices have little or no knowledge of the submicroscopic domain in chemistry and any knowledge they do have is stored in small (cognitive) chunks which are *weakly connected*. This argument leads Schneider and Stern (2010) to point to the likelihood that novices will be afraid to declare their knowledge as it probably involves the transfer of isolated pieces of information. This is because they see few connections between their learning environment and the outside world. In contrast, Taber and Watts (2000) describe explanations by experts as:

- being 'satisfactory' and in congruence with canonical models;

- making sense so that issues involved are no longer arbitrary;
- resolving inconsistencies;
- devolving logically possible alternatives to parallel explanations so as not to introduce inconsistencies within the current explanation.

Fragmented knowledge structures amongst neophyte chemists lead to surface learning strategies. Students then memorise and reproduce information without understanding (Cheung, 2015). These may include rehearsal and copying which serve to exclude the acknowledgement of concept integration within a topic. Furthermore, in relation to organic chemistry, Read (2015) acknowledges that if rote-memorisation strategies are used they can play a role that serves as a *barrier* to meaningful learning (where actual connections are made between new information and prior knowledge). The differences between novice and expert knowledge in relation to their behaviour is summarized in Table 3.2.

Table 3.2: Summary of Differences between Novice and Expert Chemist Behaviour

Knowledge Element	Novice	Expert
Prior Knowledge	Few established memories that are weakly organised	Highly organised so easily co-ordinates with new material
Knowledge Structure	Fragmented and nebulous with a narrow range of application	Deep, wide-ranging and highly organised
Perception	Limited to surface features due to limited learning encounters	Sensitive to establish appropriate links between what is observed/sensed empirically
Working Memory	Small weakly connected information chunks leading easily to cognitive overload	Chunking reduces overload and apparently complex information becomes manageable
Knowledge Linkages	Fragile or absent	Strong allowing for easy retrieval
Unfamiliar Concepts	Remain isolated from knowledge structure	Linked to a familiar schema (through pattern recognition) and integrated
Learning	Rote-memorisation strategies with no real understanding suited to recall tasks	Deep conceptual understanding of information with appropriate use of metacognitive strategies
Knowledge Application	Inconsistent based on surface features in a question and poor representational competence	Appropriate application with representational competence to allow successful problem-solving and analysis

3.3 Learning and Effective Teaching

This section details the influence of the affective aspects of knowledge building and then looks at strategies that promote learning and embrace both the cognitive and affective aspects of an individual in the science classroom.

3.3.1 Affective Nature of Learning

The features that display the differences between novices and experts, regarding their emotions, are now discussed. In addition, the relation between the affective domain and learning is considered.

According to Nersessian (2008), the *impetus* for a problem-solving process can arise from many sources: acquiring new information, encountering a puzzling phenomenon, or perceiving an inadequacy in current ways of understanding. The intensity with which such issues are approached (by the learner) is related to the <u>affective</u> nature of learning and, according to Treagust and Duit (2008), this can lead to conceptual change. Liu and Huang (2015) emphasise that the affective dimensions of chemistry learning focus on students' learning emotions. These aspects guide what contents of chemistry students choose to learn and how they learn them. Rahayu (2015) emphasises that affect is one of the most important influences on the way students think and behave in social situations (such as in a classroom) as it can promote a person's willingness and motivation to learn. Hence, Treagust and Duit (2008) claim that teachers who ignore the social and affective aspects of personal and group learning may limit conceptual change. Kahveci (2015) notes that the aims of science education are concerned not only with students' cognition but also with students' "affect". Treagust and Duit (2008) claim there is ample evidence in research on learning and instruction that cognitive and affective issues are closely linked. Kahveci (2015) notes that recent developments to improve school science by making pedagogical experiences more *meaningful* for students include project-based learning, context-based approaches and inquiry-based science education initiatives.

For success in their school chemistry, students need to have a positive sense of self-efficacy. Cheung (2015) states that modelling is a strategy for promoting this.

A further source may come in the form of feedback from the classroom teacher. Telling students that they are making progress in learning chemistry may enhance their self-efficacy beliefs about a topic, especially if it is conveyed by the teacher in a specific, considered way.

Citing Sarantopoulos and Tsaparlis (2004), attitudes are viewed by Kahveci (2015) as an outcome of the pedagogy that goes hand-in-hand with achievement. Allied to their success in chemistry, researchers found that using analogies in teaching helped to improve students' views toward the subject. Positive attitudes can also result from observing peers performing a task successfully.

Rahayu (2015) posits that motivation is an internal state that directs and sustains students' behaviour. Motivation would be required initially to make students want to participate in learning and would then be needed throughout the whole process of learning. Thus, she describes this quality as an essential prerequisite and co-requisite for learning. It includes constructs such as intrinsic and extrinsic motivation. Taber (2015) gives an example of a poor extrinsic environment for motivation as one in which new concepts, when presented too quickly, lead to working memory overload. The mismatch between learning demands and learning capacity can lead to frustration and demotivation. Williamson (2014) offers an example of the extrinsic variety that occurs when feelings of comradeship enable students to persist with problem-solving in chemistry.

Miyake (2008) also points to the advantage of the social aspect of learning as including the potential for *collective reflection*. Discussion regarding the plausibility of an idea as it evolves can serve to satisfy individuals until the group can settle on a more promising conjecture. This interaction can provide learners with a mechanism to validate their ideas against the criticisms of their peers.

3.3.2 Effective Teaching

A number of strategies for increasing the understanding of students in both a cognitive and affective fashion are considered in this section. These include scaffolding and metacognition.

3.3.2.1 A Constructivist Approach

Taber (2015) warns that teachers, as subject experts, may underestimate the complexity of what is being presented when perceived by a student who is a relative novice. Therefore, Taber (2015) states that teaching not only has to offer potential *links* with prior understanding, but those links have to be *obvious* to the learner. A constructivist educator should plan lessons in accord with their expectations of learners' prior knowledge and understanding *and also* constantly seek feedback to check that students are sense-making. Schneider and Stern (2010) contend that the emphasis on memory-limitations within these cognitive structures has some basic implications for the design of efficient learning materials by teachers. Rosenthal and Sanger (2013) refer to the potential for extraneous cognitive load to be imposed by the way representations are used to deliver a lesson. Chittleborough (2014) reminds us that the most significant factor in the learning of chemistry is the ontological framework that the three levels of chemical representation of matter provide for the learner and the teacher. Ainsworth (2006) explains that learners tend to treat representations in isolation and find it difficult to integrate information from more than one source. Treagust et al. (2003) argue that if learning is to be effective so that relational understanding is enabled, the *simultaneous* use of a variety of representations (e.g. submicroscopic and symbolic) in chemical explanations is necessary.

In this regard, the author repeatedly attempted to invoke all three representations during the development of the workbook in a manner that acknowledged working memory limits and the learners prior knowledge. The level of the submicroscopic was emphasised prior to the symbolic level. Subsequently, conceptual tasks involved linking both representations. The importance of feedback in supporting students' sense making was recognised. The PhET simulations that were employed within the pedagogical instrument allowed students to engage with more than one representation simultaneously while building molecular models.

3.3.2.2 Scaffolding

Reese (2008) views scaffolding as a strategy that can bolster the formation of deep and highly organised knowledge. This is because scaffolds such as instructional metaphors, allow the construction of (declarative knowledge) by creating conditions that motivate analogical reasoning. Thus, a novel experience may be interpreted in relation to previously encountered concrete (or relatively familiar) experiences. Chittleborough (2014) describes that a teacher can scaffold their students' learning by selecting the most appropriate form of representation(s) for the concept and for the learner. Taber (2013a) points to scaffolding as a teaching technique which allows the novice learner to initially rely on others to provide the strategy while they master individual steps of a procedure. Indeed, scaffolding can assist in chunking as the resulting nature of knowledge in working memory is usually integrated rather than fragmented (Schneider and Stern, 2010). Taber (2015) claims that this gives a learner the opportunity to scan and organise the prerequisite knowledge they have that is most relevant to *new* learning. Earlier, Taber (2012) stated that while ideas are still novel they will place a demand on the learner. However, if they are regularly reinforced, then, over time, these increasingly familiar ideas will shift from being an additional load on memory to acting as suitable support ('scaffolding') for new learning. Therefore, the author in the development of the workbook, continually emphasised visualizations/models, building the complexity of the models.

3.3.2.3 Metacognitive Strategies

While scaffolding implicitly allows students to reflect on their thinking, there are other strategies a teacher can pursue to allow for metacognition amongst their students. Miyake (2008) advises that teachers should encourage students to write (in note form) not just what they find out, but also what they need to know, and to comment on other students' notes. As the notes accumulate, this approach may bestow on students the confidence to start working on more abstract levels of knowledge construction, or conceptual change. In this way, students are treated as "epistemic agents" responsible for changing their own knowledge and sustaining their own intellectual community. This commitment to monitoring self-growth may help young people develop a continuous and reflexive behaviour of self-assessment over the course of their schooling. Cheung (2015) shares this view so that students might achieve a depth of knowledge where the relationships between different ideas in a topic are understood. Read (2015) acknowledges the avoidance of rote-memorisation strategies in order to allow this to take place. However, Yenawine, (2012) warns that while thinking critically may occur naturally in *some* people, *most* have to learn how to be constructively self-critical. In this regard, Taber (2015) states that actively inviting feedback on students' sense-making experiences (and not just the outcomes of their sense making) helps to encourage a *metacognitive attitude* to learning and so invites them to take ownership of the process. In the absence of these strategies, alternative conceptions among students are more likely to occur.

3.3.3 Nature of Alternative Conceptions

This section discusses the reasoning behind student alternative conceptions and in doing so considers the role of automatic cognitive processes such as heuristics. These mechanisms for making unconscious decisions in explanations are later considered as a component in a proposed framework of learning in Section 3.5**.**

The term 'alternative conception' is used to describe students' ideas that are incommensurate with scientific conceptions (canonical knowledge) (Driver and Leach, 1993). Taber and Watts (2000) describe alternative conceptions as at variance with a good scientific explanation and can lead to 'alternative explanations'. Hewson (1992) advises that 'alternative' is not a synonym for "inadequate" or "unacceptable". Hewson (1992) indicates that the constructivist perspective leads to an interpretation of many of the observed regularities and consistencies in students' responses as alternative conceptions. Students hold these about the natural world and how it works. Alternative conceptions are often significantly different from, and thus alternative to, generally accepted views of the subject, i.e., they conflict with ideas that teachers want students to learn. A notable characteristic of alternative conceptions that Nussbaum (1985) and Hewson (1992) describe is their *tenacious* nature. This may result in students subsuming *new* information into their already existing conceptions which serves to construct further alternative conceptions.

Within the workbook, the author took note of alternative conceptions of PNM as reported earlier. These were addressed through the development of visualization and modelling exercises. Additionally, in order to pre-empt the negative effects of the tenacious nature of alternative concepts within the area of PNM, the author took note of alternative conceptions that presented in the classroom which included those of a verbal and diagramatical nature. They were utilised in accordance with Figure 3.5 in Section 3.4.2 so that the experience of teaching and learning could be enhanced. Hence, alternative conceptions from one phase were 're-cycled' into tasks in the workbook used in the subsequent phase.

3.3.3.1 Intuitive Reasoning as a cause of Alternative Conceptions

Talanquer (2007b) argues that *commonsense reasoning* appears to play a central role in many of the naïve explanations that novice science students build about natural phenomena. The purpose of this reasoning is to simplify the complexity of problems faced by students so that intellectual effort is minimised. Ainsworth (2006) cites Elby (2000) and proposes that in many cases (novice) learners tend to rely on an *intuitive* knowledge element, known as the 'what-you-see-is-what-you-get', strategy when giving an explanation. This is often cued by the most compelling visual attribute of a representation (e.g. straight lines mean constancy, hill shape means hill). Talanquer (2007b) posits that this vision of the world is supplemented by a set of intuitive *assumptions* about the properties of chemical substances and processes and by a set of *heuristics* that guide and constrain their reasoning. Talanquer (2009) defines 'constraints' as elements of a knowledge system that direct and facilitate cognitive processes as well as restricting their possible range. He states that constraints may lose or gain strength depending on *existing* knowledge and *perceived* salient cues in a task. An example of heuristics having a negative impact on student decisions is an explanation involving an ontological misclassification as acknowledged previously in Section 3.2.1. It involves the employment of an additive heuristic incorrectly over an emergent heuristic. This can lead many students to conceive of physical and chemical properties as additive rather than emergent in nature. This results in emergent processes being (mis)classified as direct processes by a large proportion of chemistry students (Taber, 2014).

Talanquer (2006) sees heuristics as very useful in our *daily life* when applied using the proper cues since they frequently yield the right solution. Unfortunately, commonsense reasoning strategies seem to be responsible for a great number of alternative conceptions held by students. A further example is given by Driver (1985) which acknowledges the tendency of students to automatically think of explanations in terms of preferred directions in chains of events (linear sequencing). This means they can have problems appreciating the *symmetry* in interactions between systems. The example used in this case is of a container being heated. This process is seen in *directional* terms (i.e. from an initial to a final point) by students: a source supplies heat to a receptor. However, from a scientific point of view, the situation is *symmetrical* with <u>two</u> systems interacting, one gaining energy and the other losing it.

A further example encountered by the author within the action research process is the view of students that an input of energy may change a solid to a liquid but the *reverse* is much more difficult to understand. Specifically, condensation consistently proved to be the most difficult phase change for learners to understand. This is because processes, seen as reversible by scientists, are not necessarily seen this way by students. Hence, in the development of the pedagogical instrument, a greater emphasis was placed on condensation than on other changes of state, and also students were forced to confront it more often. At these confrontation points, students were challenged to represent it using models which included drawings, explanations and role-plays.

The intuitive nature of students' reasoning has been described in discussion of implicit knowledge frameworks by Talanquer (2006). This seminal work is based on both developments in 'cognitive science' and 'science education' regarding students' ideas of the physical world over the course of three decades. It characterises various *presuppositions* that appear to constrain student thinking and guide the construction of the mental models used by learners to build explanations and make predictions about natural phenomena. Talanquer (2006) concludes that the novice learner looks for the most plausible reasons (to a problem) that are *grounded* in a set of presuppositions about the surrounding world. He/she also relies on *mental strategies to make decisions* and *build inferences* based on the cognitive resources that are <u>readily available</u> and easy to apply. The approach is underpinned by the premise that *apparently* incoherent answers or explanations may have been framed by *rational thought* due to the unconscious use of heuristics in problem-solving or decision-making. Consequently, he designed a functional model for the interpretation of the central features of the explanatory framework associated with an intuitive knowledge system used by students as a commonsense chemistry resource. It is deemed by Talanquer (2006) to be a more comprehensive approach than the inventory analysis of alternative conceptions in science which predates it (this is seen as elucidating little about students' thought processes). The later approach is viewed as having greater efficacy because it has predictive power regarding students' reasoning. It also focuses attention on the nature of the conceptual framework that constrains students' ideas and explanations in the chemistry domain.

Talanquer (2006) claims that, student reasoning is characterised by unconsciously following or applying the following assumptions without considering other alternatives:

- Things are as they are perceived;
- Something exists only if it can somehow be perceived. The less an object can be sensed, the less material it is;
- Objects and materials tend to exist in "natural" states (normally stationery and inert). Only their abnormal properties and behaviours require explanation. These explanations should be based on the analysis of perceptible features;
- Reality can be used to explain the properties of scientific models.

Heuristic reasoning is of particular importance to decision-making. It involves making representations in the area of PNM since visualization is often involved and working memory may become overloaded. In this regard, heuristic reasoning leads us to automatically search for a cause that is familiar to us. It is triggered unconsciously by the surface features of academic tasks, rather than the product of analytical thinking. Such reasoning draws on cognitive capacities such as vision and memory to take advantage of *regularities* in the structure of our environment. Experts with coherent knowledge, as discussed in Section 3.2.2, often rely on a variety of heuristics to make quick and efficient decisions, because they *have learned to use them* efficiently and properly. Mental simulation and *hypothetical* thinking is employed in this (Talanquer, 2014). However, while heuristics can lead to explanations which are not always optimal but "*good enough to deal with the task at hand*", they may also be responsible for systematic errors in judgment where cognitive biases (towards an alternative conception) are exercised. This is so particularly when relevant decision-making cues are implicit rather than explicit to learners. Talanquer (2009) cites their frequent use in chemistry by novice learners. That is because, in the real world, perception limited to surface features of an event appears a good foundation for a hypothesis as appearances are usually not deceiving. However, this type of construct is likely to be inefficient in relation to the structure of matter since appearances are often misleading. According to Talanquer (2014), reasoning is simplified/constrained by *reducing the number of cues* used in making a decision. Hence, they (the cues) signal implicitly;

- how and where to look for information;
- when to stop the search;
- what to do with the results.

Talanquer (2014) describes a greater range (ten) of heuristics that effect decision-making and lead to alternative conceptions among novice learners. These will be used later in this work (see Chapter 6) in terms of evaluating student drawing. It is not necessary to discuss them in their entirety at this point. However, three related heuristics of 'Associative Activation', 'Processing Fluency', and 'Attribute Substitution' which are deemed to 'underpin most heuristic reasoning' are described below.

Associative Activation*:*

Associative heuristics are commonly used in *causal reasoning* to identify the cause and effect and make predictions about the outcome of a process. He claims that a wide variety of naïve students' explanations seem to derive from the *blind application of* simple associative rules. According to Talanquer (2014), *strongly activated* information is likely to be given more weight than it deserves which can serve to pre-empt consideration of relevant knowledge that is weakly, or not at all, activated. In general, one can expect decision making to rely on existing and 'in-running' associations between pieces of activated knowledge. Hence, the student is relying on a theory without all of the facts based on the features of a question they have perceived as relevant. The component of the nature of the 'Associative Activation' that is deemed important to this work is 'Availability'. This relates to the probability of a learner selecting relevant causes or variables *based on their* *frequency or cognitive accessibility.* Hence student explanations may be based on ideas that are not relevant to the problem, but are *part of the repertoire of concepts* with which they are more familiar or that first come to their minds in a given context. Similarly, Mozzer and Justi (2012) refer to student analogies being built on *accessible* mental images supporting an association between base and target domains when they are initially presented with the target domain.

<u>Processing Fluency:</u>

Talanquer (2014) argues that processing fluency refers to the ease and speed with which a cognitive task is accomplished by a student via accessible and easily processed features of a question. Salient explicit features are more easily processed and used as plausible factors on which to base an answer than less explicit more appropriate cues. This potentially restricts a student's ability to anticipate events by indiscriminately using particular elements in a question as cues. In this sense, constructive singularity, not alternativism is evident.

<u>Attribute Substitution:</u>

Talanquer (2014) states that this heuristic relates to processing fluency whereby there is unconscious substitution of a simplistic question for the 'actual' question being asked. It can occur due to the student noticing an explicit feature of a question, such as differences in the numbers and types of atoms present in the chemical formulas of the substances under consideration. This more strongly activated information in the question will trigger vaguely remembered chemistry associations thus serving to answer a more basic, unasked question.

This apparent 'seeing is believing' phenomenon is laying a trap for the individual concerned. Implications of heuristics in teaching and learning of Chemistry are discussed in Section 3.5.

3.4 PCP as a Meta-Theory in Relation to Student Reasoning in Chemistry

The overall aim of this section is to provide a coherent vocabulary to a proposed model of learning for students of chemistry, which is provided later in Section 3.5. This section attempts an outline of the main features of PCP that are aligned with student reasoning and indicate briefly where an overlap exists with respect to the literature of chemistry education. Constructs of transition that pertain to the disposition of a student at the time of potential conceptual change are described.

3.4.1 Concepts, Conceptions and Constructs

Nyachwaya et al. (2011) cite Nakhleh (1992) who stated that *concepts* are considered to be the *set of propositions* that a person uses to infer meaning. They give the example of a possible, proposition related to the nucleus of an atom, as "An atom contains a nucleus". Pope and DeNicolo (2001) view concepts as formal (publicly accepted) meanings and Treagust and Duit (2008) note that they are often shared by a community (e.g. the scientific community). Also, they are collaboratively produced <u>constructs</u> and constitute the realm of *what is known*. Gilbert (2005) describes a '*conception*' as something being accessed by a person in response to a particular question while Bell (2003) refers to a 'conception' as the personal understandings of an individual. Treagust and Duit (2008) also emphasise their idiosyncratic nature. They state that they are a person's mental models which are viable <u>constructs</u> to represent learning and are dynamic in nature. A link can be established between the two terms by acknowledging that *'conceptions'* are part of the act of interpreting or construing an idea or *'concept'* (Ravenette, 1999).

Fransella (2016) notes that a construct is <u>not</u> a concept but <u>does</u> share some similarities with it. Both are concerned with the *similarities* between things (e.g. acids) that determine how they are different from other things (e.g. bases). Both involve the notion of abstraction regarding how an individual makes sense of events by imposing their own meaning(s) on the world. Hence, a construct is an abstraction that involves pathways of movement of meaning (Fransella, 2016). In the view of Bell (2003), these pathways involve a *construing process* which is iterative. To construe means to place an interpretation on an entity. By implication, constructs are tools for *making a difference* both cognitively (and therefore affectively) by operating *on the product* of its own operation. In this way, they are not only based on the prior knowledge of an individual but simultaneously constrained by it. They provide an axis used to discriminate between events or experiences by their nature as a measurable bipolar conception with two opposite ends called poles.

A useful analogy is the pH scale using the construct 'Acid------Base'. Constructs have predictive power e.g. regarding a practical exam question in relation to new ideas sought such as 'Rate HNO_3 as a strong or weak acid or base – explain'. A construct represents the weaknesses and strengths of a conception. A junior second level school student might anticipate the correct answer by generating the construct: 'This is an acid----this is not an acid'. The 'This is an acid pole' is the strong side or 'Preferred pole', whereas the opposite side is the weaker, 'Least preferred pole'. One can have a *concept of a* 'construct' (it has a common meaning accepted by the PCP community) but to *generate a* construct, one can dichotomise a conception or a concept (in the case of an expert practitioner) such as 'HNO_3 is an acid'. This construct has a range of convenience that may be used to produce another such as 'HNO_3 will affect blue litmus---HNO_3 will not affect blue litmus'. In this way, as a scientist, a student seeks to predict, and thus control, the course of events.

Pope and Denicolo (2001) agree that Kelly saw conceptual development as an evolutionary process involving *progressive differentiation* of clusters of constructs into independently organised substructures. The substructures are also hierarchically integrated at progressively higher (superordinate) levels of abstraction. This process of progressive differentiation can give a student a wider range of application of their constructs e.g. when required to answer a question in an examination. According to Kelly (1955/1991), students generate constructs to aid them in their predictive efforts involving experiments around rival hypotheses e.g. 'HNO_3 will affect blue litmus' versus 'HNO_3 will not affect blue litmus'. Hence, just as a scientist lays wagers on an imminent future, teachers ask students to do the same. In this sense, Kelly (1955/1991) optimistically acknowledges the student as a dealer in probabilities rather than inevitabilities, in the role of assembling *their* reality.

3.4.2 The Commonality between the Nature of PCP and Chemistry Ideas

Gilbert (2005) highlights that models of psychology and their implications, such as that of Kelly (1955), should be considered in science education. Taber (1994) noted that Kelly's theoretical framework (PCP) has been adopted as a paradigm in this context. Later, Taber (2013) posits that PCP has been influential in early constructivist research in science education. The author's choice of PCP over other theories also involved a number of other factors which are described in more detail in Section 3.4.3. As with Dewey (Taber, 2009), Kelly challenged the dominant paradigm of teaching and learning at the time to emphasise personal meaning. He also shared with Vygotsky (Vygotsky, 1962), the acknowledgement that the process of sense-making involved social interaction. However, a significant appeal of Kelly's theory was that it appeared to resonate to a much greater degree with the work of (neophyte) scientists. Indeed, the root metaphor of PCP is that of 'man the scientist'. This is because individuals were viewed as constructing theories and testing their hypotheses against reality. Hypotheses could be revised in relation to their predictive accuracy using constructs. The key to the reconstruction process is the invalidation of our hypotheses. It is helpful that this dynamic of change can be explained by constructs of transition. Finally, his theory also involves a 'visual' dimension relating to a psychological geometry that can be used to inform the analysis of an individual's reality. This feature was seen as echoing the pedagogical intervention. It may be undertaken using a tool which can measure psychological space: the repertory grid. The instrument places the emphasis on the voice of the student in comparison to a questionnaire which could emphasise that of the researcher.

In his theory, (Kelly 1955/1991) refers to the assumption of 'opposites' such as that of positive *versus* negative regarding the atom, as important. Other examples that chemistry is a science built upon a wide variety of dichotomous <u>concepts</u> include: acid/base, oxidation/reduction and exothermic/endothermic (Talanquer, 2012). Fransella (2016) asserts that chemistry may be viewed as sharing with PCP the inherent assumption that people think in terms of contrast. An alignment also exists between chemistry education and PCP. For example, Clement (2008) notes that <u>efficient</u> mental models usually embrace the inter-relationships within a system *versus* a collection of isolated facts. Though Kelly was himself a physicist turned psychotherapist, his theory may offer a useful prism for chemistry teachers to interpret their students' explanations. In this case, Taber and Franco (2009) would contend that a truly constructivist approach to teaching has to do with more than just giving children's ideas 'credence' (by listening credulously), but rather to see them as starting points and resources to be developed towards target knowledge in future. This is because Talanquer (2010) argues that student explanations offer an opportunity to explore how scientific concepts are interpreted and how those concepts are linked. Talanquer (2014) writes that what in the past he viewed as random guessing in generating an answer; he now often interprets as the natural outcome of intuitive reasoning heuristics used by all people in their daily lives. Taber (2014) points out that this view allows scope to offer reflection on the nature of those ideas, which may or may not have developed during a teaching encounter.

The cyclical nature of such an encounter is acknowledged in Figure 3.5 where alternative conceptions identified in assessment procedures may be re-cycled to generate an improved teaching and learning experience.

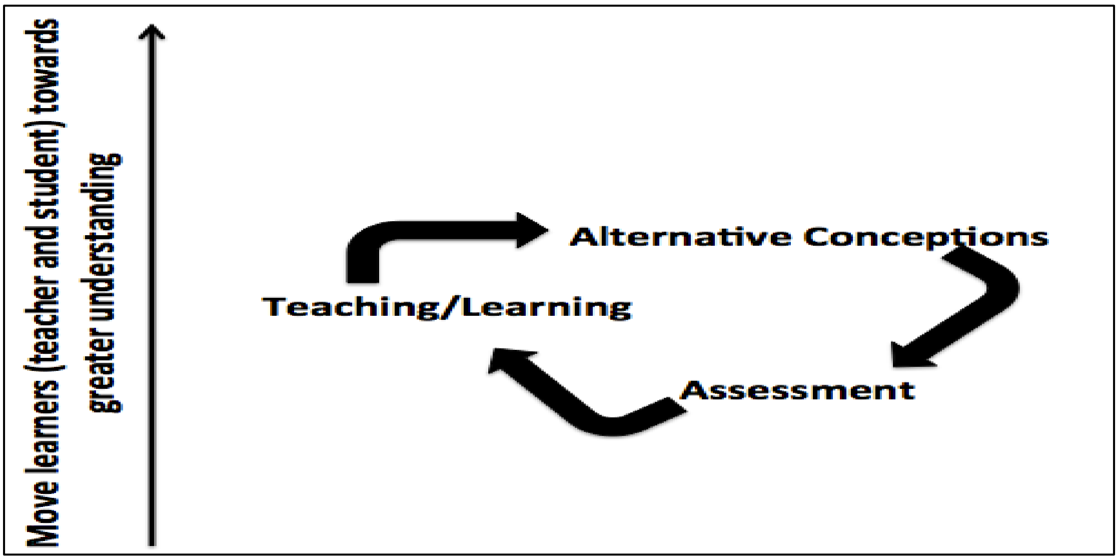


Figure 3.5 The Utility of Affording Students' Conceptions Ontological Status

3.4.3 The Nature of PCP Theory

Ravenette (1968) writes that Kelly's central metaphor was of 'man-the-scientist'. Thinking in terms of this metaphor of 'male or female the scientist', has the advantage that students are recognised as scientists even before they enter the chemistry laboratory for the first time. They are already conducting experiments regarding meaning in their young lives. By extension, they are ready to think about the meaning and application of the knowledge they will acquire in a chemistry laboratory. As a philosophy underpinning PCP, *constructive alternativism* recognises views as current hypotheses potentially open to 'hazard of invalidation' Kelly (1955/1991) e.g. 'Nitric Acid is a weak acid'. This could later become invalidated if it had been originally the preferred pole on a construct. He states this philosophical position as: "*We assume that all of our present interpretations are subject to revision or replacement*" (p. 14). The scientist cannot learn unless he/she considers the alternative to his/her hypothesis. Therefore, he reasons that not only do we <u>construct</u> our worlds, but we can <u>re-construct</u> them. Kelly hoped that learners, in this way, would put themselves in the position of opening their minds to potential alternatives which might serve their cause better. This epistemological position is a superordinate core construct of Kelly's construct system. Similarly, Driver (1983) ventured that children behave as 'amateur scientists', discovering patterns and forming conjectures to explain them. Indeed, Nakhleh et al. (2005) reflect that students' theories may be naïve in their nature but have all the essential properties of scientific theories. This is in keeping with scientists of the past who put forward now deemed 'alternative' hypotheses to then *currently* accepted scientific theories. Consequently, PCP acknowledges that each student will play an active scientific role in answering a question (such as in an exam).

Kelly's PCP theory of an individual carrying out 'sense-making' by construing and re-construing is developed in terms of a fundamental postulate (basic assumption) and eleven corollaries (simple deductions). The fundamental postulate states: 'A person's processes are psychologically channelised by ways in which he anticipates events' Kelly (1955/1991). Taking his root metaphor as 'Man: the scientist', it states his belief that a person's behaviour in the present is determined by the way he/she is anticipating some future event by using their constructs. These events may be learning tasks or problems posed in assessments and therefore they involve generating constructs to account for present knowledge and to forecast solutions (theory *building*). In this way, constructs assess the accuracy of previous forecasts (after the events have occurred), thereby testing and validating their predictive efficiency (theory *testing*). Hence, in terms of their function, Kelly's constructs are difference-making <u>and</u> inter-locking (with previous experience). He argues that experience <u>and</u> validation determine *what* scientists learn. His constructs also determine *how* a scientist learns.

Ten of these corollaries deemed by the author as being of particular relevance to this research will be described briefly. Some of them help to define the proposed model of learning described in Section 3.5. Constructs of transition are also described.

(i) <u>Organisation</u>: This states that 'each person characteristically evolves, for his convenience in anticipating events, a construction system embracing ordinal relationships between constructs' (Kelly 1955/1991). During learning and the process of evolution of a construct system, an individual recognises repeating themes which lead to the basis for a hypothesis. As constructs are organised in a hierarchical sequence, they may need to be re-arranged if their prediction is invalid. The opposite of being organised is lost and therefore struggling to make sense of events. Bannister and Fransella (2003) consider this corollary as having profound implications for the development of one of Kelly's tools for accessing how people construe i.e. the Repertory Grid (which is described in Chapter 4). An overlap with chemistry education literature and the Organisation Corollary occurs where the <u>structural</u> nature of knowledge has been acknowledged by Thagard (1992), Kiel and Newman (2008), Clement (2008), and Schneider and Stern (2010). This corollary is also echoed in discussion on pathways leading from the unknown to the known as described by Hewson (1992) and Sanger (2000).

(ii) <u>Construction</u>: People develop internal representations by recognising regularities and recurring patterns in their experience (Kelly, 1955/1991). This corollary chimes with the chemistry education literature on the generation of models from visualizations in Section 2.3.1.

(iii) <u>Experience</u>: The Experience Corollary infers from the Fundamental Postulate that a person's construct system varies as they *successively* construe the replication of events. In this way, PCP goes beyond the range of a simple stimulus-response theory. If the person makes little attempt to discover the recurrent themes (constructs) that emerge, their experience is *limited* as is their ability to anticipate future events (Kelly, 1955/1991). Conversely, due to their capacity to see regularity in the events they experience (e.g. blue litmus turns red and stays blue in some solutions), in a *rich* experience a student may distil many recurrent themes that are validated by their range of constructs. While the events encountered may be different (e.g. there are six unknown solutions to be classified as an acid or base), it is by abstracting /generating constructs from them that an individual can discover which theme is replicated. In this way, their predictive efficiency increases. If a prediction they make *is* validated (e.g. this solution will turn litmus red as it had no effect on blue litmus), their construct system might be preserved (until they encounter a future novel event). Otherwise, should their prediction be invalidated, their construct system might be *modified*. It is generally said that a person learns from experience. However, from a Kellyian PCP standpoint, it is the learning which constitutes experience (Kelly, 1955/1991). If experience is 'rich', learning is likely to be of a deep nature while if 'limited', it will tend to be shallow. A cycle that may be used to consider what constitutes learning is the *Personal Scientist Model,* which will now be referred to in the context of learning for the purposes of this work as *The Experience Cycle* (as PCP regards all students as scientists who are making sense of their experiences). This is illustrated in Figure 3.6.

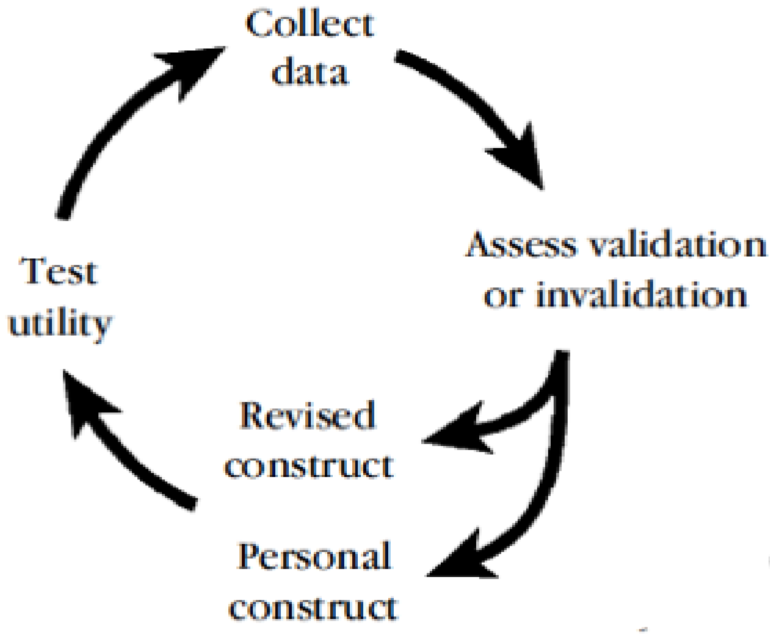


Figure 3.6: The Personal Scientist Model / The Experience Cycle
(Pope and DeNicolo, 2001)

One of the overlaps with the chemistry education literature and the experience corollary is the construction of a mental model from common themes visualised in multiple external representations (MERs) as described previously in Section 2.3.2.

(iv) Range: 'A construct is convenient for the anticipation of a finite range of events only' (Kelly, 1955/1991). Students with a limited construct range have not identified many recurrent themes from their data which might allow them to predict new events by generating new constructs. In contrast, those with a greater range of constructs have a greater possibility of validating and subsuming new events into their construct system. For example, 'It is an acid---It is not an acid' subsumes 'It is a strong acid---It is a weak acid'. In this way, the progressive differentiations used to generate constructs serves to increase the range of events an individual can construe to make further predictions about their environment. With an increased range comes a greater predictive efficiency (of constructs) that serves to make more experiences meaningful. The concept of range is illustrated diagrammatically in Figure 3.7. It overlaps with chemistry education literature in relation to the 'Associative Activation' heuristic in Section 3.3.3.1 whereby *strongly activated* information is likely to be given more weight than it deserves.

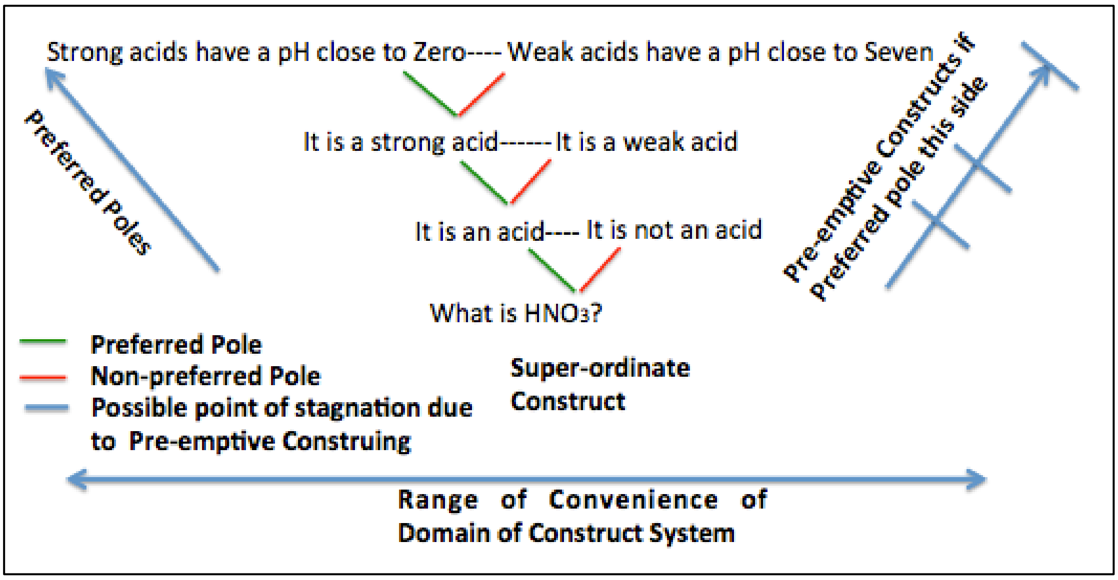


Figure 3.7: The Range of Convenience of a Construct System

(v) Commonality: To the extent that one person employs a construction of experience which is similar to that employed by another, then his/her processes are psychologically similar to those of the other person (Kelly, 1955/1991). The term 'construction of experience' relates to the experience corollary. This is a more elaborate idea than 'if two people experience the same events, they will duplicate the other's psychological processes' (a stimulus-response theory). It *is* in the similarity in the 'construction of experience' due to the events that there is the basis for creation of similar psychological processes, and *not* in the similarity of the events themselves. In this way, Bannister and Fransella (2003) state that people are similar because they construe in similar ways events (which may be different) but which have the same meaning for them. With reference to overlapping areas between this corollary and the chemistry literature, Talanquer (2009) and Taber (2013) find that strong commonalities exist among our students' intuitive views or naïve explanations of the structure of matter. Davidowitz and Chittleborough (2009) also identify commonalities within knowledge structures.

(vi) Sociality: Warren (1998) observes that, while the meaning attributed to events is *individual,* this understanding is arrived at because a consistency (of meaning) across individuals occurs which underpins their social relations. Kelly (1955/1991) states 'To the extent that one person construes the construction processes of another, they may play a role in a social process involving the other person'. This corollary insists that we come to understand ourselves via our understanding of other people whether or not those people are similar to us. Ravenette (1999) views the classroom situation in terms of being concerned with construing the construction processes of others (secondary construal). As a chemistry educator, one may assume the role of a teacher and/or assessor in a social process with their students in order to do this. Overlap with the chemistry education literature and this corollary are evident when considering the affective nature of learning (Section 3.3.1).

Pope and DeNicolo (2001) deem it necessary, that, in reflecting on conceptual change, at least two more of Kelly's corollaries need to be considered – namely *'Modulation'* and '*Fragmentation*'. Hence these corollaries relate to ideas already mentioned in Section 3.2.

(vii) <u>Modulation:</u> 'The variation in a person's construction system is limited by the permeability of the constructs within whose range of convenience the variants lie" (Kelly, 1955/1991). Warren (1998) adds that this mechanism involves the acceptance of new (subordinate) constructions by an existing construct within its range of convenience. In order to do this, a construct must be free to modulate i.e. to invoke new arrangements among the systems, which are subordinate to them. An example is provided by modulating the superordinate construct of:

'It is an acid---It is not an acid' (Superordinate) to include:

'It is a strong acid----It is a weak Acid' (Subordinate)

This allows new events to be discriminatively subsumed by those constructs already contained in the system. Pope and DeNicolo (2001) argue that the freedom, which a person has to undergo conceptual change in this manner in order to respond to new events, such as answering a never seen before examination question, depends on the '*permeability*' of their constructs. This is the level to which an individual can re-construct their construct system *if* it is invalidated. Bannister and Fransella (2003) require that to generate new theories, new elements (which have not yet been construed within its framework) need to be assimilated within its range of convenience. They cite as examples the relatively impermeable construct of *fluorescent* --- *incandescent* in relation to light sources as it is unlikely that the range of convenience of this construct is extendable. Conversely, a construct such as *light* --- *dark* has a much wider range of convenience. Permeability implies that a construct system evolves to allow an individual better anticipate events. In the 'Rate HNO_3 as a strong or weak acid or base – explain' example, 'It is an acid---It is not an acid' is a permeable construct, as it was seen to play a role in evolving the construct system. However, 'Strong Acids have a pH close to zero---Weak acids have a pH close to 7' has greater permeability as it has a wider range of convenience and can be better used to anticipate the question asked and/or be applied to new questions regarding the categorisation of acids. On the other hand, a construct is impermeable if it is made up of certain elements only and no others can be admitted to it. For example, 'It is an acid---It is not an acid' would have been such a construct if a student could not further elaborate their construct system using it. [Note: While it is known that only concentrated solutions of strong acids have very low pH, this construct was used with junior cycle students merely to convey differentiation between strong and weak acids].

(viii) <u>Fragmentation</u>: Kelly (1955/1991) states that a person may successively employ a variety of construction subsystems which are inferentially incompatible with each other. Fragmentation is partly derived from the Modulation corollary, which allows for the tolerance of inconsistency between subsystems. This is because a re-construction of a construct system may be deemed invalid later on. The *permeable* superordinate features of one's construct system underpin the idea of fragmentation as they maintain a level of *tolerable* inconsistency. Inconsistency may arise when students hold on to their current hypotheses or constructs and temporarily adopt another perspective (fragmentation). Kelly (1995/1991) argues that this is so, although a person's past bets may not make sense regarding current minor bets, his/her wagers on the outcome of life <u>do</u> tend to add up. This idea is reflected in the assertion by Pope and DeNicolo (2001) that the system functions so as to minimise incompatibilities between constructs in order that *optimum potential* for elaboration of the system is maintained. Consequently, one may not win each time, but one's wagers in total more than break-even. The elegance of this theory is that the student is seen as free <u>not to</u> believe their hypothesis is true when it is proposed. As Gilbert (2005) suggests, Kelly's fragmentation corollary implies the constructive alternativist can test new hypotheses without having to discard the old hypotheses or constructs. As a result, it permits you to be inconsistent with what you know long enough to see what will happen. In the example in Figure 3.8, a student could hypothesise that nitric acid is both a strong acid and a weak acid, until their construct is subject to further validation. An example of an overlap between this corollary and the literature is seen in Section 3.2 where conceptions are not discarded but co-exist with each other. The one that is used more frequently is the conception that is viewed as more plausible at the time.

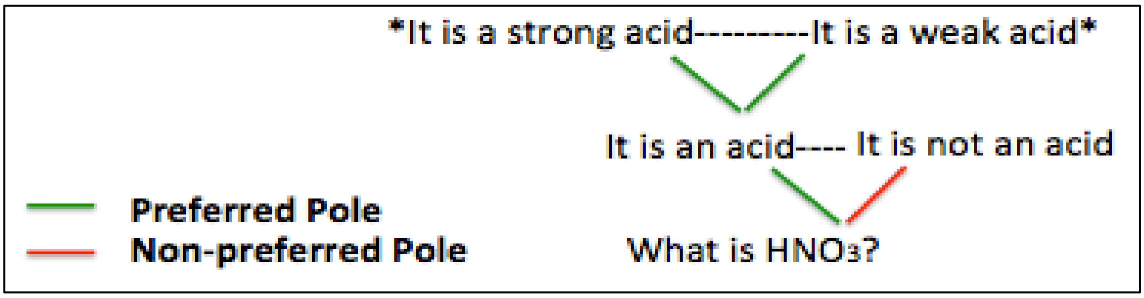


Figure 3.8: An Example of Construct Fragmentation (* indicates fragmentation along the construct)

(ix) <u>Dichotomous</u>: A person's construct system is composed of an infinite number of dichotomous constructs (Kelly, 1955/1991).

(x) <u>Choice</u>: Kelly (1955/1991) states a person chooses the alternative in a dichotomised construct which they anticipate as the greatest possibility of the elaboration of their construct system.

<u>Constructs of Transition:</u>

Criswell and Rushton (2012) conclude that a skill vital to effective chemistry teaching is finding ways to support students in the transition from their everyday ideas about phenomena to the more formal views of science. Bannister and Fransella (2003) show that Kelly focuses our attention on certain specific constructs regarding potential conceptual change including *anxiety, aggression,* *hostility and pre-emptive* which influence conceptual change. The idea most pertinent to this work is that of aggression which is identified by the term ‘Kellyian Aggression’ for purposes of clarity when it is used in Chapter 6.

‘Aggression’ is the active elaboration of one’s construct system (Kelly, 1955/1991) e.g. attempting to work through a previously unseen question. Thus, a person decides to *actively* experiment in order to check the validity of their construing. It is possible that one may extend the range of convenience of their construing during this process. A related example is shown in Figure 3.9.

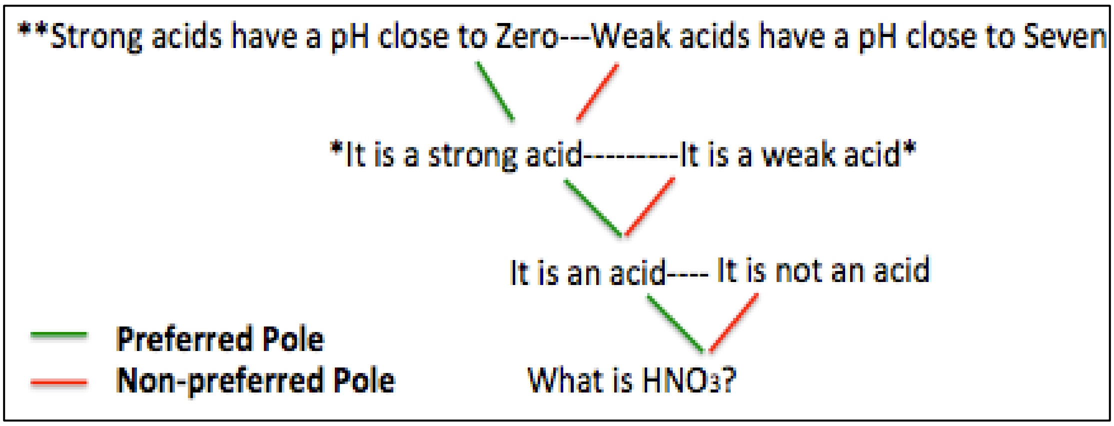


Figure 3.9: An Example of Greater and Lesser Aggression (* indicates lesser aggression, ** indicates greater aggression)

3.5 Implications for Teaching and Learning Chemistry

This section considers the main implications the author views as arising from the themes in the research literature that were examined in this chapter regarding the teaching and learning chemistry. It reflects a cognitive and affective journey for both the teacher and learner. Hence, the teaching and learning ideas that emerge are often intertwined. Terms from PCP appear in italics below. They are also illustrated in parentheses where they resonate with the idea drawn from the research literature that is being described. It is helpful if the teacher presumes little or nothing and is prepared to be a facilitator who ‘walks in their students’ shoes’. In the field, this is enabled by the constant monitoring of students ideas using dialogue. In this way, students are afforded the epistemological status of a scientist seeking to understand and explain natural phenomena (Fundamental Postulate). To enhance this process, it is advisable to employ cognitive tools such as modelling and visualization during teaching thus enabling learners to concretise the abstract nature of PNM. These components serve to formulate the experience of the learner including the linking of the particulate, symbolic and macroscopic (Range). These links can be forged by allowing students to develop mental models by providing them with opportunities to recognise recurrent patterns (Construction). The provision of sufficient time is vital to allow students generate, test and validate their mental models (Experience). In this way understanding is constructed and re-constructed (if necessary) so that learning is potentially deeper.

In the classroom, it is important for the teacher to paraphrase most student comments so that they feel their contributions are valued and understood. It is helpful to undertake this process using conditional language so that the notion that knowledge is tentative is conveyed. This leads to the avoidance of opinions being 'judged' simply as right or wrong. 'Visual paraphrasing' is an important feature of teaching with visual tools in order to ensure that words are anchored with images. Pointing is often sufficient to achieve this. The linking of seemingly disparate comments by the teacher provides students with a simulation of how knowledge is created versus transmitted. These approaches acknowledge the affective dimension of learning and enhance the level of satisfaction that a learner may experience regarding their learning experience. Consequently, a student may exercise transitional constructs associated with permeability and growth, such as aggression, more frequently. They also allow for the unfolding of alternative views and choices (Choice) leading to the development of ideas in a public manner. Hence, the importance of metacognition is naturally underscored. It also gives an implicit demonstration of how ideas scaffold off one another. Prior to class, it is important for the teacher to 'prepare' resource materials to allow for the scaffolding of ideas to occur. This has the advantage that meaningful negotiation can occur more fluently during teaching and learning when the environment often becomes a set of interactional spaces where peer to peer evaluation can take place (Sociality). Furthermore, 'layering' can be employed whereby learning materials re-visit familiar topics in a more elaborate and challenging fashion. In this way, the overwhelm of working memory is often avoided. Finally it is helpful, both in terms of preparation and of teaching, for the teacher to be familiar with the automatic simplifications and associations students attach to various topics. This can serve to make the learners aware of their intuitions and use of heuristics.

Table 3.3 is a grouping of ideas from the previous paragraph presented in an attempt to converge important features of teaching and learning. Later, this work will attempt to illustrate more specifically how they might act as components of a model of learning / conceptual change. This will be revealed and discussed in Chapter 8.

Table 3.3: Summary of Components of an Initial Model of Conceptual change

Component	Component Source	Function
Fundamental Postulate	PCP	Understanding / explaining natural phenomena
Modelling and Visualization	Research Literature	Concretisation of abstract concepts
Triplet	Research Literature	3 levels of chemical representation
Range	PCP	Allows greater predictive efficiency
Construction	PCP	Development of internal representations
Experience	PCP	Learning
Affective	Research Literature	Emotions and motivation
Experience	PCP	Learning
Transitional Constructs	PCP	Constructs invoked during change
Aggression	PCP	Openness to sense-making
Permeability	PCP	Openness to conceptual change
Choice	PCP	Decision allowing elaboration of mental model
Scaffolding	Research Literature	Supports to allow smooth encounters with unfamiliar information
Sociality	PCP	Consideration of another person's mental model
Heuristics	Research Literature	Simplifications due to cognitive biases

3.6 Conclusion

This chapter focused on how an individual student of science learns conceptually. The learning models and dynamic cognitive processes cited in the literature that promote or hinder the understanding of a topic were described. The considerations that a teacher might follow with respect to these ideas were outlined. Cognitive processes were contextualised within the theoretical architecture of PCP. The implications of this approach for the teaching and learning of chemistry was discussed. The ideas that emerged in this discussion were then considered as components for an initial model of learning with respect to this study. The next chapter discusses how PCP was used as an adjunct to an action research methodology to construct a workbook that would serve as a pedagogical tool for students. This instrument is developed with the following research question in mind: 'Can an Inquiry-based Learning approach to the PNM that includes modelling and visualization among junior second level school students serve to increase their conceptual understanding?' It is hoped that the proposed model of learning will serve as a framework later in Chapter 6 to describe the pedagogical reasons behind the level of success of students with respect to learning in this study.

CHAPTER 4: FRAMEWORK OF THE RESEARCH

Introduction

Chapter 3 reviewed PCP. This chapter describes the design of how the research question was answered. The theoretical basis of the research design is then given. This is done by providing the philosophical rationale for the study's methodology whereby PCP is used as an adjunct to 'Practitioner Action Research' (described in Section 4.1.3) with the methods used to collect and analyse data from the participating students. It also describes the research participants and ethical nature of the study. The following section describes how this work went about answering the research question: 'Can an Inquiry-based Learning approach to the PNM that includes modelling and visualization among junior second level school students serve to increase their conceptual understanding?' It briefly describes the context of the curriculum relating to PNM that was used to develop teaching and learning materials. The study framework within which this work was carried out is illustrated to include how its impact was measured. A secondary question emerged as the research evolved into phase 3 and phase 4. This is aligned with the conclusions drawn from Chapter 2 and Chapter 3. The question is: 'Can a Model of Learning and Conceptual change be developed through an IBL pedagogy incorporating modelling and visualization but informed by PCP?' This question will be addressed in Chapter 8.

The position of PNM as a central idea in school and college science curricula has been acknowledged in Chapter 1. It is accepted that many areas of graduate study across the sciences depend on a good understanding of this model. Also, it has been shown in Chapter 1 that students' understanding of this subject is limited. It was decided that it would be worthwhile to base the research question on whether an intervention in the area of PNM could improve the learning of students in junior second level school setting. In order to prepare to answer the research question, a set of teaching and learning materials had to be delivered. This was done in the spirit of IBL, which, as outlined in Chapter 2, is a pedagogical approach with potential benefits for students understanding of study material, generally. The research question required validation to determine its effect. Constant analysis was conducted to determine the direction of the research and its impact. This was carried out using a methodology of practitioner action research.

4.1 Theoretical Basis of the Research Design

This section describes the basis and justification for the methodology used in this study.

4.1.1 The Paradigms of Educational Research

The following section describes a brief overview of the theoretical nature of educational research with particular reference to general 'practitioner action research'.

As Pope and DeNicolo (2001) postulate, there are many aspects of PCP that could be used in support of current educational research practice. My methodological approach has been influenced by that of PCP. According to Warren (1998), the Kellyian philosophical viewpoint of *Constructive Alternativism* emphasises that all present interpretations of the universe are subject to revision and replacement.

Mertens (2005) points to a paradigm as a 'way of looking at the world', as it is composed of certain philosophical assumptions that guide and direct thinking and action. Taber (2007) names the two philosophical dimensions considered to underpin educational research paradigms. They are ontology and epistemology. My interpretation of how these dimensions are applied to this research is now described.

Taber (2007) notes that ontology is the nature of things that exist in the reality of the world. McNiff and Whitehead (2006) interpret ontology as "*a theory of being*" while it is defined by Crotty (1998) as "*the study of being*". Warren (1998) argues that these interpretations of reality will not work if they are capricious; our constructs must be tested or validated against experience in the world, especially experience with others. Hence, the philosophical connections Kelly (1955/1991) makes (via a fundamental postulate and the corollaries he develops to elaborate it), take matters beyond the subjective and into the social realm where other people are part of the practice being undertaken. According to Kelly (1955/1991) this reality is subject to many alternative constructions. This is because we seek to improve our own constructs by altering them to provide better fits so that the future reality may be better represented. Thus, each of us has our own unique map of reality and uses it to make sense of our world. Hence, my ontological position emphasises the *function* of personal constructs – representations erected by living organisms to be tested against subsequent events. They are wagers on our future reality and are framed by the philosophical position, or point of view, that is constructive alternativism. A related ontological concern that pertains to the study is to increase the range of convenience of my students with regard to PNM.

McNiff and Whitehead (2006) relate epistemology with how we understand knowledge, and how we come to acquire knowledge. Crotty (1998) notes that epistemology is "*a way of understanding and explaining how we know what we know*". The epistemological position I am adopting in this study is from McNiff and Whitehead (2006) in their citation of Berlin (1998), that indicates action researchers need to make the epistemological assumption that knowledge is created not discovered, in a process which often involves trial and error. Therefore, knowledge in this context is uncertain. This position is coupled with the view of Kelly (1955 / 1991) that students are active, meaning-making, individuals. A related epistemological concern anchoring this work is a) how I might facilitate my students as they attempt to make sense of PNM and b) simultaneously find out more about how they understand.

Hitchcock and Hughes (1995) argue that it is naïve to believe that the subjects of the research are not affected by it and, while action research protocol admits that they are, it attempts to channel that effect in an educational direction. McNiff and Whitehead (2006) point out that *self-study* has emerged in recent times in which individual researchers are placed at the centre of their own enquiries. Hence, the focus of the research is the practitioner. The 'I' therefore, while central, cannot be in isolation. This is due to the social nature of living and working. PCP according to Warren (1998) involves an I-thou dialogue in the work setting which is irreducible. This is a relationship between I, as a subject and You, as another subject, where there are two equal persons. This status is in contrast to a view whereby the relationship is between I, as a subject and You, as an 'it' i.e. an object which is a member of a category and not an individual. This allows for what Warren (1998) refers to as a consistency or harmony across individuals to occur in which the practitioner can 'walk in the shoes' of the students with whom they work. These ideas illustrate how approaches within action research are consistent with a PCP philosophy. In this way, Elliot's (1991) view that "*the fundamental aim of research is to improve practice rather than to produce knowledge*" may be realised.

4.1.2 Action Research as the Appropriate Methodology

Action Research was chosen as the appropriate methodology for this research. I recognised the need to engage with a methodology that would enable me to investigate and improve my practice so that my values could be realised. It enabled the process to take place where knowledge was viewed as tentative and where reality was constructed in a manner that was congruent with PCP. I sought to teach in ways that honour my educational values of justice, care, dignity, freedom, and <u>excellence</u> and also acknowledge my students as unique participants in classroom and laboratory, capable of thinking critically.

Specifically, <u>care</u> was exercised to ensure that students' opinions were valued. Interactions were therefore underpinned by the <u>freedom</u> of students to understand, debate and voice their viewpoints. In this way each individual was afforded <u>dignity</u> when they offered their opinions. Hence, <u>justice</u> was afforded to learners whereby their contributions were not judged as right or wrong but they understood that it was okay to have alternative views and make mistakes. Finally, teachers and learners aspired to attain an excellence in understanding which was underscored by the desire for the capacity of learners to reach their potential.

Therefore, I understand that the traditional 'transmission' model of education offers neither justice nor freedom to learners and consequently may serve as an obstacle in terms of allowing them to become critical thinkers. It is also intended that this methodology will allow me, as a practising teacher, to be in a position to do research in education which will benefit my students, myself and my colleagues.

4.1.3 Guiding Principles for Personal Research as a Practitioner

The following section describes the nature of values and their importance in guiding my research and how PCP assisted in the modification of my pedagogical style which seemed not to meet them. The reasons for adopting the mode of action research known as 'Practitioner Action Research' in relation to this study are then outlined.

My approach to self-development as a prelude to bringing development to others reflects a starting point described by Gert and Burbules (2003): while many of our actions are habitual in nature they are mostly 'good enough' to enable us to function. However, difficulties arise in those situations in which our patterns of action and behaviour are insufficient at which point we may be required to construe how we can direct our observations and inquiries to suggest alternative lines of action. At such times, an examination of our values is useful.

Whitehead (1998) defines values as "*those qualities which give <u>meaning</u> and <u>purpose</u> to our personal and professional lives*". In the view of Elliot (1991), realisation of the values which define the improvement of practice leads to concrete forms of *action* and involves a continuing process of *reflection*. Indeed, Warren (1998) associates the verb *action* with a *reflective* mind.

It is useful to consider the application of PCP to link values to action at this point. It involves a similar process to what would occur in a psychotherapeutic setting whereby a client receives support in their construing of their life circumstances. Their re-construing may be facilitated by guided experimentation with newer, more effective theories. Kelly (1955/1991) states:

> "*The scientist lays wagers on an imminent future; the clinician asks his client to do the same.*"

Values are the deepest discussable construct in a person's construing system. They are referred to by Kelly (1955/1991) as 'bets on our future'. For Kelly, values represent the person's theory of how to live to secure their choices on two super-ordinate constructs as a biological organism. They are '*Survival*' versus '*Death*' and '*Growth or Flourishing*' versus '*Stagnation*'.

The beliefs that give rise to values at this super-ordinate level are not discussable because they are almost preconscious or else taken for granted. They are concerned with fundamental questions like: ‘Who am I?’ and ‘What is my purpose in life?’ However, the value to which the superordinate constructs are connected *is* discussable. Science is a system of anticipation and so are values (Kelly, 1955/1991). They provide us with a structure to anticipate how to survive or grow and are super-ordinate to the peripheral constructs involving actions or behaviour. This structure on the nature of anticipating can be captured by Kelly’s’ notion of a systematic framework of constructs. This framework is a construct system. Hence values are intermediate constructs within our system that give coherence to it. They can be reawakened to make better sense of circumstances such as the realisation that we are conducting a failing hypothesis. While values are hard to observe directly, behaviour is observable. Whereas values are the reasons for behaviour, behaviour is the way our theories may be tested. Like constructs, a person’s values are similar to a wager or a bet on the future. For example, a person may choose a value like integrity but he or she cannot prove that it works. They have to test it time and again through behaviour so that they can be reasonably confident that it is right to hold that value. So, a person’s values are like their own theory of how they should operate in the world to succeed by anticipating outcomes in life. In that sense all behaviour is viewed more like a question than a statement – does this behaviour validate my value regarding how my life should be lived? For example, if one has a value that learning should be democratic, a consequent motivation might be to develop a pedagogy that supports this value and allows students to gain a conceptual understanding (instead of a surface understanding) of a topic. Hence, in terms of behaviour, a teacher might follow-up with an action that is the production of a lesson that produces a better alternative pedagogy to a traditional approach. Values can therefore serve as a powerful perceptual filter regarding actions to be taken. An alternative pedagogical technique one might choose to attempt for this purpose is that of Inquiry Based Learning. Similarly, Pope and DeNicolo (2001) claim values are intellectual tools or devices which are linked to the coherentist theory of truth (the view of knowledge as construction of reality).

Through my work, study and learning I have come to realise the gap which exists between my values and intentions as an educator and my actual delivery of my educational message. Values (though usually inexplicit) are ‘espoused’. Dilts (1999) claims that, on a personal level, we hold or represent the "deeper structure" of our values to ourselves non-linguistically. This is done in forms such as inner pictures, sounds, words and feelings, so they are not necessarily explicit. Therefore, ‘lived’ values can subtly become incongruent with those which are ‘espoused’ – hence it is possible to become a *living contradiction*. I was experiencing myself what Tripp (2005) describes, citing Whitehead (1989), as a living contradiction, in that my values were not realised in my practice. Hence, in an attempt to allow my core values guide my actions, consistent with Lomax et al. (1996), I have attempted to alter my attitudes, my approach to others and the pedagogical processes which I use. Through this means, I have attempted to promote more effectively the learning of others. Upon reflection, I realise that my values <u>about justice, care, dignity, freedom and excellence</u> have influenced my decision to change my teaching approach. In context of Kelly’s psychology of human sense-making, as people, we are pursuing our core needs for “life” (survival as a biological organism). Anything or anybody that thwarts one’s attempts to meet these needs will be construed as not having respect for one’s human dignity. The adoption of the pedagogical strategy of IBL so it might provide my second-level, first year students with greater opportunities for learning chemistry, and the PNM in particular, is part of the public action I have undertaken in response to my values. It is a manifestation of a value of mine that allows the needs of my existence to be met. The pedagogy is derived from my value of what it means to be a good teacher which in turn is derived from my need to grow and survive and contribute. In this way values are forecasting how I should live so that my actions meet my needs. Through engaging in new actions and behaviours, it is hoped for myself and my students as participants, that we increase our capability to grow and flourish.

The adoption of the specific stance of the study as one of ‘Practitioner Action Research’ was appealing as it is a version of action research that is usually described in terms of ‘praxis’ i.e. development of knowledge through purposeful action (Petra, 2007). Typically, this occurs in a framework of limited time and space and so resonates with the nature of a teacher’s practice. Hence, a teacher is compelled to constantly have to face the question in relation to their students:

'what in the given circumstances is the best way to act to achieve what is important at the moment?' Stringer (2013) echoes the reality of this stance by pointing to the need to understand how things are happening, rather than merely to what is happening. This idea is aligned my epistemological position described in Section 4.2.1. The contention by Munn-Giddings and Winter (2013) that we need to make our judgements in a tentative exploratory way that leaves them open to revision also confers a certain freedom on the practitioner action researcher giving them the scope to perform an in-depth study. In this way, the work genuinely becomes "bottom-up" in orientation (Stringer 2013) as it has attributes that are both phenomenological (focusing on people's actual lived experience/reality) and hermeneutic (incorporating the meaning people make of events in their lives). This approach resonates with my ontological position described in Section 4.2.1. Bound and Stack (2012) advise that the hermeneutic nature of practitioner actioner research can be captured using an autobiographical lens (such as a teacher journal) and through the lens of the learner. Both means are deemed by the author to be practical and achievable. In this way, Campbell and Groundwater-Smith (2007) argue that the relationship becomes one that moves from an emphasis of having 'power over students' to a more desirable one where there is 'power with students' and interests are mutual. This stance is aligned with the values of the author which are discussed in section 4.2.2. Bullough (2009) indicates that such an approach allows teaching to become more supportive and purposeful. It also has the advantage that it may trigger a potential cultural change where passive consumers (such as colleagues who may be open to ideas) can be brought along (Joyce et al., 2009).

4.2 Study Framework

This section describes the model of practitioner action research used in this study and the timeline with which the work is associated.

In most kinds of action inquiry one monitors the effects of one's action during the action phase. In action research one will often produce data on the effects of a change on practice during implementation (through observation, for example). The structure of action research in relation to improving practice is viewed as cyclical with respect to time. There are several models of Action Research but this work will use an adapted version of the Kemmis and McTaggart (1982) model

Acknowledging the spiral nature of this approach, it permits the research design to charter progress within the study over four phases, and is shown in Figure 4.1.

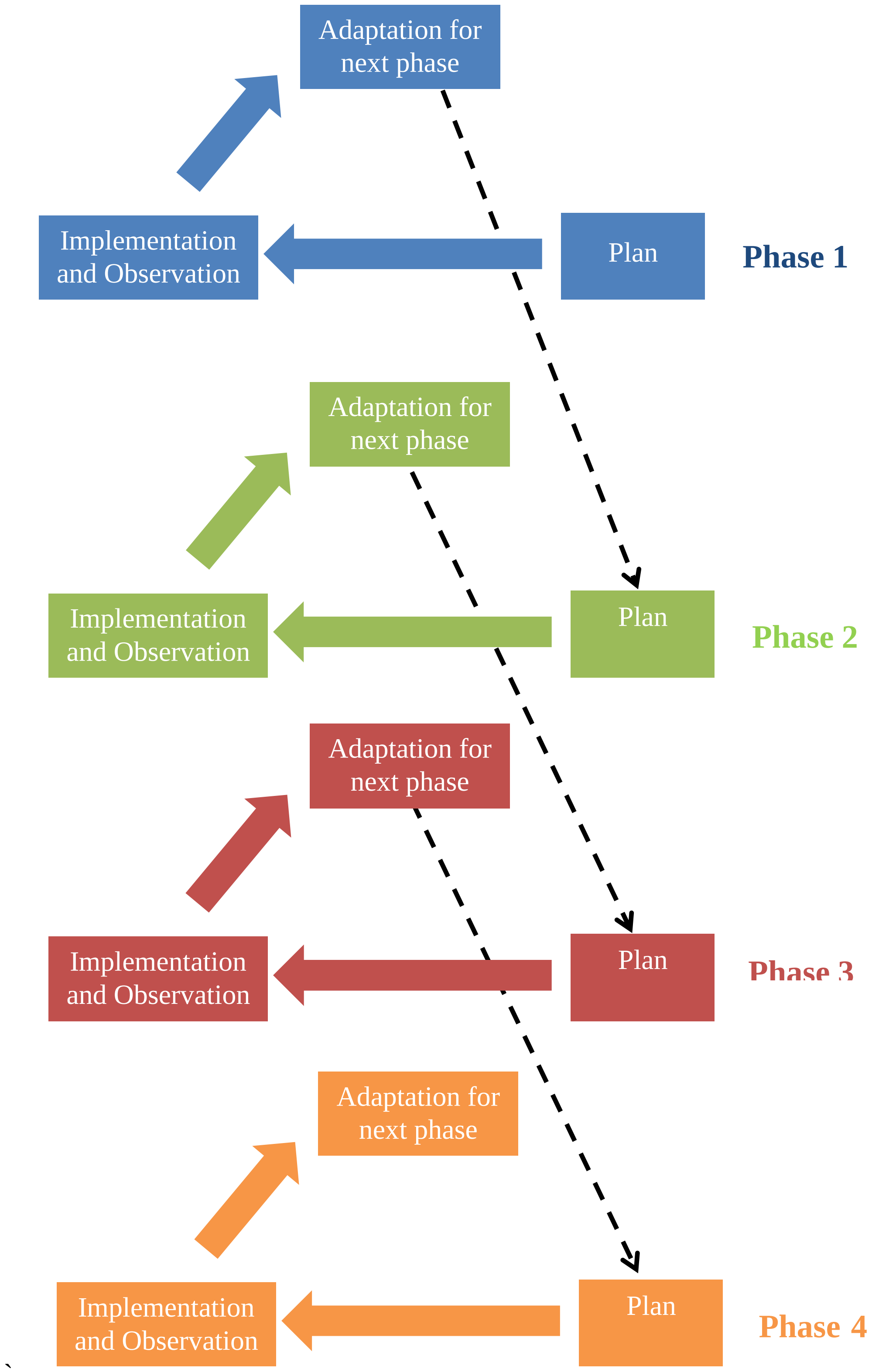


Figure 4.1: An Action Research Spiral (Adapted from: Kemmis and McTaggart, 1982)

It is apparent that Kemmis and McTaggart's view of action research is as a spiral of self- reflective cycles which include:

- Planning a change;
- Acting and observing the process and consequences of the change;
- Reflecting on these processes and consequences and then replanning;
- Acting and observing;
- Reflecting.

and so on...

The application of this spiral model is given in Figure 4.2. It is used to create a research framework which gives an opportunity to visit a phenomenon at a higher level after each iteration. This enables progress towards a greater overall understanding.

An illustration of the research scheme giving details of the nature of the pedagogical intervention is given in Figure 4.3 and detailed in a timeline in Table 4.1.

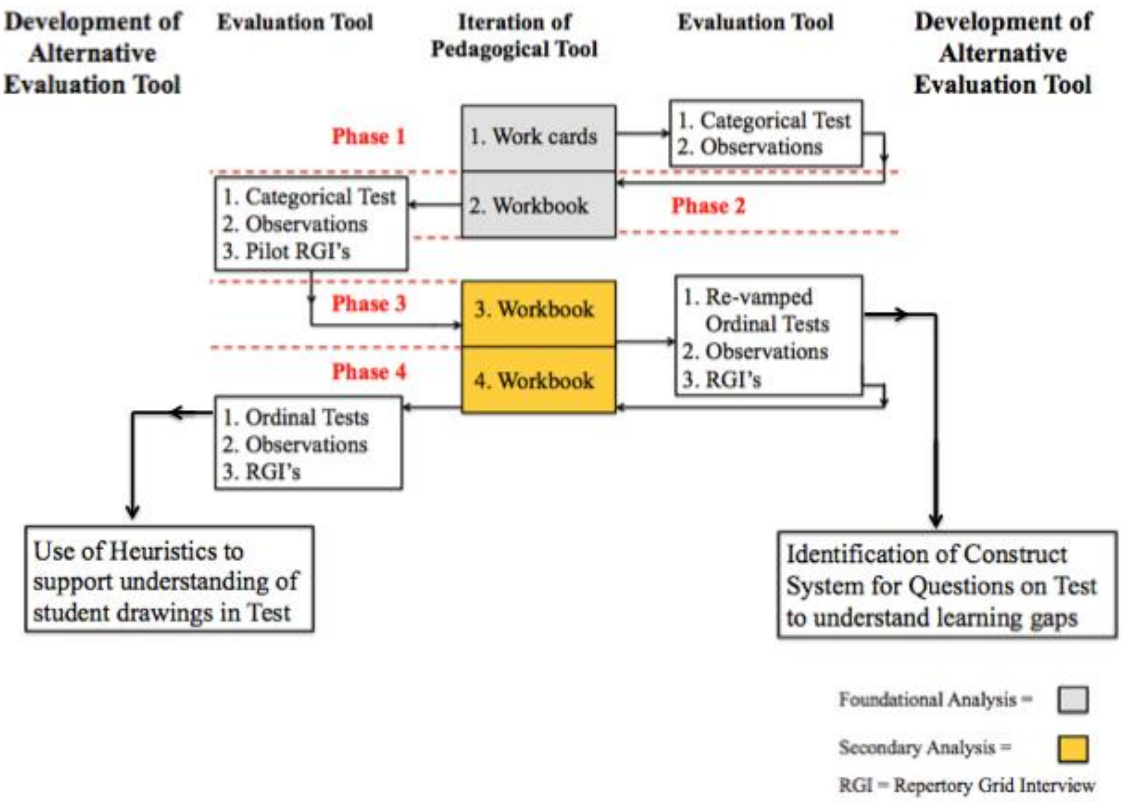


Figure 4.2 Research Framework Employed

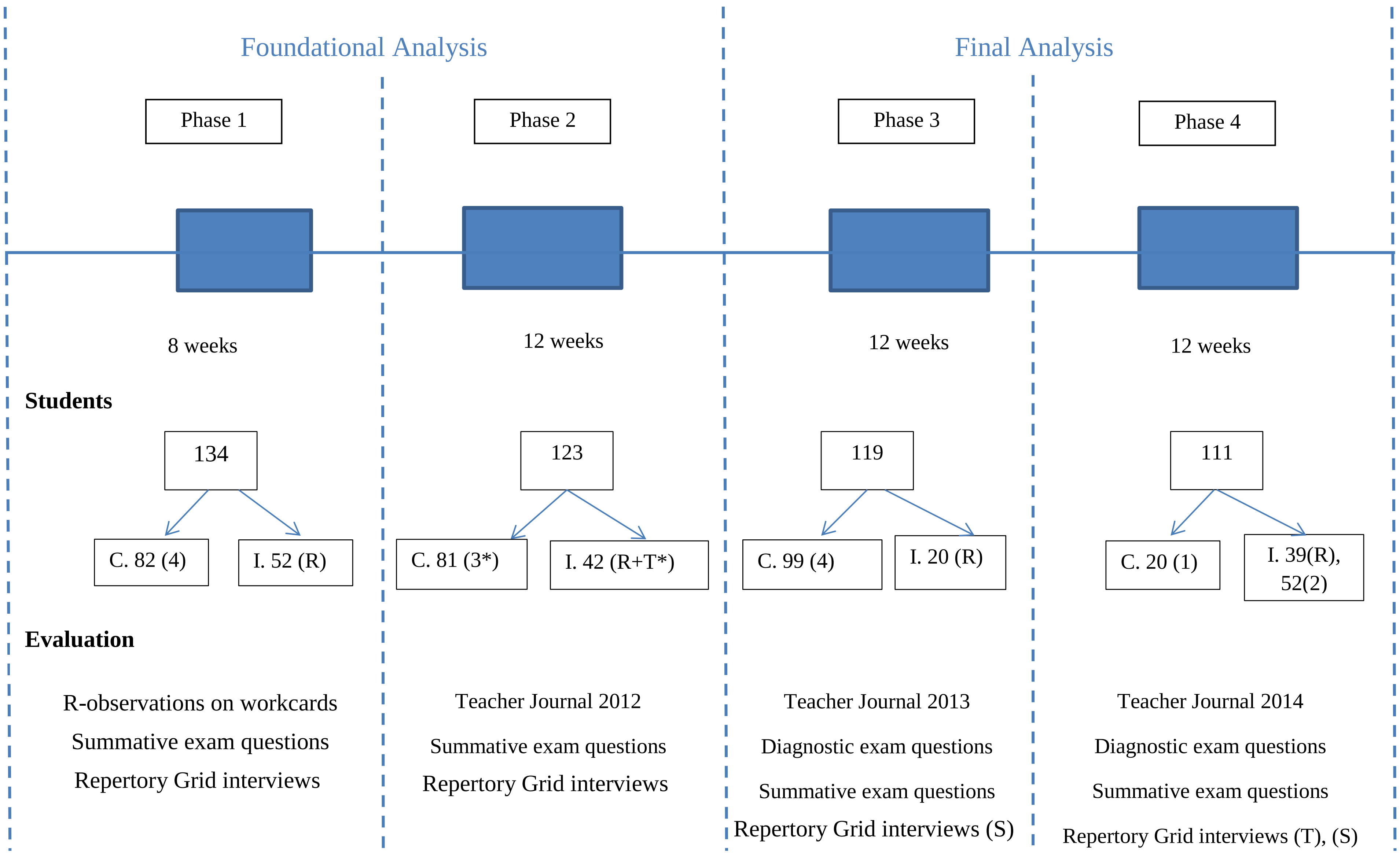


Figure 4.3: Framework of Research

Legend C = Control; I = Intervention; R = Researcher; Number in brackets indicates the number of Teachers involved; * = Teacher in both intervention and control groups; S = student; T= teacher

Table 4.1: Timeline of Practitioner Action Research Study

Phase	Stage of Cycle	Timeline	Purpose	Participants
1	Plan	June '10 – Dec '10	Develop IBL Workcards Review research literature	N = 134 I = 52 C = 82
1	Implementation & Observation	Jan '11 - April '11	Teaching using IBL workcards Field notes taken Development of Test	
		May '11	Tests conducted	
		June '11	Tests Corrected	
1	Adaptation	July '11 – Aug '11	Tests Analysed	
2	Plan	Sept '11 – Dec '11	Review research literature Workcards content updated Workcards merged into workbook	N = 123 I = 42 C = 81
2	Implementation & Observation	Jan '12 - April '12	Teaching using workbook Field notes taken in Teacher Journal	
		May '12	Repertory Grid Interviews conducted Tests conducted	
		June '12	Tests Corrected	
2	Adaptation	July '12 – Aug '12	Tests Analysed Repertory Grids Analysed	
3	Plan	Sept '12 – Dec '12	Review research literature Workbook content updated	N = 119 I = 20 C = 99
3	Implementation & Observation	Jan '13-April '13	Teaching using workbook Field notes taken in Teacher Journal Re-vamped Tests Developed Tests conducted /corrected	
		May '13	Repertory Grid Interviews conducted Tests conducted	
		June '13	Tests Corrected	
3	Adaptation	July '13 – Aug '13	Development of Alternative Evaluation Tool 1 Workbook content updated	
4	Plan	Sept '13 – Dec '13	Review research literature Workbook content updated	N = 111 I = 91 C = 20
4	Implementation & Observation	Jan '14-April '14	Teaching using workbook Field notes taken in Teacher Journal Tests conducted /corrected	
		May '14	Repertory Grid Interviews conducted Tests conducted	
		June '14	Tests Corrected	
4	Evaluation of Final Implementation	July '14 – Aug'14	Development of Alternative Evaluation Tool 2 Workbook content updated	
Legend				**N = Total number of students in year group** **I = Number of students in Intervention group** **C = Number of students in Control group**

Phase 1 and phase 2 represent the foundational analysis phase of the study while subsequent phases form the final analysis phase. The evaluation procedures used to conduct the analysis are notably more elaborate in the final two phases as they include both a primary 'Evaluation Tool' and secondary 'Alternative Evaluation Tool'. Like the teaching and learning materials, 'Alternative Evaluation Tools' were developed based on constant reflection from feedback obtained during the practitioner action research. Student achievement, informed by primary and secondary evaluation tools in the final two phases, was interpreted in terms of the proposed model for learning. The interpretations and model are revealed in chapter 8. This section has described the practical nature of the research study.

4.3 Student Profile

In the four years of the research in my school, all students were girls from a mixed socio-economic background. There is a population of over 750 students in the school. Science is not a compulsory subject in the school after first year. Students sample the subject in first year for the full academic year. All classes in the first year group are mixed-ability. The classes that formed the control and intervention groups were selected randomly on basis of how the timetable system in the school assigned teachers to them. Hence, the intervention group in phase 1 was formed from the classes I was timetabled to teach. In phase 2 of the work, a Higher Diploma in Education student (already a science graduate), was assigned one of my classes and taught one of the two intervention classes for the entire year. We met regularly to plan chemistry classes while they were running and the student-teacher kept a reflective journal of her classes. In phase 4 of the work two other teachers (including a student-teacher) participated in teaching their classes using the workbook that was developed. All other classes in the study were taught using a 'traditional' approach, by other teachers.

Prior to Phase 1, permission was obtained to undertake the monitoring of ongoing practice from the principal of the school and its Board of Management in my work setting.

The prior knowledge that a student may have according to their primary school experience, according to Government Publications (1999), includes strands on matter. In this unit it is stipulated that students need to be aware:

- Materials can be in solid, liquid or gas form;
- Air is made of different gases;
- Of the practical applications of these gases in everyday life such as carbon dioxide in fire extinguishers and fizzy drinks;
- That a gas, such as air, occupies space, has mass and exerts pressure;
- Air resistance and atmospheric pressure exist regarding gases.

4.4 Final Workbook

As shown in Figure 4.2, the pedagogical tool evolved over four phases, each informed by the results of the previous evaluation. The learning outcomes associated with the initial workcards used in phase 1 and the final workbook developed for and implemented in phase 4 are given as Appendix B and C, respectively.

4.5 Evaluation Methods and Data Analysis

The following section describes how three sources of data was obtained and analysed. The rationale for using repertory grids in the study and how they were generated and used to analyse the pedagogy. It also describes the nature of the quantitative analysis.

4.5.1 Qualitative Analysis: Teaching Journal

The teacher journal was constantly used to assist in the evolution of the workbook as a pedagogical instrument from phase 2 to phase 4. As every entry was written within a few hours of each lesson, it enabled the author to make inferences from cognitive and affective perspectives regarding the best direction to adopt for the workbook so as to optimise student understanding in the next phase. There was no formal structure to the Teaching Journal, but it consistently included unsuccessful aspects of each lesson. Photographs of student models and drawings were often taken to supplement written descriptions and provide concrete examples of alternative conceptions that were hindering students' grasp of canonical knowledge. The artefacts produced, formed an essential component of the adaptation of the workbook and the development of summative and / or diagnostic assessments.

4.5.2 Quantitative Analysis

Diagnostic and Summative tests were developed and used to determine student understanding. The timeline of implementation of these tests is shown in Figure 4.3. The details of the questions used in these tests are described where they were analysed in the following chapters. Data collected from exam paper analysis was entered in an Excel spreadsheet. Statistical data was generated in "R". All students present completed exam papers at the end of each teaching phase. This data was anonymised and then entered. Students' names were replaced with code identifiers. The foundational phase data included categorical data only. Pearson Chi-squared tests were undertaken on the data to see if there was a significant difference between control and intervention groups. Cohen et al. (2009) indicate that this test can be used for nominal groups of data. The fact that control and intervention sample sizes in phases 1 and 2 in relation to the use of the Chi-squared test is irrelevant as the focus lies on testing relative proportions in different groups (Agresti and Kateri, 2011). In the case of the analysis of phases of 3 and 4 where data was numerical, Welch Two Sample t-tests were undertaken to analyse if there was a statistical difference between control and intervention groups. One of the assumptions in t-tests is that variances in both groups are the same. This is unlikely to be true where the sample sizes between control and intervention groups are different. However, this was the case in the final phases as they were samples of convenience. The variance is usually larger within a smaller sample size and the converse is true with regard to a larger sample. The Welch t-test is an extension of the standard t-test, which takes into account such different sample sizes. Moser and Stevens (1992) emphasise that the calculation includes an allowance for a separate variance value in each group as opposed to a common value across the groups. For both types of test, a p-value of less than 0.05 was significant at a 5% level. Any correlation different to 0 implied a relationship between two variables if the p-value was significant.

4.5.3 Repertory Grids

The following section describes repertory grid techniques which evolved from Kelly's (1955/1991) 'Organisational Corollary'. It states that constructs do not exist in isolation. In Kelly's fundamental postulate, 'A person's processes are psychologically channelized by the ways in which he anticipates events'. The 'Ways' are the constructs of the grid, and the 'events' are the elements.

4.5.3.1 What Are Repertory Grids?

Pope and DeNicolo (2001) claim that the bi-polar dimensionality of constructs allows for the extraction of matrices representative of inter-relationships between constructs and elements present in a grid. According to Salmon (1988), the repertory grid is derived from the theory of personal constructs which suggests that each person has integrity and, having personally created the person we now are, we have the capacity to recreate that person. It allows researchers to walk in the shoes of another and attempt to view the world through the eyes of another. Jankowicz (2004) describes the grid as a generic term for a number of simple rating-scale procedures used to arrive at straightforward descriptions of how a person views the world. Jankowicz (2004) holds that in essence, meaning is conveyed by both words and numbers where the numbers characterise elements with respect to constructs. Pope and DeNicolo (2001) argue that a repertory grid can allow for the exploration of the nature and sharing of construing within a group of people. In this regard, we can measure the relative degree to which elements match both pole descriptors on a construct for a group of students. Jankowicz (2004) argues that the 'Ideal' element (considered in the repertory grids used in this study) may be helpful in any situation in which the grid is being used to make a prediction. A check can be carried out to see if any elements came close to the 'Ideal'. Hence, according to Fransella (2003) the 'Ideal' element can act as an anchor against which all other elements can be compared. In this way, inferences can be made on the discrepancy between other elements and the ideal element. Fransella et al. (2003) note that a frequently-used scale on a repertory grid is 1–5, where 1 represents the closest match to the preferred pole and 5 the closest match to the non-preferred pole. In this way, it is hoped to move towards the acknowledgement of Lodico et al. (2010). They state that since we construct reality in accord with the concepts most appropriate to our personal experiences, it is desirable that the researcher attempts to understand the complex, and often multiple realities of the person.

4.5.3.2 Generating Repertory Grids

According to Pope and DeNicolo (2001), the Repertory Grid approach requires the finding of common features in the accounts of individuals, and then discovering ways to test the frequency with which these students select items reflecting these commonalities in surveys. Hence, they argue that it serves to ensure genuine participation via the constructs of respondents. As personal constructs are involved, it guarantees an ontological authenticity which emphasizes the function of the personal constructions. Pope and DeNicolo (2001) also maintain that the Repertory Grid offers bilateral control of the process between both researcher and participant – a form of cooperative inquiry. This is viewed as performing a difficult task since coming to understand our own worlds is challenge enough but that attempting to enter the world of others is 'awe-inspiring'. It may be achieved by:

- Quantifying the ideas expressed in the interviews via a rating scale to reveal the depth of the participants' belief in the ideas they espouse;
- The repertory grid technique allows the questions posed by the researcher to be framed in the language of the subjects;
- It sometimes provided a response more appropriate to the intention of the interview question than the response received from asking the question directly because of the bi-polar nature of the construct being rated;
- The possibility of rating an 'Ideal' element in a grid allows the elements involved to be benchmarked so the study can be directed towards this perceived ideal. Simultaneously, the quantitative discrepancy between the current status of the research and the 'Ideal' can be visualised.

4.5.3.3 Administration of the Grid

The repertory grid is an M by N matrix of elements and constructs. It is the product of a structured interview procedure in which respondents classify and evaluate elements on a numerical scale according to their own personal constructs. Students were invited to volunteer to undertake two repertory grid interviews. In the first, their views of themselves as scientists were elicited. In the second, their perceptions of the pedagogy were recorded. Two teachers were invited to volunteer to undertake one interview focusing on the pedagogy using a repertory grid technique.

Two sets of elements were used – each one corresponding to relevant part of the interview. Both sets of elements are briefly described below and were presented to participants on a white or coloured A4 size print-out.

(a) Two different groups of elements featured in this part of the interview. One set represented successful scientists and comprised of the following: pictures of Galileo, Alexander Fleming and Bill Frankland. The second set consisted of two unsuccessful commercial medicinal products sold for a time to the public in the United States of America.

(b) This part involved three elements focusing on approaches to learning the PNM. One element set consisted of 5 cards representative of the *workbook* (the pedagogical instrument used by students). Another set involved the corresponding sections of a generic textbook represented by 4 cards. The final set contained 5 cards, each illustrating an example of student modelling (the tool used within the pedagogy).

4.5.3.4 Element Comparison during Repertory Grid Interviews

The 'triadic method' was used as the element-comparison procedure, since it is closest to Kelly's theory as to how constructs are formed. Using this approach, elements are randomly divided into sets of three and the respondent is then asked to name a way in which two of these elements are similar and different from the third. What the respondent names is a construct. Additional triads are presented until the respondents cannot offer a new construct.

Typically, in semi-structured interviews the researcher has a list of themes and questions to be covered, although these may vary from interview to interview (Saunders et. al., 2009). Therefore, some questions may be omitted in particular interviews and the order of questions may vary depending on the flow of the conversation. In this way, semi-structured interviews provide an opportunity to 'probe' answers, where it is desirable that interviewees explain, or build on, their responses. In this research, this 'probing' is done using techniques known as 'pyramiding' or 'laddering' which are described below. Fransella (2003) sees the structured component of a 'semi-structured' interview (involving repertory grids) deriving from the interviewer trying to ensure the student does not stray away from their current ladder or pyramid at any point in time. Hence, the interview is structured in the sense of the format but is unstructured in relation to the possible direction.

4.5.3.5 Laddering and Pyramiding

To elaborate on personal meaning, Ravenette (1999) cites Hinkle (1965) as indicating that both 'laddering' and 'pyramiding' are valuable techniques in obtaining a person's constructs during an interview. While Ravenette (1999) acknowledges that constructs are the main building blocks in a person's meanings, he argues that one needs to go beyond them so they are not ends in themselves. Fransella and Dalton, (2000) reason that since all constructs are theoretically organised into a *system* and so have links with each other, it is possible to follow through this network (i) to more and more abstract super-ordinate constructs known as *laddering* and (ii) to more and more concrete peripheral sub-ordinate constructs known as *pyramiding*. It is worth noting that Jankowicz (2004) rates core constructs as those that tend to be further up in this hierarchical system (and hence are more value-laden). Fransella (2003) views pyramiding as a process which moves towards eliciting examples of behaviours.

4.5.3.6 Construct Elicitation: 'Person as a Scientist' and 'How I see the Pedagogy' Interviews

In each case the person was presented with three elements as described above. In the second phase (where Pilot Repertory Grid Interviews were conducted) and final two phases, all of the students interviewed had received short biographies of three scientists, as elements to read the evening before. They also received a brief history of two products that were made by pharmaceutical companies and subsequently withdrawn from the market, e.g. Lotrenex.

An example of how the triadic method procedure was initiated in the context of the Frankland, Fleming and Lotrenex elements in part (a) of the interview is as follows:

Three elements were randomly selected and presented separately to each of a pair of student interviewees as A4 cards conveying a picture of the element with its name. Each respondent was asked to say whether there was some important way in which two elements were alike and thereby different from the third. The opposite of the similarity was then asked for. This pair of opposites is known as a construct.

Each construct was then laddered (up) to obtain more abstract personal values attached to it. Frankland and Fleming were seen as alike and different to Lotrenex, because they were "persistent" whereas Lotrenex "gave up easily". They preferred the 'persistent' pole of the construct over the 'gave up easily' pole. When asked *why* they thought the scientists were 'persistent', the answer given was "they loved what they were doing". The counterpoint to 'they loved what they were doing was given as "They (Lotrenex) did it for financial gain". Then, another triad was presented to the respondent and the process was repeated. Every attempt was made to make the students involved feel at ease during the interview. The technique of *pyramiding* (down) was used to obtain concrete perceptions of the way the real scientists behaved or how the pedagogy was construed. An example of how the triadic method procedure was initiated in the context of the Modelling, Book and Workbook elements in an interview with an individual teacher is as follows:

A teacher was presented with a random card from each element sample. The respondent was asked to say whether there was some important way in which two elements were alike and thereby different from the third. The opposite of the similarity was then asked for. Each was then pyramided to obtain more abstract personal values attached to each construct. Modelling and the Workbook elements were seen as alike and different to the Textbook element, because they were "visual-concrete" while the Textbook approach lent itself to "taking down notes". When probed as to *what* a student or students might be doing if they were engaged in using visual-concrete materials in a classroom situation, the respondent replied

"Conversing" while the opposite to this concrete action was seen as "Individual work". It is worth noting that pyramiding questions may begin with the word *how* also. Both laddering and pyramiding techniques may have been used in relation to the same set of triads. Students who participated in the interviews were selected randomly to ensure there was a representation of various abilities included.

In the case of teacher repertory grid interviews, the analysis evolved into a more general interview in which there was a description by teachers of the 'incentives' and 'barriers' to teaching offered by this pedagogical approach. This was done because it fell within the author's methodological-range as he had used it in prior research (in an unrelated field). The approach also echoed the geometry of constructs as an incentive may be deemed the natural polar opposite to a barrier. Hence, it was hoped that the yield of valuable information from the teachers who engaged in the study would be increased.

Finally, while repertory grids appear to yield constructs that are unrelated to the topic of PNM, the *elements* used to generate the constructs within the grids <u>were</u> features of visual resources used in the teaching and learning of the topic. An exception was in the student 'How I see myself as a Scientist' interviews in which the elements used to generate constructs were people or companies who worked within the scientific field. A justification for this approach lies within PCP and it was used to identify how the pedagogy had assisted students approach their ideal version of the root metaphor of 'man/woman the scientist'.

4.5.3.7 Evaluation of Grids

In all phases of the research, regarding parts (a) and (b) of the interview, the interviewer removed any constructs that were repeated or deemed similar to a construct that was seen to have been previously elicited. This was done prior to the evaluation of elements out of consideration for the students involved so as to reduce the demands of rating the same construct twice.

In phase 2, in the course of supplying grids each student was asked to evaluate the extent to which elements may be characterised by each construct. The student was asked to rate the elements by placing a *tick in the box*. Fransella et al. (2003)

identify this as similar to Kelly's original grid: it represents a 2-point scale analysis i.e. a tick or a blank. The person is asked to place a tick under the name of each element to which the construct applies. Thus the matrix consists of a number of ticks and blanks (no ticks).

In the final two phases, grids were rated using a rating scale of 1-5. In this range, 1 represented the score corresponding to the preferred pole while 5 represented the score corresponding to the least preferred pole. During these final phases, because of the greater number of students involved, a preliminary rating exercise was conducted where students were asked to rate on a practice grid of contemporary musicians. This group of four musicians, each of whom represented an element, were popular with the student cohort and rating was done along a scale from 1 to 5 (as it was in subsequent element evaluation) against seven supplied constructs. To undertake this exercise, students were provided with an A4 piece of paper which was printed off from a Microsoft PowerPoint slide with the relevant blank repertory grid. The same empty repertory grid was projected onto the white-board of the laboratory in order to facilitate the answering of any questions that may have arisen. This exercise allowed students sense what was meant by the preferred pole (receiving a rating of 1) and a non-preferred pole (receiving a rating of 5) of a grid, and by implication, the intermediate ratings of 2 to 4. It also allowed students view how the 'Ideal' element regarding a pop-star might be rated. This in turn gave students the opportunity to understand how their rating of an 'Ideal' element might *not match* a preferred pole rating value of 1 and that the actual rating given to an 'Ideal' element may *match* the rating given to an element along a particular construct (even if that rating was not 1).

Also in the final two phases, to ensure clarity in terms of the comprehension of the elements in the 'How I see myself as a Scientist' grid, a PowerPoint presentation involving the elements of Frankland, Fleming etc. was shown to all respondents potentially engaged in the rating procedure. This took approximately 5-10 minutes and was followed by a re-capitulation. The interviewer took an opportunity to stress the importance of the Ideal element in terms of how it would guide formulating a revised pedagogy for students in the subsequent year. Then, the relevant blank repertory grids typed in Microsoft PowerPoint and printed off as an

A4 slide were distributed to members of the class engaged in rating. The same blank grid was projected onto the white-board until all students had finished the rating process. Before this process began, hard copies of the slides corresponding to the presentation were distributed to groups of two or three students as A4 sheets of paper. Students were advised they could consult these sets of cards during the presentation as they rated the elements. While the rating of elements was carried out, I circulated the room in an unobtrusive fashion to assist with any queries they had. Students were given the time they required to rate the grids in a relaxed manner whereby they could consider their ratings. The evaluation of this grid took approximately 5-10 minutes. The above measures were taken in the final phases to increase the number of student rating responses relative to phase 2 in an unobtrusive way.

Regarding part (b) of the interview ('How I see the Pedagogy' grid), constructs were previously divided into those that were to do with cognition and those which were to do with feelings. Thus, separate repertory grids with the same elements were prepared by grouping the cognitive and affective constructs and so, two distinct grids were supplied, representative of both groups of constructs.

To enhance clarity in terms of the comprehension of the elements before the rating process commenced, a PowerPoint presentation was made of all of the cards representative of each element in a time of approximately 5 minutes. Hard-copies of the slides corresponding to each element were distributed to groups of two or three students as A4 sheets of paper (one element example slide per sheet). These three distinct sets were also colour-coordinated to correspond to the background as seen in the PowerPoint presentation.

Also, two repertory grid interviews were conducted with teachers in phase 4 of the study regarding 'How I view the Pedagogy'. The same elements (as those used in part (b) of the student interviews) and techniques were used to elicit constructs before the respondent rated the elements along the constructs.

In phase 2, the data was treated as raw data and an eyeball analysis was undertaken to seek any patterns that existed in the resultant grids. Following the completion of element-evaluation on the grids in phases 3 and 4, data was averaged using R (a statistical programming language). The aggregate repertory grid was then subject to principal component analysis using the R online software package tool: 'OpenRepGrid'. This tool was also applied to results from aggregate grids on implicit knowledge present in drawings in exams in phase 4.

4.5.3.8 Reliability and Validity of Repertory Grid Methodology

Repertory grids are an attempt to enquire into a person's construct system. The person's mind in Kelly's terms is not static. Therefore when we repeat a grid application we should not seek to repeat the same result but to seek what it signifies when it shows change. Bannister, and Fransella (2003) acknowledge that Kelly is referring to reliability as 'a measure of the extent to which a test is insensitive to change'. They cite their previous work (Fransella and Bannister, 1977):

> "*It seems sensible, therefore, to regard 'reliability' as the name for an area of inquiry into the way in which people maintain or alter their construing and to estimate the value of the grid not in terms of whether it has 'high' or 'low' reliability but whether or not it is an instrument which enables us effectively to inquire into precisely this problem*".

Essentially, regarding validity, we need to consider grid methodology in terms of its theoretical basis and usefulness. Repertory grid methodology is based upon Kelly's (1955) Personal Construct Theory. The repertory grid methodology is therefore soundly based theoretically. It can be used to present perceptions in a quantifiable way that is amenable to statistical analysis. The validity of grid technique in terms of its usefulness is its capacity to enable a person to elaborate his or her construing system.

Bannister and Fransella (2003) remind us they see validity as referring to the way in which a mode of understanding enables one to take *effective* action when we interact with our world. They argue that the validity of a technique is its capacity to enable us to elaborate our construing. By elaborating, we increase the range of convenience of our constructs by widening the area to which we can apply a particular 'theory'. An example of such an application is: 'Am I allowing my students to increase their range of convenience of understanding? or, 'Can I increase my range of convenience of understanding of my students reasoning?

4.6 Conclusion

This chapter outlined the rationale for using practitioner action research methodology. The pragmatic nature of this methodology has been described. It allowed the researcher to acknowledge that there was ecological validity in the ongoing research despite the fact that that the findings may not be generalizable (Tripp, 2005). Hence, it encouraged confidence in relation to the consistent usage of the teacher journal (described in Section 4.5.1) to qualitatively capture the impacts systematic attempts made to improve practitioner practice. The level of a small-scale intervention may also be seen as serving to validate the work (Cohen et al., 2007), as the sample of students used was one of convenience due to practical limitations and realities of time and time tabling. 'Reflection in action' (Carr and Kemmis, 1986), led to an awareness of the requirement by the author to reflect during all stages of each phase. Simultaneously, 'Research in action' (Saunders et al., 2009), raised the importance of informing practice and the direction of the study by continuously referring to the most recently available relevant research literature. The idea of the relevance of adopting a novel stance (McNiff and Whitehead, 2006) provided the author with the freedom to dare to be innovative in his approach to the research conducted. It manifested itself in a (unique) set of action research cycles (illustrated in Figure 4.2) that involved creating greater conceptual understanding in the area of PNM initially and later entailed attempts to manage the interpretation of the meaning-making of students.

Finally, the methodology provided the researcher with scope to 'Manage and understand change' (Brannick and Coghlan, 2007). An example is the awareness of the importance of managing change purposefully which led to the realisation of the potential use of PCP as an adjunct to the practitioner action research.

The foundational aspects of the study are now described in Chapter 5.

CHAPTER 5: FOUNDATIONAL ANALYSIS

Introduction

This chapter focuses on the delivery of a pedagogical instrument (workbook) and how it has evolved over the course of the first two of four phases in order to answer the research question: 'Can an Inquiry-based Learning approach to the PNM that includes modelling and visualization among junior second level school students serve to increase their conceptual understanding? This set of two phases is referred to as the 'Foundational Analysis' stage of the study. The justification for the evolution of the workbook based on evaluation tools is also provided.

5.1 Implementation and Evaluation of Phase 1

This section provides an overview of the implementation and evaluation of phase 1 of the study. The implications for phase 2 are discussed.

5.1.1 Phase 1 Implementation

This section describes the development of the initial phase of the research process. It is represented in Figure 5.1. The plan to develop the pedagogical tool is also described.

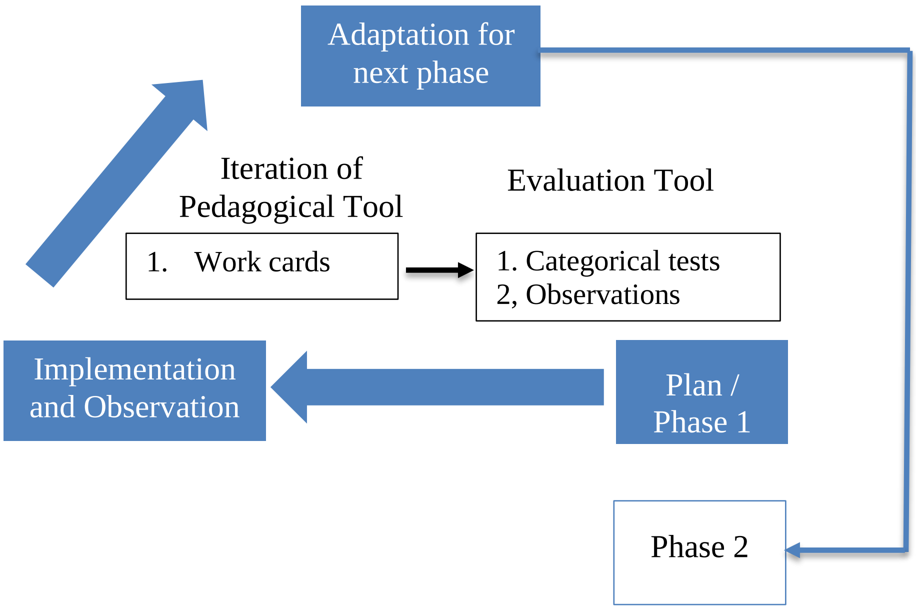


Figure 5.1: Practitioner Action Research Cycle Phase 1

Margel et al. (2008) hold that conceptual change required to genuinely understand the particulate model, is unlikely to be brought about by formal, traditional teaching using definitions and visual aids etc. It was decided to develop an initial set of work cards with units on PNM, where not all answers were seen as pre-determined and where thinking, talking and interpreting would be viewed as important. Thus, it would approach the Nussbaum (1985) model where students are to benefit from conceptual conflict, they must be encouraged to expose and articulate openly their preconceptions. In this way, the attempt is being made to recognise that individuals construct their own knowledge as a result of their conceptions and by conducting tasks (with materials and resources) through discourse with their peers. It is anticipated that social interactions between student groups in class would be facilitated by the teacher. Gabel (1999) notes student interactions can be concerned with the emergence of conflict situations that help students create dissatisfaction with, and modification of, their current views using concept substitution, analogies or reflection on the meaning of ideas. In this way, Davidowitz and Chittleborough (2009) would see the strategy as providing the opportunity for students to receive feedback on their own understanding which helps them to identify and reconcile (alternative) conceptions. Given that, in science phenomena there are often competing theories or models, a key activity of scientists is evaluating which of the alternatives under consideration offers the best meaning. The approaches mentioned resonate with an IBL pedagogy. A lead was drawn from Minner et al. (2010) where they described a study to be considered inquiry-based if it (i) instructed them via some part of the inquiry cycle (e.g. question or conclude) in relation to scientific phenomena and (ii) used pedagogical practices that emphasized, to some extent, student responsibility for learning or active thinking. To ensure students have an opportunity to engage in active debate it is envisaged they carry out IBL in groups of two or three. Driver and Leach (1993) suggest that when an individual's ideas are affirmed and shared by others in classroom exchanges, it contributes to the knowledge construction process.

Concept maps are employed within the pedagogical instrument because there is a consensus in the literature over the last three decades that they have important implications for knowledge integration. An example is provided by Llewellyn (2005) who favours them as effective questioning and metacognitive strategies.

There is a constant call to prompt students to link the macroscopic to the submicroscopic and later to the symbolic. In this way, the possibility for the conceptual integration of the three levels of representation used in chemistry is provided.

In an environment to improve learning conceptually, the role of the teacher is viewed by Ainsworth (2008) as including allowing students sufficient *time to master the process of relating representations* to one another. This requires *patience* on the part of the teacher. The role of teachers in the inquiry context is emphasized by Dolan and Grady (2010): rather than acting as information deliverers, facilitation is required, where alternatives are considered and it is acknowledged that there is not always a correct <u>single</u> approach (e.g. to modelling).

The initial phase of the study involved 134 mixed-ability students. 82 students taught by 4 teachers represented the control group while the remaining 52 students taught by the author represented the intervention group. These groups were randomly assigned to the respective teachers and were all of a mixed ability. The learning outcomes that formed the basis of the workcards developed for phase 1 are given in Appendix B. This includes the inquiry skills associated with each workcard. Following their development, suites of workcards had to be photocopied for each of these 52 students. The time span required to teach using the pedagogical instrument was approximately 8 weeks. During this time, observations were written down on the teacher copy of the suite of IBL workcards and/or on post-its during class. Comments were used to inform the modification of the successive IBL pedagogical instrument.

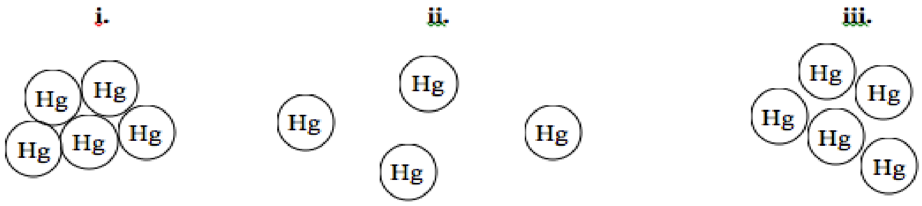
5.1.2 Evaluation of Phase 1

The following section describes the development of a summative test to assess student knowledge of PNM, including the rationale for each of the questions assigned. This is followed by analysis of the results of the control and intervention groups in Section 5.1.3.

The questions used in the summative exam and the rationale for their use are as follows.

Question 1:

1. Which of the following diagrams (i. to iii.) represents the correct model of Mercury which is a liquid at room temperature. **Answer:** _____



Question 1 was asked to test students' ability to recognise a depiction of mercury in liquid form at a particulate level. It was deemed by the author to behave as a typical liquid and was used in the question as it was not an everyday liquid students encountered. Students were given three diagrams to choose as being the best representation.

Question 2:

2. Draw a model of what 5 or 6 atoms of the element Iron (Formula = Fe) which is a solid at room temperature looks like in Box 1.

Box 1

This question was asked in order to test students' ability to draw a depiction of iron in solid form at a particulate level. Iron in its solid form was viewed as a material familiar to students (at the macroscopic level). Hence, while a more challenging question than the previous one, Question 2 was also serving to further ease students into the exam. Students were given the symbol of Iron, which they were expected to use in their drawings. Students were judged to have given a correct response to this question if they drew a number of atoms with no inter-particulate space with an Fe symbol. A symbol such as **fe** or **FE** was deemed unacceptable.

Question 3:

3. Draw a model of what some atoms of Nitrogen (Formula = N_2), which is a gas at room temperature looks like in Box 2. You may make the atoms into molecules if you wish.

Box 2

This question was posed to challenge students' ability to draw a gas at a particulate level. Students were given the formula of nitrogen gas in its elemental form, which they were expected to use. This question required students to depict the gas using molecules of nitrogen. In order to provide a correct answer, students had to indicate they had acknowledged that the particle of Nitrogen in their drawing was a molecule. This could be done by drawing a circular or oval boundary with N_2; NN; N-N; N=N; N^2 or N2 inside it. The depiction of 2 as a subscript was not necessary. In contrast, the following symbolic articulations were unacceptable: **nn**; **N**; **n2**; or $\mathbf{N_2N_2}$.

Question 4:

4. Use the names and formulae of the following chemicals along with the copy of the 'Periodic Table of the Elements' to help you complete Table 2 below.

Table 2

Name	Formula	Element or Compound	How many types of atom is it made from	The smallest particles are atoms or molecules
Carbon	C	Element	1	Atoms
Carbon dioxide	CO_2	Compound	2	Molecules
Sulfur	S			
Sodium	Na			
Carbon monoxide	CO			
Cobalt	Co			

Question 4 invited students to infer from representations provided at the symbolic level if a chemical was:

- an element or a compound

- made from one or more types of atom
- drawn using atoms or molecules

The question was asked in a tabular format and two examples were given to students (one as an element and the other as a compound) to assist them in understanding how to fill in the table while answering the question. A student needed to get all parts correct in order to be deemed to have been successful in answering the question. Otherwise, they were scored as incorrect.

Question 5:

5. Using Table 1 to help, draw five atoms or molecules of Cobalt and Carbon monoxide look like in their solid states

Box 3 for Cobalt **Box 4 for Carbon monoxide**

This question required students to draw the element cobalt and the compound carbon monoxide in the solid phase at the particulate level. In each case, they were given the symbols of each chemical in the Table in question 4 and were expected to use them. This question intentionally focused on symbols containing the same letters i.e. Co and CO. Students were expected to

- discriminate between these symbols in their answers
- use an atomic representation for cobalt and a molecular representation for carbon monoxide.

In this case the criteria required for a correct answer were that no inter-particulate distance was displayed in the drawings and the correct symbol was used within the drawn particles. The CO symbol was not acceptable for Co, nor Co for CO. Students need to have answered both parts accurately to be deemed to have attained a correct answer.

Question 6:

6. If 5g of solid carbon monoxide was melted to a liquid, how many grams of carbon monoxide would there be? __________

Draw what five atoms or molecules of carbon monoxide would look like in the liquid state in Box 5.

Box 5

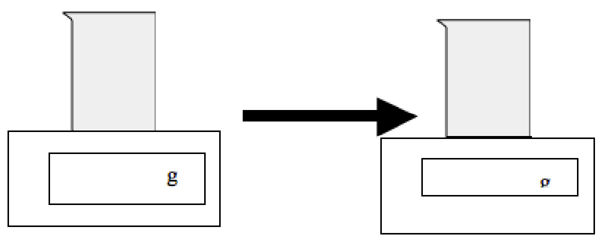
Question 6 links with the carbon monoxide component of the previous question to include a challenge to draw a phase change from a solid to a liquid. Students are therefore expected to draw carbon monoxide in the liquid phase at a particulate level. They are also given information regarding the mass of carbon monoxide in the solid phase and asked what this will be in the liquid phase.

In this case the criteria required for a correct answer were that a small inter-particulate distance was required in student drawings and that the correct symbol for carbon monoxide was used. The Co symbol was not acceptable for CO.

To answer this question correctly, students were required to supply the correct written answer to all parts of the question. Students need to have answered all parts accurately to be deemed to have attained a correct answer.

Question 7:

7.



Weighing Balance

6g of orange sodium dichromate is stirred into 20cm^3 in a beaker. 20cm^3 of water has a mass of 20g.
Name of solute = _______________
Name of solvent = _______________
Appearance of solution = _________
Mass of solution = _______________

What mass will the solution be after 20 minutes? _________________

If this solution is now a 'saturated solution', how would you make large crystals with it?

____

This question invites students to describe how a solution of sodium dichromate is made. Students are expected to: identify the solute and solvent; predict the colour of the solution based on the qualitative information in the question; calculate the mass of the solution immediately after it is made and 20 minutes afterwards; indicate how large crystals may be formed from a saturated solution.

5.1.3 Results of Evaluation of Phase 1

The results attained by the intervention and cohort groups are illustrated in Table 5.2. This table indicates that results were statistically significant with respect to five of the total of seven questions in favour of the intervention group.

Table 5.1 Summary of Phase 1 Exam Results (N=132)

Question No.	1*	2*	3*	4	5*	6	7*	N
Intervention % Correct	71.2	67.3	42.3	28.9	36.5	7.69	21.5	52
Control % Correct	52.5	37.5	15.0	15.0	13.6	10.0	5.0	82

* statistically significant at the .05 level using a Chi-squared test

Two main aspects of the above results table are deemed important. Firstly, the percentage of correct answers per question among the intervention group is considered. Secondly, any question where there is no statistical difference between the control and intervention groups at the 5% level is acknowledged. Upon inspection, the questions that can be improved upon involve exam Questions 3 to 7. These questions involved the correct use of symbols in representations, a phase change to a liquid state and the conservation of mass with respect to solvents. Of particular concern is Question 6 in which the intervention group performed more poorly than the control group (though not statistically significant). It is also of note that there is no statistical difference between the control and intervention groups in Question 4. It was therefore intended that the learning outcomes underpinning these questions should be the focus of the planning stage in Phase 2. With respect to the original question in Phase 1, the IBL approach pursued did indeed lead to conceptual gains in the PNM relative to the traditional approach and in most cases these gains are statistically significant. Therefore it seemed reasonable to allow the work to be carried on into (the subsequent) Phase 2. The focus of the work in the next phase will continue to be 'Can an Inquiry-based Learning approach to the PNM that includes modelling and visualization among junior second level school students serve to increase their conceptual understanding?'

5.1.4 Adaptation for Phase 2.

As the pedagogical tools used in this work are modelling and visualization, it was seen that it would be useful to employ models of alternative conceptions of a visual nature presented by students during phase 1 when developing the iteration of the workbook. It was intended that this would serve to achieve improved learning outcomes in phase 2. To make the suite of IBL units more user-friendly, it was envisaged that changes to presentation and content occur:

- Concept maps be made more logical as students found these difficult to comprehend (Content);
- One atomic model (i.e. hard sphere with the appropriate elemental symbol) be used in the workbook and in the exam in an effort to be more consistent in this area in the next phase (Content);
- Numbers be inserted onto the pages of the units (presentation);
- Numbers be attached to questions within each unit (presentation);
- The stand-alone IBL units be merged and bound into a booklet that remains intact throughout the course of the work on PNM. The units would then become chapters of the booklet and would be retained in the same order (presentation).

Any sections of the workbook that remain intact from its predecessor of stand-alone units were adjudged helpful to student understanding as students were seen to engage well with them. These parts were viewed as sufficiently useful on their own, or upon which to scaffold further student tasks, to merit retention.

The procedures followed in the action research cycle (i.e. 'Plan', 'Implementation and Evaluation' and 'Adaptation' for the next phase) appear to allow the author sufficient scope to be used as parameters while navigating change of pedagogical practice. In this way they to serve to allow the gaps that exist regarding my values and intentions as an educator become smaller. However, improvements can be made within the observational aspect of the action research cycle in particular. This would enable a more comprehensive view of the effect of the pedagogical tool to be gained and help to inform its future direction to improve its efficacy. Two specific procedures within this remit include:

- Take into account students' views of the pedagogy to observe what they think. Hence, their level of participation regarding the improvement of the pedagogy would be increased;
- Take more detailed observational notes regarding how students respond to the pedagogy in class to bolster the level of qualitative feedback that exists within the action research cycle. It is envisaged that this may be achieved by changing from taking 'on-the-fly' notes on post-its during class, to the writing up of a journal document containing more comprehensive observations after each class.

As it was deemed useful to allow the work to be carried into the next phase, the plan that served to answer the question 'Can an Inquiry-based Learning approach to the PNM among junior second level school students serve to increase their conceptual understanding?' follows in the next section.

5.2 Implementation and Evaluation of Phase 2

This section provides an overview of the implementation and evaluation of phase 2 of the study. The implications for phase 3 are discussed.

5.2.1 Adaptations and Implementation of Phase 2

This section describes the development of the second phase of the research process. It is represented in Figure 5.2 and illustrates how both artefacts that were produced are related to one another. It also indicates the forms of evaluation undertaken to inform the eventual refinement of the second artefact within the context of the Action Research Cycle from Kemmis and McTaggart (1982). Phase 2 seeks to answer the question: "Can an inquiry-based learning approach to the PNM that includes modelling and visualization among junior second level school students serve to increase their conceptual understanding?"

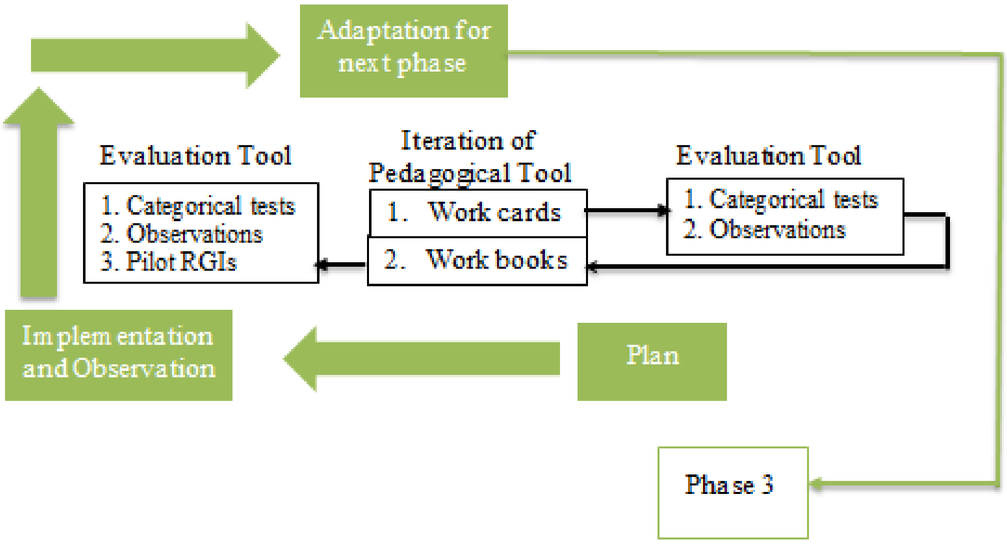


Figure 5.2: Practitioner Action Research Cycle Phase 2

In respect of the planning of phase 2, the approach of Michalchik et al. (2008) is worth remembering: while scaffolding student learning the use of (timely) questioning, prompting, drawing of students' attention to key features and verbally reinforcing the visual features of models is followed. Also, in terms of verbal responses, Harrison and Treagust (1998) point to studies showing that it is essential for teachers' explanations to be student-friendly and compatible with the students' existing explanatory knowledge. To do this, Driver et al. (2000) requires that the teacher orchestrates a discussion to identify different lines of thought and invites students to evaluate these and move toward an agreed outcome (which offers the best interpretation). This has the added advantage that making such steps explicit in teaching leads to clarification of the norms by which scientists make rational decisions between alternative hypotheses.

Regarding drawing in a group context, Ainsworth et al. (2011) claim that, though it is not at all commonplace in classrooms, learners focus on interpreting others' visualizations. At the same time, if students are given time to explore new ideas in terms of their own thinking it puts them in a better position to make 'informed decisions' about the validity of their claims which is a core strategy for developing expertise. This approach involving moving from the provision of singular accounts of phenomena to the consideration of plural interpretations is endorsed by Driver et al. (2000).

Ainsworth (2008) notes that beginners using powerful tools do not achieve the same results as experts and in relation to this idea, the author viewed one way of going towards narrowing this gap was to sequence students work in an appropriate way. It was decided (following observation and consideration) that the sequence of tasks undertaken in Phase 1 be maintained.

The drawing of chemical phenomena at the particulate level worked well as it clearly allowed students to undertake what Ainsworth et al. (2011) identify as:

- making their thinking explicit and specific, so that meanings generated could be exchanged and clarified between peers;
- learning by critiquing the clarity, coherence, and content of what they and their peers have drawn.

These advantages are likely to yield the result, noted by Davidowitz and Chittleborough (2009), that drawing the sub-micro representations of substances presents a much greater challenge than simply identifying observable features presented by the substance (at a macroscopic level).

The workbook begins with an acknowledgement of the recommendation by Ainsworth (2006) that there should be a consistency between models used to convey target entities (in this case the atom). Hence, solid spheres are used to convey the reactant particles in both possible methods of demonstrating the formation of ammonium chloride.

Concept maps within this edition of the workbook represent forms where both '*concepts*' and '*linking phrases*' are missing as opposed to only the latter in the previous iteration. This is aligned with the approach of Yin and Shavelson (2008), since students had struggled with the completion of the maps in phase 1.

Another change in approach regarding the second iteration of the IBL units and the drawing of particles involved using arrows which could be large or small depending on the state of matter the students were trying to depict. This was to emphasise dynamic modelling over the previously used static approach. This is consistent with the dynamic visualizations the students would meet later in the workbook.

The second phase involved 123 mixed ability students. Forty-two students were taught by two teachers (the researcher and another teacher) over a period of approximately 12 weeks (Figure 4.3). This represented the intervention group. The remaining eighty-one students in the year group were taught by three teachers in a traditional way and this represented the control group. One teacher (not the researcher) was involved in the teaching of both cohorts.

A second iteration of the workbook was developed based on the reasons previously described. The pedagogical instrument included visual alternative conceptions generated by students in the Phase 1 intervention group to enhance the pedagogy in terms of the potential for conceptual understanding of PNM.

A teaching journal combining the reflections of both teachers involved in teaching the intervention group was generated to inform the modification of the pedagogical tool in the following year.

5.2.2 Evaluation and Results of Phase 2

Evaluation in phase 2 was through basic repertory grid analysis and summative tests. Each are considered below.

5.2.2.1 Repertory Grid Interviews

The following section explains the nature of both types of repertory grid interviews that were conducted to inform how the pedagogy could be potentially modified from a student point of view.

Repertory grid interviews were carried out with a group of 4 students with a view to informing the refinement of the next iteration of the pedagogical tool.

The set of students who provided the information for each grid were drawn from the intervention cohort so as to be representative of a range of abilities. The findings are firstly presented in terms of 'How I see myself as a scientist' in relation to the scientists presented to them as elements in the repertory grid interviews (Galileo, Frankland and Fleming). Findings are then presented in terms of 'How I see the pedagogical tool' which was the version of the workbook that was developed to support IBL in phase 2. The form of analysis used for the repertory grids is an 'eyeball analysis'. Jankowicz (2004) views this as a preliminary or basic analysis with respect to other forms of analysis with repertory grids involving the relationships between the constructs and the elements. He describes *constructs* as indicating *how* the respondent thinks and the *ratings* as indicating *what* they think. Following an examination of the relationships, conclusions may be drawn.

How Students Perceive themselves as Scientists

A summary of the results of how the students see themselves as scientists is provided in the repertory grid (Figure 5.3).

Ratings	**1**	**2**	**3**	**4**	**5**	
Persistent	12 5	5	6			Gave up when told it did not work
Thorough / Organised	8 4	2 1 4	2 2	2 1	1	Did not test things fully
Loved what they did	13 5 1	4 5 2	1	1		Did science for financial gain
Careless (wrt others)	5	2	3	2 1	8 5 5	Cared for others
Confident	17 2 6	2 3 1	2 2			Did not believe what they did
Risk-takers	12	4 1	2 3 4	1	2 1	Played it safe for themselves

Legend:

black = student chose this rating to indicate where they see a good scientist on the construct;

Blue = how the student sees themselves as a scientist now;

Red = how the student sees themselves ideally as a scientist

Note:

Not all students responded to the rating exercise. This is also the case in Figure 5.4.

Figure 5.3: How I as a Student see Myself as a Scientist (N = 21)

The following sections detail how students perceive themselves as scientists in relation to Galileo, Fleming and Frankland in terms of constructs of contrasting poles including:

Persistent --- Gave up when told it did not work:

All students placed themselves in the middle of this polar range in that all gave themselves a rating of three. However, it is clear *that they would like to move towards the 'persistent pole'*. This is in congruence with where they see scientists such as Frankland, Fleming and Galileo.

Thorough/Organised---Did not test things fully:

Once again students see themselves now as being mainly in the centre of the grid with one exception who sees herself at the 'thorough / organised' pole. Scientists are viewed as being at or near this pole, and *this is also the pole towards which students ideally see themselves moving over time.*

Loved what they did --- Did science for financial gain:

Currently, students see themselves as being quite close to the pole 'loved what they did' and *ideally see themselves as being even closer to it*. It is also at this pole where they see scientists.

Careless with respect to others --- Cared for others:

Students believe scientists to be almost evenly distributed along the whole construct. However, they see both themselves now and *their ideal selves as being at the pole 'cared for others'.*

Confident ---Did not believe in what they did:

Students perceive scientists to be at the 'confident' end of the pole of this construct. At the moment they see themselves as being mainly near this pole but some are in the middle. *The respondents almost entirely see themselves as ideally at the 'confident' pole of the construct*.

'Risk-takers --- Played it safe for themselves':

Students see scientists as a group of people who are mainly risk-takers.

However, they see themselves as being in the middle of this construct or towards the pole 'played it safe for themselves'. *Ideally, they would like to be in the middle of the polar range of the construct.*

The results suggest that students are displaying features of Kellyian permeability exhibited by their current position and desire to move closer to this pole. They are also exhibiting features of Kellyian aggression in relation to how they rate themselves in relation to being ‘thorough’ versus ‘not testing things fully’. Linked to the ratings along this construct is the view students hold of themselves as being ‘confident’.

How Students see the Pedagogical Tool

A summary of the results of how the students see the pedagogical tool is provided in the grid (Figure 5.4).

Ratings	1		2		3		4		5		
Asks Questions	7		4		2	5	1	1	1	1	Gives facts / instructions
More difficult to understand Qs	6		2		2	1	3		2	5	Easier to understand Qs & definitions
Think for yourself & forget	6	1	11		2	3	1	1		1	Just read & forget
Harder to study for exams as our answers written	7		1	1	3	1	4	1	1	3	Easier to study for exams
Forces you to think	11	1	3	2		1	3	1	1	2	Saves you thinking
Not structured	3	1	7		1		4	1	3	4	Structured
Gives you an opportunity to be a real scietist e.g. Fleming	4	3	10		3	2		1	1		Does not give you an opportunity to be a real Scientist
Gives you an opportunity to develop your thoughts	5	3	7		3	2	1	1			Doesn''t really develop your thoughts
Gives you confidence to be a scientist	7	1	5		2	2		2	5	1	Doesn''t really develop your thoughts

Legend:

Black = student chose this rating to indicate where they see the <u>workbook</u> on the construct;

Red = how the student would ideally like to see the workbook

Figure 5.4: How I as a Student see the Pedagogical Tool (N = 21)

Asks questions --- Gives facts / instructions:

Students see the workbook that supported IBL as one which mainly asks questions as opposed to giving facts and instructions. *Ideally, they would like to see it in the middle of the construct - as a mixture of both.*

More difficult to understand the questions asked --- Easier to understand the questions and definitions:

Most students view the workbook as being at or near the pole of 'More difficult to understand the questions asked'. *Ideally, they would like to see the workbook as being towards the opposite pole, which is 'Easier to understand the questions and definitions'*.

Think for yourself and forget --- Just read and forget:

Currently, students perceive the workbook to be near the pole 'think for yourself and forget' and ideally they would like to see it move towards the other pole with most students favouring the final location to be in the middle of the construct.

Harder to study for exams as our answers written --- Easier to study for exams:

At the moment students believe the workbook to be mainly towards the pole 'Harder to study for exams as our possibly inaccurate answers are written', although some believe it to be closer to the opposite pole. However, *the majority of students would ideally wish to see the workbook being at the opposite pole, 'easier to study for exams'.*

Forces you to think --- Saves you thinking:

The majority of students see the workbook as being a pedagogical tool that forces you to think. *Their ratings are evenly spread across the construct regarding where they would like to see it ideally.*

Not Structured --- Structured:

While some students view the workbook as being near the 'structured' pole, a greater number believe it to be at or near the 'not structured' pole. *Responses indicate that they see the workbook ideally being at the 'structured' pole.*

Gives you an opportunity to be a real scientist --- Does not give you an opportunity to be a real scientist:

Students perceive the pedagogical tool to be mainly at or near the pole that gives them an opportunity to be a real scientist. *Some ideally see this as the end of the construct at which to remain* but the rest (a minority) would like to see it move to the middle of the construct range.

Gives you an opportunity to develop your thoughts --- Don't really develop your thoughts:

Respondents view the pedagogical tool to be mainly at or near the pole that gives them an opportunity to develop their thoughts. *Some ideally see this as the end of the construct at which to stay located* but the minority of others would like to see it move towards the middle of the range of the construct.

Gives you confidence to be a scientist --- Gives you confidence to be a student for exams:

Most respondents view the workbook as being located on or near the pole 'Gives you confidence to be a scientist'. A sizeable minority believe it to 'give you confidence to be a student for exams. Ideally, most students would like to see it move toward the middle of the construct.

In summary, the above results indicate that the pedagogical approach using IBL is one that students perceive as forcing them to think and develop their thoughts. This is seen as being due to the fact it asks questions of learners rather than just 'gives facts'. It is therefore not surprising that students view the teaching and learning approach as giving them an opportunity to be a real scientist because it gives them confidence to do so. While it is gratifying that the affective dimension of learning is being acknowledged, a concern is helping them not forget after they have engaged in critical thinking.

5.2.2.2 Summative Exam Results

The results obtained by the intervention and control groups are given in Table 5.4 using the same exam as in phase 1, but with question 7 removed.

Table 5.2 Summary of Phase 2 Exam Results (N = 123)

Question No.	1	2*	3*	4*	5*	6*	N
% of Intervention Correct	50.0	71.4	57.1	26.2	42.9	14.3	42
% of Control Correct	45.7	22.2	19.8	8.6	13.6	1.2	81

* statistically significant at the .05 level using a Chi-squared test

Table 5.2 indicates that the intervention cohort out-performed the control cohort in all questions in the exam. There was a significant difference between the percentage of students in the intervention who were successful in answering Questions 2 to 6, in comparison to the control group.

The results comparing the intervention group in phase 1 with the intervention group in phase 2 are given in Table 5.3.

Table 5.3 Summary of Phase 1 versus Phase 2 Exam Results (n= 94)

Question No.	1	2	3	4	5	6	7	N
Phase 1 Intervention (% Correct)	71.2	67.3	42.3	28.9	36.5	7.7	21.5	52
Phase 2 Intervention (% Correct)	50.0	71.4	57.1	26.2	42.9	14.3		42

The above table shows that the Phase 2 cohort *did* advance their knowledge in comparison to that of Phase 1 in all questions apart from those of Questions 1 and 4. Question 7 is not considered as it was not undertaken in the Phase 2 exam. An examination of Table 5.2 in conjunction with Table 5.3 would suggest that the areas where improvements need to be made are Questions 1 and 4. With regard to Question 4, approximately 20% of the entire cohort of students associated the number of types of atom present in an element or compound with the mass number or the atomic number of an element that they associated with the question. This information was not given in the question but was stated in the periodic table they received with their exam script. In relation to both Question 1 and Question 4, students were <u>not</u> invited to draw their answers and this may have been inhibiting for them given their capacity to convey their ideas. Regardless, it was intended that the learning outcomes underpinning both questions should be the focus of the planning stage in Phase 3. General alternative conceptions in relation to the use of the incorrect inter-particulate distance, the inability to use symbols and the inability to distinguish between an atom and a molecule would also be included during the planning stage.

5.2.3 Adaptations and Implications for Phase 3

The modified classroom observational approach has allowed students' concurrent responses to the pedagogy to be captured in a more comprehensive manner. However, it is envisaged, that to obtain a greater degree of input from the repertory grids, the entire intervention cohort of the next phase be involved in the rating process. It is also desirable that this process employs numbers rather than symbols as measures of perception to move from an eyeball analysis approach to one where there is greater statistical rigour. This would be useful to help to inform the direction the pedagogy could go to improve its efficacy.

The impact of the pedagogical instrument is evaluated below in terms of:

- (relative) student performance in the PNM exam (described previously in section 5.2.3);
- students' view of themselves as scientists following their engagement with the pedagogy;
- students' perception of the pedagogy in relation to learning.

The repertory grid analysis points to empowering students to be confident as scientists and to persist rather than give up. This may be related to learners loving what they do (regarding science) and while they are prepared to take risk, this trait is tempered by caring for others. In terms of the pedagogy, students see it as encouraging them to ask questions, to think and develop their thoughts and gives them confidence to be a real scientist. An example of this from class is illustrated by: '*I gave the class 10 minutes to make their models and in the last 8 minutes each group presented their models. This class really love presenting which is great*' (Teaching Journal, 2012).

Curiously, they would like these traits to be moderated in relation to how they learn. This apparent tension may be due to the presence of a culture of high achievement in examinations being construed as a measure of success. Students also indicate that they find the questions in the workbook difficult to understand and they wish for it to be presented in a manner where definitions are easier to understand because it is harder to study for exams. They also call for it to become more structured in order to move towards where they view it ideally. It is evident that some of the features of repertory grid analysis can be described in terms of PCP transitional constructs such as 'aggression'. They also point to the acknowledgement of the affective nature of learning. The consideration of such phenomena as the work progressed led to the development of a model of conceptual change revealed in Chapter 8.

The length of the unit is a challenge especially as the time required for teaching and learning to occur using IBL is greater than the time required to teach some of the concepts in chemistry using the traditional avenue of instruction. However, Snir et al. (2003) argue that attempts to teach middle school students about PNM can fail due to students "*taking on too much, too fast*", thereby paying insufficient attention to critical conceptual issues. Hence, it is believed that sufficient time needs to be given to students to allow them to develop an understanding of this topic and that the pedagogy cannot be rushed. An example taken from the teacher's reflection illustrates this point in relation to student understanding of the water molecule. '*Students found it difficult to model three particles per water molecule and behave in a uniform fashion i.e. to remain together as a trinity in a molecular unit'* (Teaching Journal, 2012). Therefore, the molecular structure of water was included to guide students in phase 3 of the workbook. Due to reflections like this, role-play activities can then evolve pedagogically. An example is, '*The human modelling exercise was powerful and it really helps"* attests to their efficacy in relation to learning' (Teaching Journal, 2012).

Simultaneously, it is viewed that this pedagogical style allowed both teachers who taught the intervention group (including the author) to evolve in the direction that Bodner and Klobuchar (2001) describe as moving from 'teaching by imposition to teaching by negotiation'. An example of an instance such as this is '*most of the class was spent doing group-work by the students with the teacher guiding intermittently'*

(Teaching Journal, 2012). Also, the teaching conducted while using the IBL approach meant that our role became increasingly diagnostic and aligned with the vision of Driver and Leach (1993), where there was an emphasis on listening to students in order to understand their thinking.

An intervention may follow, if and when appropriate, with suggested ideas to assist learners to help them to reduce their explanatory incoherencies and move towards a conceptual affinity with scientifically acceptable models. Because of the nature of the pedagogy, 'listening to students' included 'observing' their models.

It was noticed that it was an oversight to include mercury specifically as the model in the exercise in the workbook in Phase 2 as mercury was also used as the atomic model in Question 1 of the PNM exam. It would have been better to use a different element in the question. Also, in relation to the exam, Driver and Leach (1993) advise that it is important to know about learner's likely conceptual starting points. The nature of the analysis of questions in a categorical manner does not recognise starting points, or indeed, the conceptual pathways that students may use as they answer questions. In this sense, the analysis is blunt and requires modification to move beyond the scope of marking students right or wrong in a binary fashion. To reward the attempts that students are making to answer questions in the exam, and gain an insight into how they reason as they answer questions, another approach is required. Firstly, the nature of the marking needs to move from categorical to ordinal. Secondly, a cognitive psychology needs to be invoked to attempt to understand how students think *in an exam situation*. However, Kellyian psychology has served this work thus far, by assisting in the provision of student insights regarding the pedagogical tool and their construal of themselves as scientists. Therefore, the author will 'return to the well' and attempt to use PCP to meet the challenge of modelling how students reason as they navigate questions in a PNM exam. This new direction may serve to identify learning gaps in student mental models which could be provided as feedback to assist in their learning in future. Meanwhile, it is envisaged that a new PNM exam should be developed in which students need to be more reliant upon their *conceptual* understanding and are asked to *explain* their answers. The assessment of such an exam may prove more revealing regarding students' (alternative) conceptions than the approach used in the first two phases. Currently, exam Questions 1 and 4 may allow students to guess the answer(s) because there is no need to provide such an explanation.

5.3 Conclusion

The question: ‘Can an Inquiry-based Learning approach to the PNM that includes modelling and visualization among junior second level school students serve to increase their conceptual understanding?’ was posed at the beginning of Phase 2. Analysis confirms that this is true in the majority of the questions asked of students in the PNM exam. It also suggests that the students who engage with this pedagogy have a more elaborate understanding of the area of PNM than the intervention group. Therefore, it seems reasonable to continue with this work and allow it to be carried on into (the subsequent) Phase 3. At this stage of the cycle, the question that will be asked is:

‘Can an Inquiry-based Learning approach to the PNM that includes modelling and visualization among junior second level school students serve to increase their conceptual understanding?’ A relevant secondary question that will be asked is: ‘Can learning gaps be identified in the assessment of student mental models following an IBL approach that enhances their learning of PNM?’ These may be blended into one over-arching question:

‘Can I continue to use IBL as a pedagogy to increase student competence in comprehending the area of PNM while developing a framework of understanding that has the potential to reveal learning gaps in students’ knowledge?’

CHAPTER 6: FINAL ANALYSIS: PHASE 3

Introduction

The previous chapter focused on how the practical development of an educational intervention over two phases was carried out. It involved quantitative and qualitative analyses, which were combined in a triangulation process that served to enhance the conceptual understanding of the PNM among junior second level school students. PCP as an adjunct to action research methodology was applied in Phase 2. The gap between the author's espoused and lived values, as a science teacher, was considered. Students who undertook IBL demonstrated a greater conceptual understanding of the PNM than their counterparts who did not. This chapter focuses on the practical nature of the further development and delivery of the pedagogical instrument rooted in IBL using the same methodological approach. It details how the artefact used as this instrument has evolved over the course of the first of the final two (of four) Practitioner Action Research phases. This set of two phases is referred to as the 'Final Analysis' stage of the study. The development of an (exploratory) evaluation tool to analyse student explanations and understanding in this phase is also provided. This is done using the lens of PCP, with a view to the provision of better feedback to learners regarding their thinking around PNM.

6.1 Reflections and Adaptations for Phase 3

In order to plan the development of an evaluation tool, the author drew on Liu and Lesniak's (2005) citation of Strauss (1998) who had called for active interactions between science education and psychology. Interestingly, Gilbert (2005) specifically indicates that as of over 25 years ago, the British Association for Science Education suggested that alternative models of psychology, such as that of George Kelly (1955), should be considered for their implications with respect to science education.

Varelas et al. (2006) point to a need for increased sensitivity to understand, *what* sense learners are making. Regan et al. (2011) acknowledge on the other hand that, while learners attempt to establish meaning, alternative conceptions among them can be allowed to persist. However, Talanquer (2012) argues that focusing on dispelling specific alternative conceptions may be unproductive if the underlying *ways of reasoning* are not elicited, and challenged. Siry (2013) also acknowledges the need for going beyond simply documenting what learners know (or don't know), and cites Fleer (2009) as describing their concept formation in terms of dynamic processes which may offer a "new direction for science education research". Consequently, Talanquer (2012) notes educators have the responsibility to carefully analyse their knowledge about learning and teaching. He claims, in this regard, *dichotomies* are powerful because they help us discriminate and therefore simplify the analysis of complex systems such as the cognitive domain. Similarly, George Kelly's Theory of Personal Constructs (1955/1991) acknowledges the dichotomous nature of ideas. In a PCP context, while constructs involve difference making, they are also dynamic in nature since they have an inter-locking function (with each other) as learners predict outcomes. Thus, an individual tries to orchestrate constructs properly to make sense e.g. a student in relation to a problem scenario or a teacher in relation to student thinking.

Pope and DeNicolo (2001) describe Kelly as taking the epistemological view that the student is an active meaning-seeking individual in this process. It is an optimistic stance that does not impose theories on learning that may be restrictive e.g. many have argued that the concepts introduced in school are too abstract for students to deal with at their stage of cognitive development (Regan et al., 2011). If Pope and DeNicolo's (2001) view of *'concepts'* as formal (publicly accepted) meanings is considered in the context of the Gilbert's (2005) description of a '*conception*', as something being accessed by a person in response to a particular question, then a link can be established between the two terms. This is achieved by acknowledging that *'conceptions'* are part of the act of perceiving or construing an idea or *'concept'*. Thus 'conception' is used to refer to the personal understandings of an individual. In this way, Ravenette (1999) argues that a conception arises out of the process of 'construing', which means to place an interpretation on or give meaning to, the concept that one construes. The axis used to discriminate between concepts, events or experiences is known as '*construct*'. It is a measurable dichotomous bipolar concept in that it has two opposite ends called poles. By scrutinizing how constructs interlock, a teacher may be allowed to 'walk in his / her students' shoes (Kelly, 1955/1991) and gauge where the gaps in their learning are. Talanquer (2013) posits that such analysis of the subject matter based on conceptual dimensions could help teachers recognise areas (in the curriculum) that need more attention. Pope and Denicolo (2001) refer to such an approach as central to illuminating the rich diversity of meanings that participant learners have in relation to events.

To obtain a perspective from which predictions of events are being made by students, according to Gilbert (2005), frameworks focus upon a characterization of (student) responses. Where there is a group of many students, he indicates that to generalise beyond the individual is to construct groupings of responses, which are construed as having similar intended meanings. This is to construct a category of responses commonly in the context of a specific set of questions.

This process can involve examining students' open-ended responses in order to begin to diagnose students' thinking and *conceptual* understanding of PNM (Nyachwaya et al., 2011). In the context of this study, open-ended responses include drawings. In this phase features of such explanations common to the answers provided will be considered and will then be framed in terms of constructs representative of the answers provided by the student body. This approach acknowledges Kelly's fundamental postulate, which states, peoples' psychological processes are channelized by the way they anticipate events. Thus, the focus falls on the constructs (the ways) used by students to anticipate the events (the questions). The processes are the construals students undertake when they are invited to think and increase their range of understanding. Factors affecting these construals were described in more detail in Chapter 3.

Two key adaptations underpinning this phase are (a) dialogic approach and (b) development of workbook learning content. Each are considered below.

(a) Dialogic Approach

The approach described in this section aims to create further opportunity for a conversational flow between student and teacher around modelling. It attempts to build on the use of questions in IBL recommended by Oliveira (2010). Pope and DeNicolo (2001) advocate fostering educational outcomes in the context of student learning. Varelas et al. (2006) suggest that a dialogic approach fulfils a need to have genuine conversations about one's attempts to understand. This may be achieved by framing the areas of discussion around a variety of activities (including doing hands-on explorations, writing, drawing, discussing). In this way, teacher and students share the power and the burden of making meaning. Treagust and Duit (2008) indicate that discourses may take the forms of a student's discussion with a teacher, student-student interactions and group discussions (whether doing the talking or not) in order to achieve an enhanced mental model. This is essential for the quality of the learning outcomes. Such discourse allows the dynamic of change, from possible alternative conceptions to the scientifically accepted concept to occur in a non-traumatic way where alternatives are represented. In such an environment, Criswell (2012) describes students as fulfilling their value as assets to each other where their thoughts may become capital off which to build their solutions. In the view of Taber (2013), student dialogue serves to allow a moderation process to occur, and potentially the coming to a consensus.

Echoing and affirming the emphasis previously in Phase 2 where the teacher supports the students in modelling, Siry (2013) argues that the teacher's mediation is central through careful, patient, facilitation while allowing students explore new concepts and processes. In such a way, a "synergistic relationship" may evolve. Criswell and Rushton (2012) suggest that different ideas may arise within a group and that students will have to negotiate and perhaps argue with each other about the validity of these ideas until a "consensus" is reached. Prain and Tytler (2013) indicate that this engagement enables communal knowledge to be built, defended and established. In these actions, Talanquer (2012) indicates that students actively engage in high-level reasoning activities, such as building models, generating arguments, and constructing explanations on selected topics. According to Talanquer (2013), over time model-based reasoning involves revising models to increase their explanatory and predictive power. Erduran and Duschl (2004) point to features of focusing on model refinements as including typically the properties shared and not shared between models, between a model and the phenomenon that is modelled, and the relationship between the model and the actual entity. Prain and Tytler (2013) note that the essence of this teaching and learning approach via modelling, involves teachers facilitating the construction and refinement of representations (of phenomena) through coordinated public discussion of their explanatory adequacy. In doing so the teacher brings classroom science closer to the knowledge-building practices of science itself. Indeed, students responding to the repertory grid in Phase 2 saw their engagement with the pedagogical tool as being one which 'Gives you the opportunity to be a real scientist' rather than the opposite. The genuine nature of this experience was echoed by their response that it 'Gives you the confidence to be a scientist' rather than 'Gives you confidence to be a student for exams'. Prain and Tytler (2013) explain that this epistemological approach allows students come to know in science through the negotiation and refinement of (multi-modal) representations and through validation. It allows individuals to build personal meanings and understand the conventions of modelling in a topic area. This approach leads Michalchik et al. (2008) to claim that the role of the teacher is critical in the classroom ecology, central in both leveraging the value of the multiple representational forms and in the design of the learning activities.

(b) Development of Workbook Learning Content

As students who engaged in repertory grid interviews pointed to questions in the workbook as difficult to understand, it was decided to project more questions from the workbook on the data projector so that, if required, the questions could be subject to whole-class clarification. It is worth noting that the unmodified material in the workbook in Phase 3 is retained for the same reasons as mentioned in previous planning stages. However, a description of the areas that <u>were</u> altered and the reasons behind their modification are given.

A space for students to take their own notes was provided at the end of each chapter of the workbook. This was done as a result of the claim by Gabel (1999) that *without reflection* on information in long-term memory, alternative conceptions present remain unaddressed and additional information is not integrated into the cognitive structure as knowledge. *With reflection* students examine alternative conceptions, revise their existing understanding and re-store it in a more integrated way that is in better accord with accepted scientific thinking. Hence, new information entering the memory may be linked to information already present to form a coherent system of concepts that enhance problem-solving. Yenawine (2012) holds that in order to help students become committed to monitoring conceptual self-growth, they should reflect on what they know already as individuals. This approach promotes self-assessment which is an inquiry skill. Finally, the majority of respondents to repertory grid interviews in Phase 2 saw the workbook as unstructured and the 'Ideal' workbook as being structured. This reflective space at the end of each chapter was intended to allow students to structure their thoughts regularly in a timely fashion.

In addition, in terms of structure, sequential numbers were tagged to each question to indicate which chapter the question referred to e.g. 1.1, 1.2 etc. and to serve as a tracker, allowing navigation and progress through the chapters to be gauged.

There was an increased emphasis on the nature of the patterns in the states of matter. This was due to the observation by Treagust et al. (2011) that the spacing of particles in the three states of matter are often depicted in a distorted manner in textbooks, whereas the scientifically accepted ratio of 1:1:10 applies to the spacing between particles in solids, liquids and gases (de Vos and Verdonk, 1996). Unfortunately, this discrepancy continues to be perpetuated among students when their teachers inadvertently overlook the relative spacing in particle diagrams. Treagust et al. (2011) cite an Australian study where students assumed that particles in a solid were in contact with each other. Sanger (2000) also notes that intuitive ideas concerning the nature of matter, acquired by students in their early years of schooling, generally fail to change to scientifically acceptable understandings. In order to prevent this phenomenon occurring, he advises defining the attributes for gas samples as particles that occupy the entire space of the container and are as far apart from each other as possible while for solid and liquid samples, the particles are much closer to each other. In terms of structural appearance, Sanger (2000) indicates that in solid samples particles show some kind of organisation or a repeating pattern. Particles in liquid samples, on the other hand, are randomly distributed and do not show organised patterns. The phase 3 workbook includes an emphasis on using arrows connected to particles of matter to make them appear dynamic in nature.

The state of matter that received increased attention in this iteration of the workbook was that of liquid. This was due to student exam performance with respect to representing liquids in phase 2 and the following observation: *'(students) found liquids the hardest to model'* (Teaching Journal, 2012). To this end, and in respect of solids and gases, (hard-copy) animations were developed with grid lines and letters for each animation frame displayed to assist students in gauging the level and direction of particulate movement. Numbers were also featured on the inside of each particle visible in the frame to act as a tracker for learners.

There was a continued emphasis on PhET as a simulation tool. This is due to its design approach which allowed for flexible use in a lesson by enabling support through a range of 'external guidance' styles. This conferred freedom upon the author firstly, to use the simulations as the foci for learning activities in three locations within the workbook and secondly, frame them with directions and questions of his own that were perceived to enhance student understanding. The addition of the PhET simulation exercise was intended as an opportunity to visually integrate the names of the changes of state in matter and the corresponding behaviour that occurs at the particulate level. This was intended to extend the range of visual opportunities that students were afforded to make such conceptual links. It is related to the observation regarding a demonstration that '*When probed about what happened (demonstration of acetone evaporating), students gave two main replies –"it soaked into your skin" or it "evaporated'* (Teaching Journal, 2012).

Emphasis on the particulate level was increased to offer a visual opportunity for learners to *meaning-make* conceptually with regard to that phrase in the definition of a compound that states, "…elements are <u>chemically combined"</u>.

An additional chapter was introduced into the workbook (as Chapter 13) to emphasise the symbolic level. All of the questions within the chapter represent previous students' alternative conceptions so that learners can extend their knowledge to link the symbolic and the particulate. The introduction of this chapter was prompted by the entry: '*Students then moved onto the 'Collect Multiple'* *tab and built multiple molecules. A number of groups found the building of two ammonia molecules difficult and for some reason, placed the nitrogen atoms adjacent to one another as an N_2 molecule and tried to build 6 hydrogens around this pair. When they overcame this barrier, there was a minor epiphany for some people who exclaimed that they now understood the concepts of atoms, molecules, elements and compounds'* (Teaching Journal, 2012).

Finally, there was a continued emphasis on the iterative nature of occurrence of themes in the workbook where they would be re-visited at a later time.

6.2 Implementation and Evaluation of Phase 3

The following section describes the implementation of the teaching units aimed at increasing the knowledge of students in the PNM in phase 3 (shown in Figure 6.1). Figure 6.1 emphasises the continued implementation of the practitioner action research cycle. Phase 3 involved 119 mixed-ability students, of which 99 were taught by four teachers and represented the control group. The remaining 20 were taught by the author and represented the intervention group. These groups were randomly assigned to their respective teachers. A third iteration of the workbook was developed for the intervention group based on the reasons previously discussed.

Two evaluation tools were developed (see Section 6.3) to evaluate student understanding of PNM during and at the end of the phase. These were represented by summative and diagnostic assessments. The diagnostic assessment was only taken by the intervention group. The rationale for developing questions within these tools that had a greater emphasis on drawing and conceptual problem-solving is described in the Section 6.4. A further level of evaluation was conducted by detailed consideration of these analysis components.

Written observations of classroom events in relation to students' engagement with the pedagogical instrument were recorded in a reflection journal by the author while teaching the intervention cohort. There was an attempt to capture the affective and cognitive nature of experience of learners as they responded to problems in groups with a view to facilitating the planning of Phase 4.

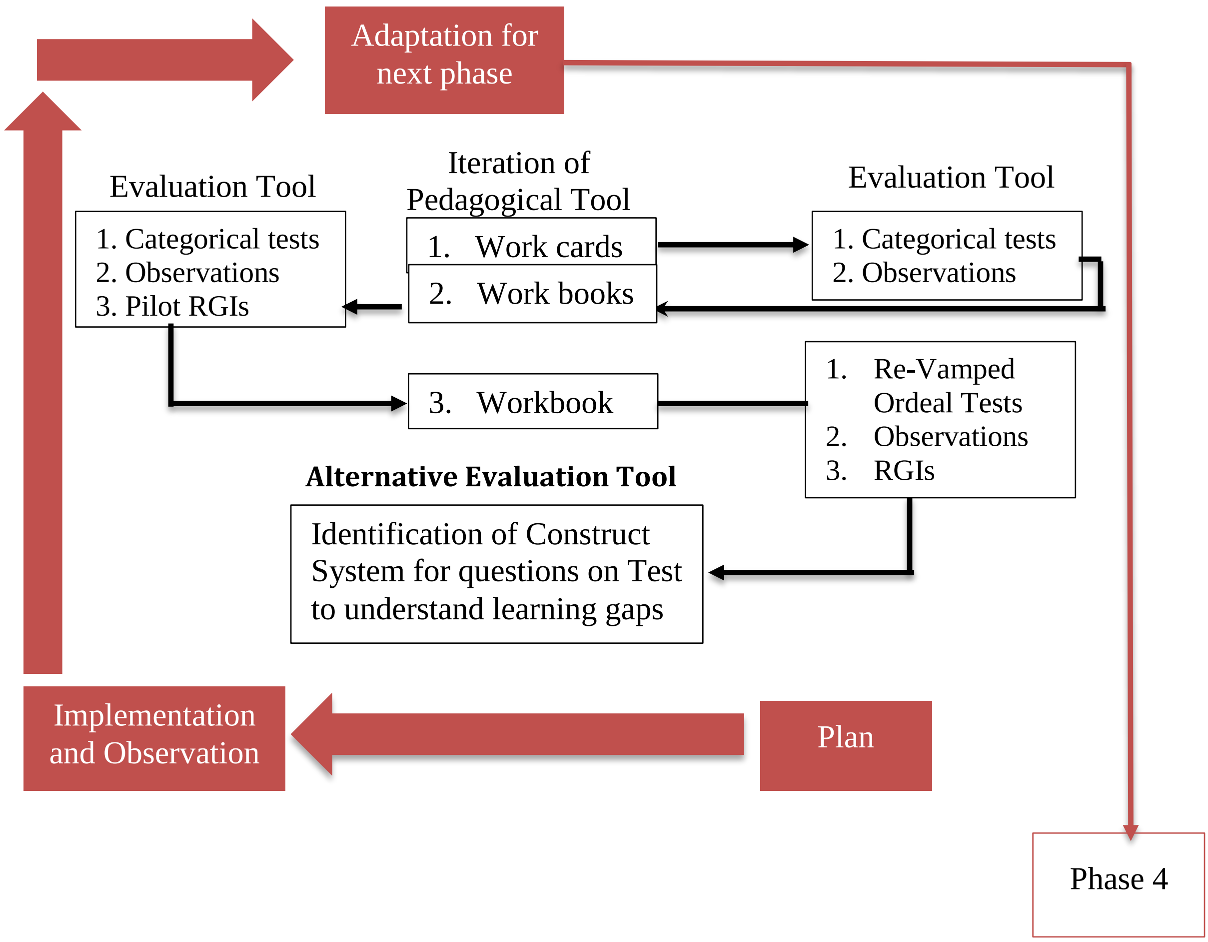


Figure 6.1: Practitioner Action Research Cycle Phase 3

6.3 Development and Analysis of Diagnostic and Summative Assessments

The following section provides the rationale for the development and analysis of assessment tools used for phase 3.

Diagnostic and Summative Assessments

The traditional stance on assessment in chemistry is highlighted by Nurrenbern and Pickering (1987) who note that Chemistry educators have assumed that being able to solve problems is equivalent to understanding molecular concepts. Later, Pickering (1990) concluded that to solve a problem, while desirable in itself, does not imply much actual understanding of the particulate level. This is because of what Sawrey (1990) describes as a 'Drill-work' problem solving campaign in education leading to the neglect of the qualitative and conceptual side of the discipline. Hence, students have far more success solving traditional questions than conceptual questions. Nakhleh and Mitchell (1993) argue that this is because the chemical concept behind the problem (if algorithmic in nature) is not sought.

They cite as an example, the lack of knowledge of concepts related to chemical formulae subscripts evident through conceptual questions asked of entrants to undergraduate studies in chemistry. Cracolice et al. (2008) acknowledge that a measure of success in an algorithmic problem may be attributed to the direct use of a set of procedures in conjunction with rote-memorisation. However, a conceptual problem requires students to navigate it successfully by working from an understanding of a concept *to* a solution without an emphasis on memorisation. Reasoning skills as opposed to 'plug and chug' strategies need to be invoked (to solve conceptual problems). As the pedagogy used in the workbook was rooted in Guided Inquiry Based Learning, it requires students to engage with learning conceptually, rather than at a level where they were simply required to recite facts. Thus, the focus of, and the reason underpinning the assessment in this work continued to be the determination of the conceptual understanding students had in the area of PNM. It is of note that this represents a departure from what Gabel (2003) describes in terms of the wider context of teaching and learning in chemistry. Here assessment (and instruction) has traditionally focused exclusively on symbolic representations, assessing knowledge of definitions and the ability to recall facts rather than testing for 'conceptual' understanding of the discipline. Hence, Nyachwaya et al. (2011) claim that it has been often reported that many students could correctly answer conventional examination-type questions yet fail to demonstrate genuine conceptual understanding upon further probing.

When drawings were used to assess understanding, students had to provide an explanation of the reason for their choice of drawing. The advantages of drawing for learning have been already described in Section 2.1. However, it is worth noting its value in terms of the assessment of student learning. Nyachwaya et al. (2011) reason that as students have to consider alternatives regarding how to represent particles (while drawing), students' internal representations of particle models may be assessed with a higher validity. Hence, while drawn and written forms of explanation both have their place, it is the view of the author that when drawn <u>and</u> written forms of explanation are coupled in a question, they can be used to complement each other.

The diagnostic assessment took place for the intervention cohort during class within the time range that students were engaging with the pedagogy. Summative assessment formed a component of the overall end-of-term summer exam which was undertaken by all students.

It is helpful to discuss the nature of the questions developed in the above written and drawn assessments using conceptual, causal and procedural labels.

- Machamer (2007) claims that conceptual knowledge involves storing and organising simple factual knowledge into useful clusters. This may function to provide an in-depth understanding of the interrelations among pieces of knowledge in an area.
- Heyworth (1999) describes procedural knowledge as involving the use of a strategy to guide the search for a solution procedure starting from the initial state of the problem (the information and data given) through to the goal state (the required answer) by applying concepts. Machamer (2007) refers to this form of knowledge as *knowing how,* e.g. strategies for solving jigsaw puzzles, applying a concept to differentiate two changing quantities.
- Schneider and Stern (2010) note that causal relations can exist between conceptual and procedural knowledge.

Analysis - The Development of Construct Systems to Model Reasoning

As the marking scheme evolved from being *categorical* in nature (in Phases 1 and 2), into one that became a more (statistically) useful *quantitative* entity, it was deemed helpful to decide on how to fairly assign marks for the variety of answers to each exam question in Phases 3 and 4. In order to anticipate scores awarded for student answers, the author viewed the development of a hierarchical construct system based on the pool of learner responses as a natural fit for this purpose. In this case, the processes were the constructs representing student ideas evident in the answers while exam questions represented the events. Students would receive a discrete mark according to the construct pole representing their answer. It was envisaged that each framework (construct system) could also serve to indicate alternative conceptions held by students and the conceptual pathways they may have followed to arrive at them. Students were required to construe in order to move along these pathways. It is worth noting that this approach represents a process of secondary construal i.e. the author is construing the construal paths of the learners. The assumption that a group of students can construe in a similar way arises out of Hewson's (1992) assertion that, as the knowledge construction process is influenced by a variety of social experiences e.g. social agreements about meaning, knowledge constructed by individuals is not normally personal and idiosyncratic in nature.

In cases where students were (partially) unsuccessful in answering a question, it was decided to use a novel concept named here as 'Critical Differential Poles' to measure the 'learning gap' that existed between one construct and another. In this way, the reasons for gradations of knowledge could be tracked. For simplicity, the construct systems appear with the preferred pole to the left hand side of the table and each row of a table represents a construct. For presentation purposes, 'IPD' referred to in the 'Critical Differential Pole' column refers to 'Interparticulate Distance'.

The construct table may be more easily read from bottom to top. This direction shows increasing levels of comprehension. It is also helpful to read the table from right to left. There is a juxtaposition of poles from the opposite ends of a construct. The capacity of a pupil to experiment successfully out of a hitherto preferred pole means the reader can move up a level. The inquiry being conducted by the student is not purposeless but is carried out to form a hypothesis. The construct poles are stopping points on a journey of comprehension and are reflected in the Kelly (1955/1991) Experience Cycle. Although primarily a cyclical illustration of *experience*, it appears also to fit the purpose of a learning cycle. A good scientist will find a lower level construct inadequate and will look to explore to move their construing up a level in order to increase their range of understanding and extend their construct system. The top-most tier of this table is the learning destination to which one attempts to guide students as a teacher of science.

It is worth noting that the relative success levels attributed to answering a question did not correspond to marks in numbers that were in a regular pattern of descending order such as 5, 4, 3, 2, 1, 0. Instead, marks were weighted in an irregular pattern such as 5, 3, 2, 1, 0. This was not pre-ordained but reflected the efforts made by students to reach each construct level.

The author and another chemistry educator, both experienced in chemistry education, coded all sets of student responses to each question in each exam. All answers including drawings to each question were observed carefully, compared, and assigned tentatively to one of a set of groups of marks that emerged from the responses. Once all of the answers to each question were categorised, all responses were observed again to ensure consistency in the definition of each class and to verify category membership. This inductive process frequently led to the reformulation of some of the groups of explanations and to the reclassification of some responses. It also led to the recognition of 'critical differential poles'. The author then coded the entire data set. The codes were then re-checked against students' work and ultimately verified as consistent.

6.4 Question Detail of Diagnostic and Summative Assessments

The following section gives the actual questions used in the diagnostic and summative tests, including the rationale for each question, the construct systems that arose for each question and the marking scheme used in the evaluation of each answer. Table 6.1 summarises the sequence of the questions in each assessment. This information is presented above a construct system that characterises student thinking in response to a given question. A marking scheme that describes how the construct system evolved is also illustrated. This scheme contains samples of students written and drawn work

Table 6.1 Questions used in Diagnostic and Summative Assessments

Diagnostic Assessment			Summative Assessment		
Question no.	Construct System	Marking Scheme	Question no.	Construct System	Marking Scheme
1	Table 6.2	Table 6.3	1(a)	Table 6.26	Table 6.27
2	Table 6.4	Table 6.5	1(b)	Table 6.28	Table 6.29
3(a)i	Table 6.6	Table 6.7	1(c)	Table 6.30	Table 6.31
3(a)ii	Table 6.8	Table 6.9	1(d)	Table 6.32	Table 6.33
3(a)iii	Table 6.10	Table 6.11	1(e)	Table 6.34	Table 6.35
3b	Table 6.12	Table 6.13	2	Table 6.36	Table 6.37
4a	Table 6.14	Table 6.15	3(a)	Table 6.38	Table 6.39
4b	Table 6.16	Table 6.17	3(b)	Table 6.40	Table 6.41
5(a)	Table 6.18	Table 6.19	4	Table 6.42	Table 6.43
5(b)	Table 6.20	Table 6.21	5	Table 6.44	Table 6.45
7	Table 6.22	Table 6.23			
8	Table 6.24	Table 6.25			

Analysis of Diagnostic Assessments:

Question 1: *Blown up balloon with 5g of air in it was brought into a room to help decorate it for Martina's birthday. The balloon burst and the air inside was released into the room. The room already had 1,650g of air in it – did anything happen to the mass of the air in the room? Explain if you think something did happen.*

What ____

Reason ____

Question1: *The above question related to the law of conservation of mass in a familiar event where students could answer yes or no to the initial question but needed to address the causal nature of the demand by providing an explanation for their answer.*

Table 6.2: Diagnostic Exam Question 1 Construct System

	SUPERORDINATE CONSTRUCT: STUDENTS CONVEYED A SPECIFIC QUANTITATIVE UNDERSTANDING OF THE CONSERVATION OF MASS. THEY HAVE DISPLAYED SCIENTIFIC PROTOCOL AND DETAIL WITHIN THEIR ANSWER.		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
Increased Comprehension	Student conveyed the additive nature of the diffusion process and can convey it both qualitatively and quantitatively.	Student understands diffusion and gives quantitative and partial quantitative detail regarding law of conservation of mass.	Full Quantitative grasp.
	Student understands diffusion and gives quantitative and partial quantitative detail regarding law of conservation of mass.	Apparent understanding of diffusion with possible alternative understanding of the law of conservation of mass.	Absence of Quantitative grasp (Addition operator not employed).
	Apparent understanding of diffusion with possible alternative understanding of the law of conservation of mass.	Alternative understanding of diffusion and the law of conservation of mass.	Absence of Qualitative grasp.
	Alternative understanding of diffusion and the law of conservation of mass.	No understanding of the Law of Conservation of Mass.	No understanding of Diffusion.

Table 6.3: Diagnostic Exam Question 1 Marking Scheme

MARKING SCHEME	GRADE
• Students were able to convey a specific quantitative understanding of the conservation of mass. Written Examples: • 'Air escaped from the balloon and diffused into air in the room'. • 'The number of Grams increased by 5g i.e. 1,650g + 5g = 1,655g'.	**5mks + 5mks**
• Student has displayed a lack of acknowledgement of scientific protocol or detail within their answer[a]. • Student understands the additive nature of the process but portrays a mainly qualitative understanding[b]. Written Examples: • 'Number of grams increased'[a] or 'Mass increased'[a] • '5g of air came into the room'[b] or '5g of air came into the air'[b] (space in receipt of 5g specified) or '5g got added'[b].	**5 mks +3mks**
• Student appears to understand diffusion and gives some qualitative detail but lacks any quantitative perception [c]. • Additive nature of process not recognized. Written Examples: 'Yes' [c] [Not at all specific] or 'Air is released into the air' [c] or 'The air mixed [c].' '5g released'[d] [not specified to where]	**5mks**
• Student has an alternative understanding of the law of conservation of mass. Written Example: 'Nothing happened'	**1mk**
• Blank	**0mks**

Question 2: *When particles of a substance move really fast, what is causing this to happen? Explain.*

What ____

Reason ____

Question 2: *The question required students to provide a factual answer regarding the phenomenon causing increased particulate movement i.e. increased temperature, followed by an explanation to the cause of this event. Students need to be able to relate increased temperature to increased energy. Therefore, in its entirety, the question is causal.*

Table 6.4: Diagnostic Exam Question 2 Construct System

	SUPERORDINATE CONSTRUCT: STUDENTS UNDERSTAND THE ROLE OF ENERGY IN MOVEMENT AND CAN RELATE RELATIVE PARTICULATE MOVEMENT TO RELATIVE TEMPERATURE		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
Increased Comprehension	Can relate the relative level of particulate movement to the relative Temperature.	Understands that temperature is related to particulate movement but fails to allude to the proportional nature of the relationship.	Principal clause used regarding causal factor
	Understands that temperature is related to particulate movement but fails to allude to the proportional nature of the relationship.	Appears to understand the temperature is related to particulate movement but is unsure how.	Lack of qualitative detail regarding causal factor.
	Appears to understand the temperature is related to particulate movement but is unsure how.	Substitutes a causal factor (such as force) or non-causal factor such as 'gas' in for Temperature.	Substitution of alternative idea.
	Substitutes a causal factor (such as force) or non-causal factor such as 'gas' in for Temperature.	No understanding of the concept of Energy in relation to movement.	No understanding of the concept of Energy.

Table 6.5: Diagnostic Exam Question 2 Marking Scheme

MARKING SCHEME	GRADE
• Students acknowledge that energy causes particles to move and uses a principle clause. Written Examples: • The hotter, the quicker it moves'.	5mks + 5mks
• Student does not give detail around the degree of temperature and fails to distinguish between hot and cold temperatures. • There is no principal clause used. Written Example: • 'Temperature causes movement'.	5mks + 3mks
• Student mentions the word 'temperature' but in the incorrect context and does not understand the relative effect of temperature. Written Example: 'Cool temperature'.	5mks
• Student does not mention the word 'temperature' Written Examples: • 'Force' / 'Gravity'/ Pressure. [a] 'Gas'.[b]	1mk
• Blank	0mks

States of matter of iron	**Question 3a.** *What 6 particles of iron would look like in the solid state. Use arrows to indicate amount and direction of movement.*	*One particle of iron looks like…* Fe

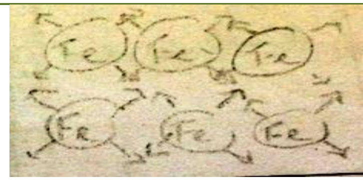
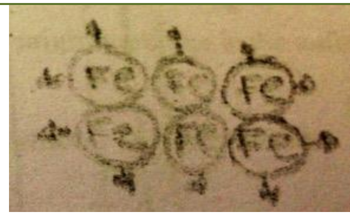
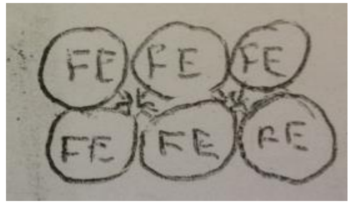
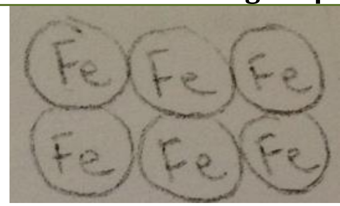
Question 3(a)

The question asked students to draw iron at the particulate level in solid, liquid and gas phases. They need to use procedural knowledge to apply the factual knowledge they have regarding the behaviour of all states. It is specified that arrows should be used to provide dynamic illustrations.

Table 6.6: Diagnostic Exam Question 3a Solid Construct System

<table>
<tr><td rowspan="6">↑ Increased Comprehension</td><td colspan="3">Superordinate Construct:
Students understand the role of Energy in movement and can relate relative particulate movement to relative temperature.</td></tr>
<tr><td>Preferred Pole</td><td>Non-Preferred Pole</td><td>Critical Differentiation Pole</td></tr>
<tr><td>Full understanding of the portrayal of the solid state at particulate level.</td><td>Full understanding of the portrayal of the solid state at particulate level (excluding the inclusion of a small interparticulate distance).</td><td>IPD (Absence of).</td></tr>
<tr><td>Full understanding of the portrayal of the solid state at particulate level (excluding the inclusion of a small interparticulate distance).</td><td>Partial understanding of how to convey the solid state at particulate level.</td><td>Range of (appropriate) features depicted.</td></tr>
<tr><td>Partial understanding of how to convey the solid state at particulate level.</td><td>Substitutes solid state with another state of matter or particulate representation level with the macro representation level or particles of iron with other particles.</td><td>Substitution of Question features.</td></tr>
<tr><td>Substitutes solid state with another state of matter or particulate representation level with the macro representation level or particles of iron with other particles.</td><td>No understanding of solid particle behaviour at the particulate level.</td><td>No understanding of how to represent the solid state at the particulate level.</td></tr>
</table>

Table 6.7: Solid Drawings of Iron Particles Marking Scheme

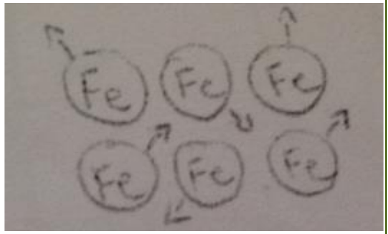
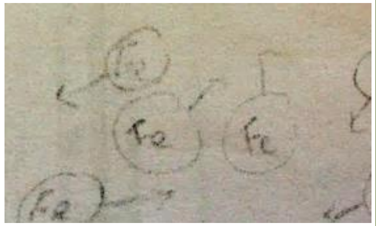
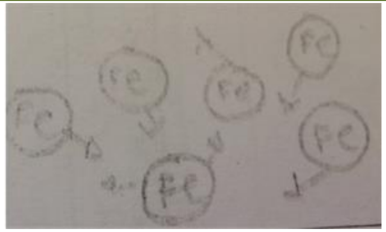
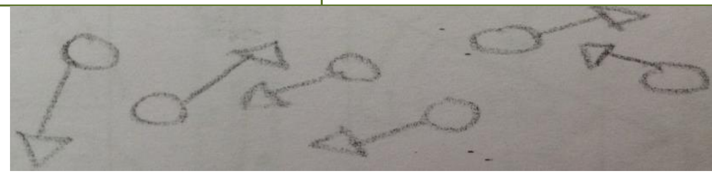
Grade	**Marking Scheme**	*Illustrated Example*	
5mks	Student is able to display a solid in a drawing, which includes <u>all criteria from</u>**:** Randomly directed arrows, a small level of movement that is vibrational in nature and smaller than for a liquid, visible iron symbols, similarly sized particles and a **little** inter-particulate space (between approximately 75% of particles) – see Figure α1.	 **Figure α1**	
4mks	Student is able to display a solid in a drawing, which includes <u>all criteria from</u>**:** Randomly directed arrows, a small level of movement that is vibrational in nature and smaller than for a liquid, visible iron symbols, similarly sized particles **but no** inter-particulate space (actually incorrect in absolute terms) – see Figs. β1 & β2.	 **Figure β1**	 **Figures β2.**
3mks	Student drawing illustrates **no** inter-particulate space and includes **any 1 of the following criteria:** randomly directed arrows, a small level of movement that is vibrational in nature and smaller than for a liquid, visible iron symbols, similarly sized particles – see Figure γ1.	 **Figure γ1**	
1mk	Students attempt may indicate their inability to accurately depict the particulate level behaviour of the solid state. Examples: include the drawing of: the incorrect state, overlapping atoms of iron, a distorted particle shape, the macro version or a solid lattice		
0mks	Blank		

States of matter of iron	**Question 3a.** *What 6 particles of iron would look like in the liquid. Use arrows to indicate amount and direction of movement.*	*One particle of iron looks like…* Fe

Table 6.8: Diagnostic Exam Question 3a Liquid Construct System

Increased Comprehension	**SUPERORDINATE CONSTRUCT:** Students could demonstrate a complete understanding of how to portray the liquid state at particulate level by accurately displaying all requisite features of this state in their diagram.		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
	Full understanding of the portrayal of the liquid state at particulate level.	Full understanding of the portrayal of the solid state at particulate level excluding an accurate interparticulate distance.	IPD (too large).
	Full understanding of the portrayal of the solid state at particulate level excluding an accurate interparticulate distance.	Partial understanding of how to convey the liquid state at particulate level including an alternative interparticulate distance.	Range of (appropriate) features depicted.
	Partial understanding of how to convey the liquid state at particulate level including an alternative interparticulate distance.	Substitutes liquid state with another state of matter.	Substitution of Question features.
	Substitutes liquid state with another state of matter.	No understanding of liquid particle behaviour at the particulate level.	No understanding of how to represent the liquid state at the particulate level.

Table 6.9:Liquid Drawings of Iron Particles Marking Scheme

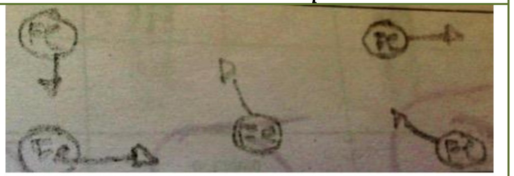
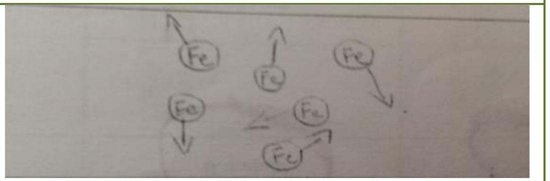
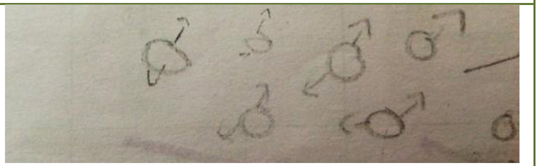
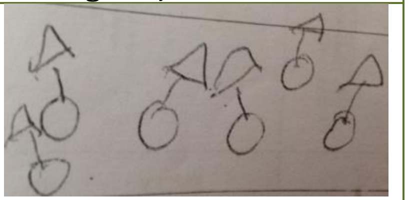
Grade	Marking Scheme	*Illustrated Examples*	
5mks	Student is able to convey a liquid in a drawing which includes <u>all criteria from:</u> Randomly directed arrows, visible iron symbols, arrows larger than for solid particles, similarly sized particles to solids (and other particles in this phase) and the same number of particles as illustrated in the solid phase, **a little inter-particulate space (like within a solid)**.	 **Figure α1**	
4mks	Student is able to convey a liquid in a drawing which includes <u>all criteria from:</u> Randomly directed arrows, visible iron symbols, arrows larger than for solid particles, similarly sized particles to solids (and other particles in this phase) and the same number of particles as illustrated in the solid phase **but wrongly indicates an inter-particulate space that is larger than a solid** (actually incorrect in absolute terms) **and much less than a gas**	 **Figure β1**	 **Figures β2.**
3mks	An incorrect inter-particulate distance which appears to be approximately at an <u>intermediate</u> distance between a <u>solid</u> and a <u>gas</u> and any <u>2 of the following criteria:</u> Randomly directed arrows, visible iron symbol included, similarly sized particles as solids (and other particles in this phase) and the same number of particles as illustrated in the solid phase (Figure γ1.)	 **Figure γ1**	
1mk	Student's attempt may indicate their inability to depict the particulate level behaviour of the liquid state.	 **Figure**δ1	
0mks	Blank		

States of matter of iron	**QUESTION 3A.** *What would 6 particles of iron look like in the gas state. Use arrows to indicate amount and direction of movement.*	*One particle of iron looks like…* Fe

Table 6.10: Diagnostic Exam Question 3a Gas Construct System

	SUPERORDINATE CONSTRUCT: Students could demonstrate a complete understanding of how to portray the gas state at particulate level by accurately displaying all requisite features of this state in their diagram.		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
Increased Comprehension	Full understanding of the portrayal of the gas state at particulate level.	Full understanding of how to convey the gas state at particulate level excluding one criterion.	Range of features depicted.
	Full understanding of how to convey the gas state at particulate level excluding one criterion.	Partial understanding of how to convey the gas state at particulate level.	Range of features depicted.
	Partial understanding of how to convey the gas state at particulate level.	Substitutes gas state with another state of matter or particulate representation level with the macro or inclusion of interparticulate lattice links.	Substitution of Question features.
	Substitutes gas state with another state of matter or particulate representation level with the macro or inclusion of interparticulate lattice links.	No understanding of gas particle behaviour at the particulate level.	No understanding of how to represent the gas state at the particulate level.

Table 6.11: Gas Drawings of Iron Particles Marking Scheme

Grade	Marking Scheme	*Illustrated Example*
5mks	Student is able to convey a liquid in a drawing which includes all criteria from: Randomly directed arrows, a large inter-particulate space (much greater than within solid and liquid phases), visible iron symbols, arrows larger than for liquid phase, similarly sized particles as solids, liquids and other particles in this phase and the same number of particles as illustrated in the liquid phase with all available space filled (Figure α1)	 **Figure α1**
4mks	Student is able to convey a liquid in a drawing which includes **randomly directed arrows, a large inter-particulate space and any 4 of 5 criteria from:** visible iron symbols, arrows larger than for liquid phase, similarly sized particles as solids, liquids and other particles in this phase, and the same number of particles as illustrated in the liquid phase with all available space filled. (Figure β1)	 **Figure β1**
3mks	A representation lacking in detail which includes: **randomly directed arrows, a large inter-particulate space and** any 3 of 5 criteria from: visible iron symbols, arrows larger than for liquid phase, similarly sized particles as solids, liquids and other particles in this phase, the same number of particles as illustrated in the liquid phase with all available space filled. (Figure γ1)	 **Figure γ1**
1mk	• Student's attempt indicates their inability to depict the particulate level behaviour of the gas state. • Examples include the drawing of: a distorted particle shape, a gas lattice, the incorrect state of matter drawn, a macro version of a gas. (Figure δ1)	 **Figure δ1**
0mks	Blank	

Question 3b: *Colour in on the thermometer the approximate level at which you would guess the liquid in the thermometer to be if iron was i. a solid, ii. a liquid or iii. a gas.*		
i. Solid	ii. Liquid	iii. Gas
		

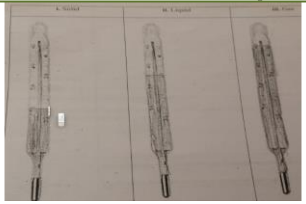
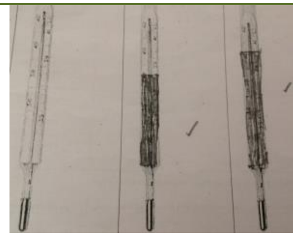
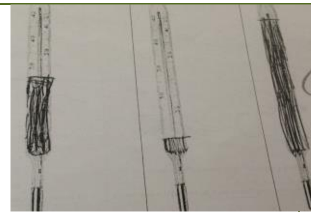
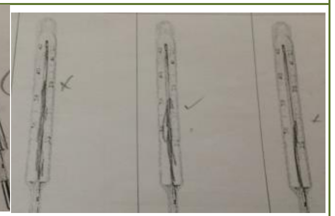
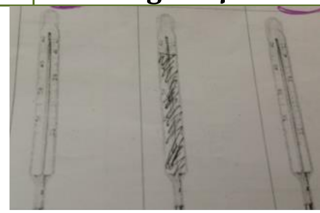
Question 3(b):

The second part of the question concerned the drawing or marking of a relative position on a thermometer as to where they predict the reading on a thermometer will occur for each of the three states of iron. Again, their procedural knowledge is required to apply the factual knowledge they have regarding the relationship between relative temperature and the three states of matter.

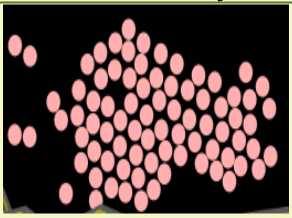
Table 6.12: Diagnostic Exam Question 3b Construct System

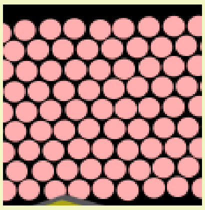
Increased Comprehension	**SUPERORDINATE CONSTRUCT:** Students displayed a quantitative understanding of the relation between relative temperature and state of matter.		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
	Full understanding of the quantitative relationship between state of matter and relative temperature.	Appears to understand quantitative relationship between state of matter and relative temperature but did not follow question protocol.	Insufficient scientific detail.
	Appears to understand quantitative relationship between state of matter and relative temperature but did not follow question protocol.	Student partially understands the association between relative temperature and state of matter in an alternative way.	Alternative sequence of phase changes with respect to increasing T.
	Student partially understands the association between relative temperature and state of matter in an alternative way.	No understanding of the relationship between relative temperature and phase change.	No understanding of the relation between relative temperature and state of matter.

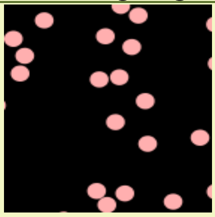
Table 6.13: Question 3(b) Marking Scheme

Grade	Marking Scheme	*Illustrated Example*
5mks	Student has the capacity to associate relative temperature with phase change. (Figure α1)	**Figure α1** 
4mks	• Student is not acknowledging the necessity for sufficient scientific detail. <u>Examples:</u> Student has not marked in the temperature for the solid on the thermometer as they are assuming the reader understands that approach signifies a low temperature. (Figure β1)	**Figure β1** 
2mks	Student marks one answer in clearly correct – the gas is correct but the liquid and solid are mixed up γ2 or liquid is correct but solid and gas are mixed up γ1 or two temperatures are not distinguished γ3. (Figures γ1, γ2, γ3.)	 **Figure γ1**  **Figure γ2**  **Figure γ3**
1mk	Student misunderstands the concept of the association between degree of temperature and state of matter. (Figure δ1)	**Figure δ1** 
0mks	Blank	

QUESTION 4. *Which of the three diagrams below is most likely to be argon gas?*


A


B


C

(a) Explain your choice:

(b) Explain why you think the two representations you did not pick are not a good choice:

Letter of representation You did not choose	*Explanation why you did not choose.*

Question 4:

In this case students are provided with static diagrams of the three states of matter in particulate form and are asked to indicate which of the three diagrams best represents argon gas. They are asked for an explanation regarding the choice they have made and an explanation as to why they discounted the other representations. The initial factual nature of the question (involving a decision to select which diagram is most likely to be Argon gas) becomes causal when students are asked to justify their selection (or non-selection) with an explanation.

Table 6.14: Diagnostic Exam Question 4a Construct System

SUPERORDINATE CONSTRUCT:
Students displayed a qualitative understanding of the gaseous state at a particulate level using dynamic descriptions

Increased Comprehension

Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
Full qualitative understanding of gaseous representations at particulate level.	Full qualitative understanding excluding key dynamic information.	Range of dynamic descriptors (limited).
Full qualitative understanding excluding key dynamic information.	Demonstrates partial qualitative analysis of gaseous representations at particulate level.	Absence of dynamic descriptors.
Demonstrates partial qualitative analysis of gaseous representations at particulate level.	Alternative understanding of visual representations of states of matter at the particulate level.	Insufficient range of particulate level reasoning.
Alternative understanding of visual representations of states of matter at the particulate level.	No understanding of visual representations of particulate level diagrams.	No understanding of visual patterns.

Table 6.15: Question 4(a) Marking Scheme

MARKING SCHEME	GRADE
• Student correctly inferred Argon gas was best represented by box C from examining the diagrams and referring in their explanation to the evident level of disorder and inter-particulate distance. <u>Written Example:</u> • 'C as the particles are all spread out randomly'.	**5mks**
• Student failed to fully describe their chosen scenario qualitatively and omitted key words such as 'all' or 'all space'. <u>Written Example:</u> • 'C because it's not stuck together. It moves randomly'. • 'It is spread out more'.	**4mks**
• Student makes the correct selection but fails to explain their reasoning on a particulate level where there is no reference to inter-particulate distance. <u>Written Example:</u> • 'C is gas particles' or 'It matches the characteristics of a gas'.	**2mks**
• Incorrect selection made as student is unable to associate particulate level and or visual models of matter with their names.	**1mk**
• Blank	**0mks**

Question 4b
Students were asked to explain why they did not choose the two remaining options available in the initial selection. Both descriptions were combined into one overall answer and then taken into account together for analysis purposes.

Table 6.16 Diagnostic Exam Question 4b Construct System

Increased Comprehension ↑	**SUPERORDINATE CONSTRUCT:** Students displayed a qualitative understanding of the solid and liquid states at a particulate level using dynamic descriptors		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
	Full qualitative understanding of representations at particulate level.	Full qualitative understanding excluding reference to one of the states of matter.	Perception filtered out part of question (Associative Activation).
	Full qualitative understanding excluding reference to one of the states of matter.	Surface-level qualitative understanding of particulate level.	Limited qualitative range of understanding.
	Surface-level qualitative understanding of particulate level.	Alternative understanding of visual representations of states of matter at the particulate level.	Range of particulate level reasoning (limited).
	Alternative understanding of visual representations of states of matter at the particulate level.	No understanding of visual representations of particulate level diagrams.	No understanding of visual patterns.

Table 6.17: Question 4(b) Marking Scheme

<table>
<tr><th>MARKING SCHEME</th><th>GRADE</th></tr>
<tr><td>Student correctly indicated the phase relating to the options they did not select in part a). They also offered a technically full and accurate qualitative understanding in terms of the factors of inter-particulate distance and disorder.
<u>Written Examples:</u>
‘B represents a solid perfectly as particles are close together and A represents the movement of liquid particles where they are spread out more randomly’.
‘A shows what a liquid is like where the particles are more attracted while B shows a solid where the attraction between particles is even bigger’.</td><td>5mks each</td></tr>
<tr><td>Student mentions the phase names of the two options of A and B. They subsequently offer partial evidence of their qualitative understanding by giving a <u>single</u> explanation in relation to A and B instead of <u>two</u> separate explanations.
<u>Written Example:</u>
‘A is a liquid as the particles are moving less than the C. B is a solid.’</td><td>4mks each</td></tr>
<tr><td>Student makes the correct selection but fails to explain their reasoning on a particulate level[a] or student fails to make reference to relative inter-particulate distance[b].
<u>Written Examples:</u>
‘C is gas particles’ or ‘It matches the characteristics of a gas’[a].
‘A – they are spread out but not enough. B – they are too close together’ or ‘They are not that much random’[b].</td><td>2mks each</td></tr>
<tr><td>Incorrect</td><td>1mk each</td></tr>
<tr><td>Blank</td><td>0mks</td></tr>
</table>

QUESTION5: *Draw what the particles of water look like in the unfrozen area near us and in the white ice further away.*

A water particle (symbol = H20) looks like: 

Use arrows to indicate how much and the direction they can move.

UNFROZEN AREA	FROZEN AREA

Question 5:

The question is procedural in nature as it requires students to go beyond their knowledge of the facts regarding the behaviour of states of matter to its application. As they are not required to explain their drawn responses, it is not causal in nature. Specifically, students are provided with a photo of the macroscopic level of water in the liquid and solid states and are asked to draw their corresponding particulate representations.

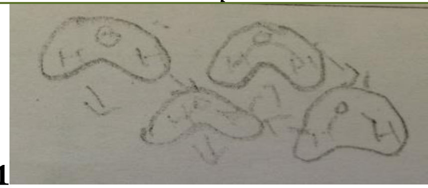
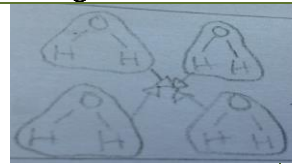
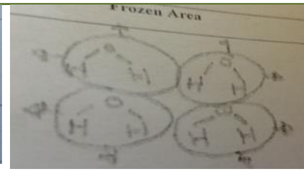
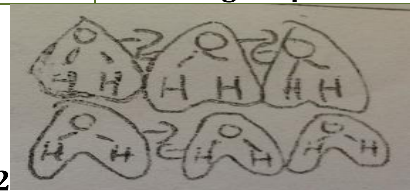
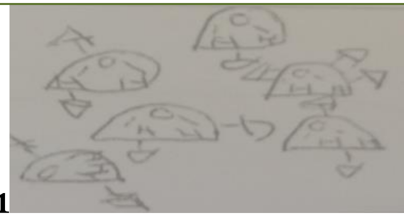
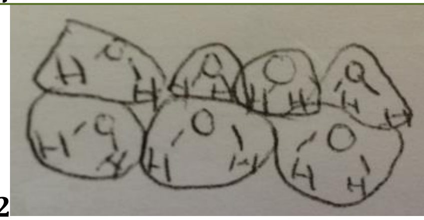
Table 6.18: Diagnostic Exam Question 5(a) Construct System

SUPERORDINATE CONSTRUCT:
Students displayed a capacity to interchange between macro and particulate levels and exhibit a qualitative understanding of the solid state in their drawing

Increased Comprehension

Preferred Pole	Non-Preferred Pole	Critical Differentiation Pole
Full qualitative understanding of solid representations at particulate level.	Full qualitative understanding excluding IPD or partial qualitative understanding including IPD.	Qualitative (Range) or IPD (absent).
Full qualitative understanding excluding IPD or partial qualitative understanding including IPD.	Partial qualitative understanding of solid particulate level including an alternative understanding of appropriate IPD.	Qualitative and IPD.
Partial qualitative understanding of solid particulate level including an alternative understanding of appropriate IPD.	Substitutes solid state with another state of matter or particulate representation level with the macro or has an alternative understanding of how to represent the particulate.	Substitution of Question features.
Substitutes solid state with another state of matter or particulate representation level with the macro or has an alternative understanding of how to represent the particulate.	No understanding of how to relate the macroscopic to the particulate level.	No understanding of how to relate macroscopic level to the particulate level.

Table 6.19: Question 5(a) Marking Scheme Frozen Area

Grade	Marking Scheme	*Illustrated Example*
5mks	Student is able to display a solid in a drawing, which includes <u>all criteria from</u>**:** Randomly directed arrows, a small level of movement that is vibrational in nature and smaller than for a liquid, visible water symbols, similarly sized particles and a **little** inter-particulate space (between approximately 75% of particles) – (Fig α1.)	**Figure α1** 
4mks	• A **little** inter-particulate space (correct characteristic) and **fewer than all of** the following: Randomly directed arrows, a small level of movement that is vibrational in nature and smaller than for a liquid, visible water symbols, and similarly sized particles – see Figureβ1. • Student is able to display a solid in a drawing, which includes <u>all criteria from</u>**:** Randomly directed arrows, a small level of movement that is vibrational in nature and smaller than for a liquid, visible water symbols, similarly sized particles **but no** inter-particulate space– (Figs. B1, B2 & β3.)	 **Figure β1**  **Figure β2** **Figure β2** 
3mks	• Student drawing illustrates **unsatisfactory** inter-particulate space (more than a little) and includes **any 1 of the following criteria:** Randomly directed arrows, a small level of movement that is vibrational in nature and smaller than for a liquid, visible water symbols, similarly sized particles see - Figure γ1. • Student drawing illustrates **no** inter-particulate space and includes **any 1 of the following criteria:** randomly directed arrows, a small level of movement that is vibrational in nature and smaller than for a liquid, visible water symbols, similarly sized particles –(Figure γ1, γ2.) **Note:** Table continued on page 154	**Figure γ1**  **Figure γ2** 

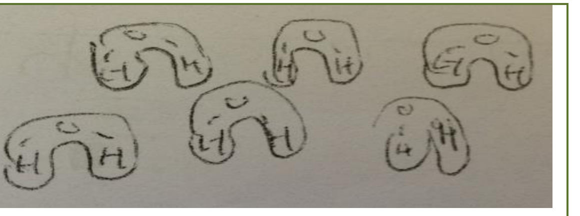
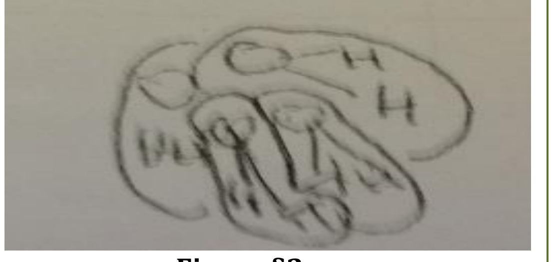
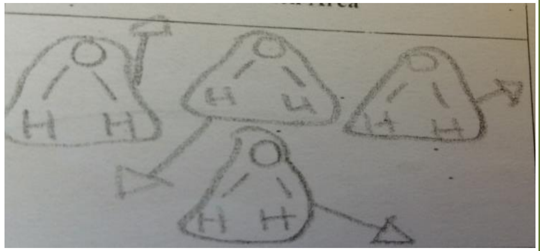
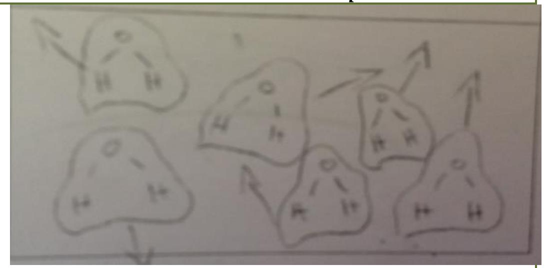
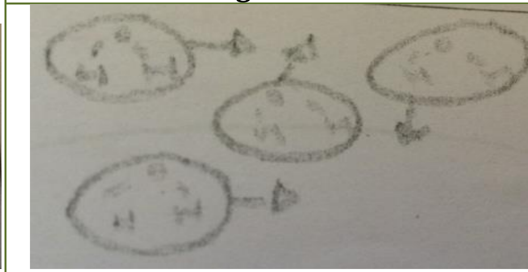
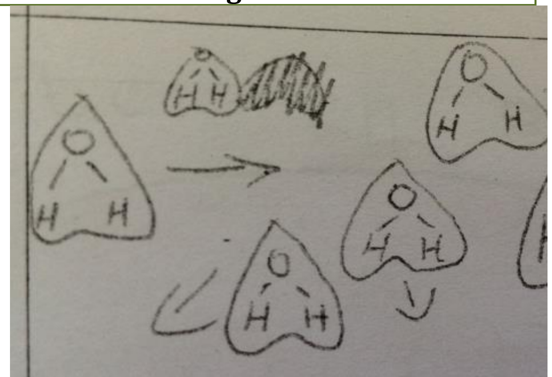
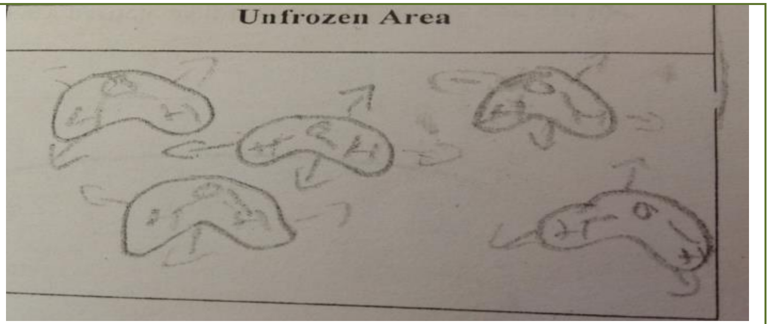
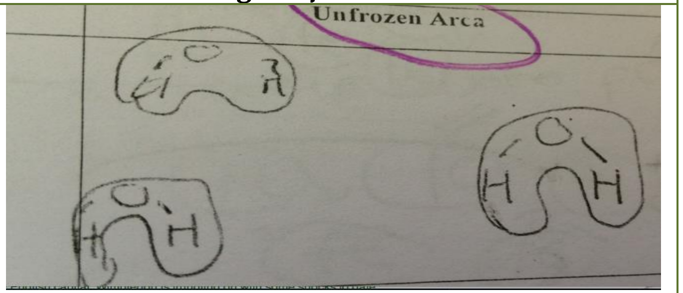
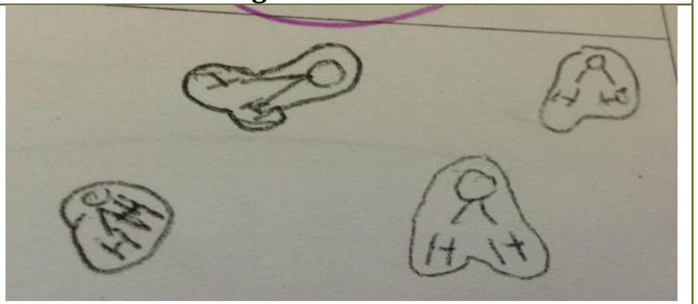
1mk	• Student's attempt may indicate their inability to recognise ice as a solid or to accurately depict the particulate level behaviour of the solid state. • Examples include the drawing of: the incorrect state (Figure δ1); overlapping molecules of water, a distorted particle shape (Figure δ2); the macro version (ice) or a solid lattice. Figures δ1, δ 2.	 **Figure δ1**  **Figure δ2**
0mks	Blank	

Table 6.20: Diagnostic Exam Question 5(b) Construct System

<table>
<tr><td rowspan="6">Increased Comprehension ↑</td><td colspan="3">SUPERORDINATE CONSTRUCT:
Students displayed a capacity to interchange between macro and particulate levels and exhibit a qualitative understanding of the liquid state in their drawing.</td></tr>
<tr><th>Preferred Pole</th><th>Non-Preferred Pole</th><th>Critical Differentiation Pole</th></tr>
<tr><td>Full understanding of the nature of movement of a liquid at particulate level.</td><td>Full qualitative understanding excluding IPD.</td><td>IPD (too large).</td></tr>
<tr><td>Full qualitative understanding excluding IPD.</td><td>Partial qualitative understanding of liquid particulate level including an alternative understanding of appropriate IPD.</td><td>Qualitative and IPD.</td></tr>
<tr><td>Partial qualitative understanding of liquid particulate level including an alternative understanding of appropriate IPD.</td><td>Substitutes liquid state with another state of matter or has an alternative understanding of how to represent the particulate.</td><td>Substitution of Question features.</td></tr>
<tr><td>Substitutes liquid state with another state of matter or has an alternative understanding of how to represent the particulate.</td><td>No understanding of how to relate the macroscopic to the particulate level.</td><td>No understanding of how to relate macroscopic level to the particulate level.</td></tr>
</table>

Table 6.21: Question 5(b) Marking Scheme Unfrozen Area

Grade	Marking Scheme	*Illustrated Example*
5mks	Student is able to convey a liquid in a drawing which includes <u>all criteria from:</u> Randomly directed arrows, visible water symbols, arrows larger than for solid particles, similarly sized particles to solids (and other particles in this phase) and the same number of particles as illustrated in the solid phase, **a little inter-particulate space (like within a solid)**. (Figures α1, α2, α3.)  **Figure α3**	 **Figure α1**  **Figure α2**
4mks	Student is able to convey a liquid in a drawing which includes <u>all criteria from:</u> Randomly directed arrows, visible water symbols, arrows larger than for solid particles, similarly sized particles to solids (and other particles in this phase) and the same number of particles as illustrated in the solid phase **but wrongly indicates an inter-particulate space that is larger than a solid** (actually incorrect in absolute terms – see * page 27) **and much less than a gas**–see Figure β1. **Note:** Table continued on page 157	 **Figure β1**

3mks	An incorrect inter-particulate distance which appears to be approximately at an intermediate distance between a solid and a gas and any 2 of the following criteria: Randomly directed arrows, visible water symbol included, similarly sized particles as solids (and other particles in this phase) and the same number of particles as illustrated in the solid phase –see Figure γ1.	 **Figure γ1**
1mk	Examples: Include the drawing of: the incorrect phase or distorted particle shapes or a liquid lattice drawn. Figures δ1, δ 2.	 **Figure δ1**  **Figure δ2**
0mks	Blank	

QUESTION 7: *Will there be any difference in the amount of movement possible by liquid particles of water when poured into a container like a beaker in comparison to a container like a basin as shown below? Explain ...*

Question 7:

Question 7 is causal in nature as it requires students to explain if the level of movement of water particles will be affected by a difference in volume of the container in which the liquid resides.

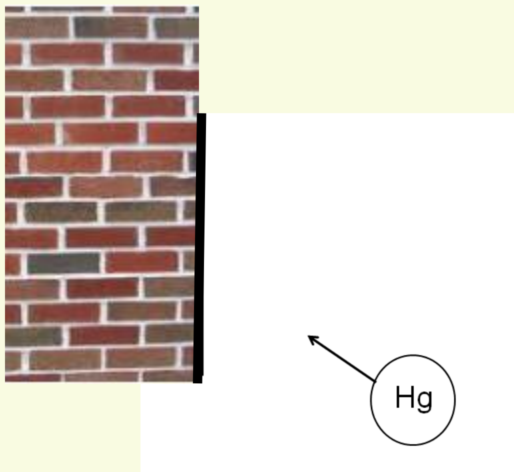
Table 6.22: Diagnostic Exam Question 7 Construct System

Increased Comprehension	**SUPERORDINATE CONSTRUCT:** Students displayed an understanding that a liquid is unaffected by transfer to another vessel at particulate level.		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
	Full understanding of the portrayal of the liquid state at particulate level.	Full understanding of the portrayal of the solid state at particulate level excluding an accurate interparticulate distance.	IPD (too large).
	Full understanding of the portrayal of the solid state at particulate level excluding an accurate interparticulate distance.	Partial understanding of how to convey the liquid state at particulate level including an alternative interparticulate distance.	Range of (appropriate) features depicted.
	Partial understanding of how to convey the liquid state at particulate level including an alternative interparticulate distance.	Substitutes liquid state with another state of matter.	Substitution of Question features.
	Substitutes liquid state with another state of matter.	No understanding of liquid particle behaviour at the particulate level.	No understanding of how to represent the liquid state at the particulate level.

Table 6.23 Question 7 Marking Scheme

MARKING SCHEME	GRADE
• The student understands the relationship between the shape of a liquid and the level of movement of its particles and offers a comprehensive qualitative explanation. Written Example: • 'No matter what the size of the container is, the level of movement of its particles are the same'.	**10mks**
• Student offers less detail and gives a single reason as their explanation (in terms of volume or shape) Written Example: • 'No as it will just look different' or 'The movement is the same no matter what the size is'.	**8mks**
• Student offers no detail as to why they answered No.	**4mks**
• The student does not fully understand the behaviour of particle movement in liquids Written Example: • 'The liquid is more spread' or 'Yes, as there is more room'.	**1mks**
• Blank	**0mks**

QUESTION 8: *Use an arrow to draw the future path of the mercury particle as it travels beyond its current location in as much detail as you can give.*



Question 8:

The final question of the exam challenges students to go beyond simply retrieving knowledge (factual) to being procedural in nature where they are required to apply knowledge of particulate movement to draw the trajectory of an atom of mercury.

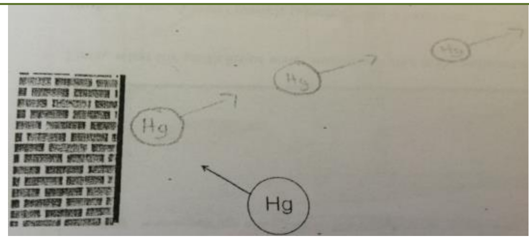
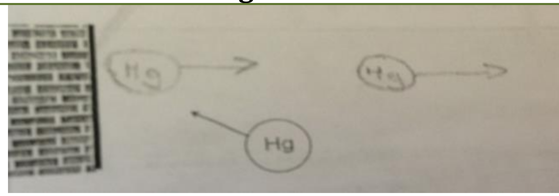
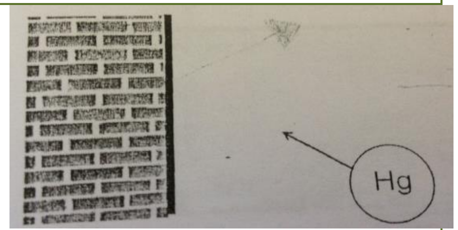
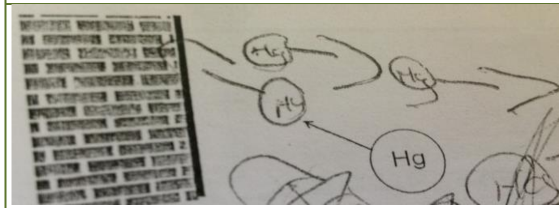
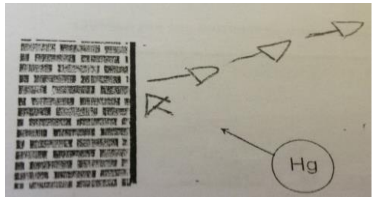
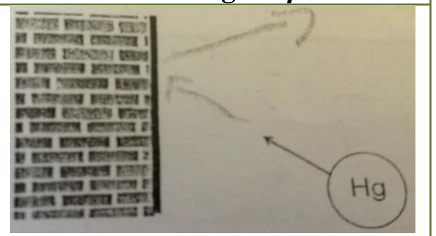
Table 6.24: Diagnostic Exam Question 8 Construct System

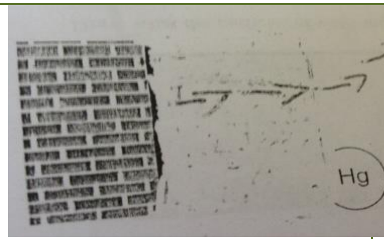
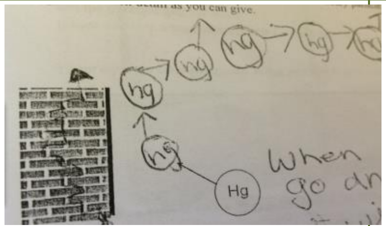
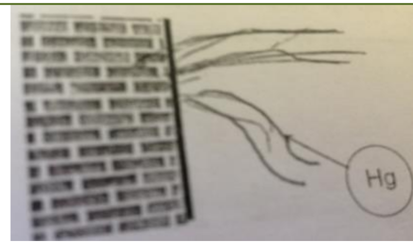
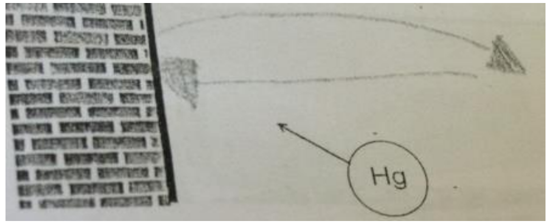
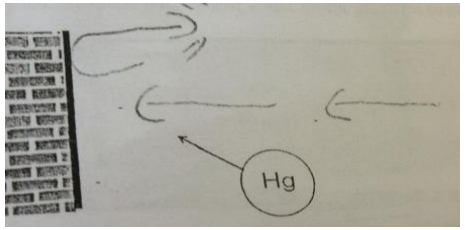
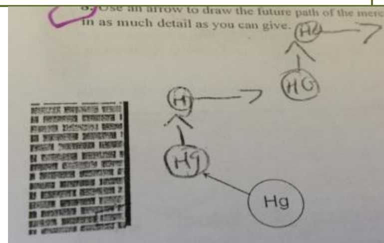
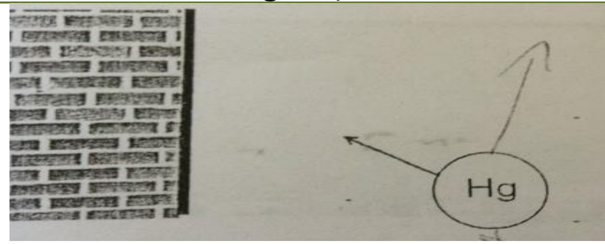
SUPERORDINATE CONSTRUCT:
Students displayed an understanding of the nature of atomic collision in their drawing.

Increased Comprehension

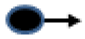
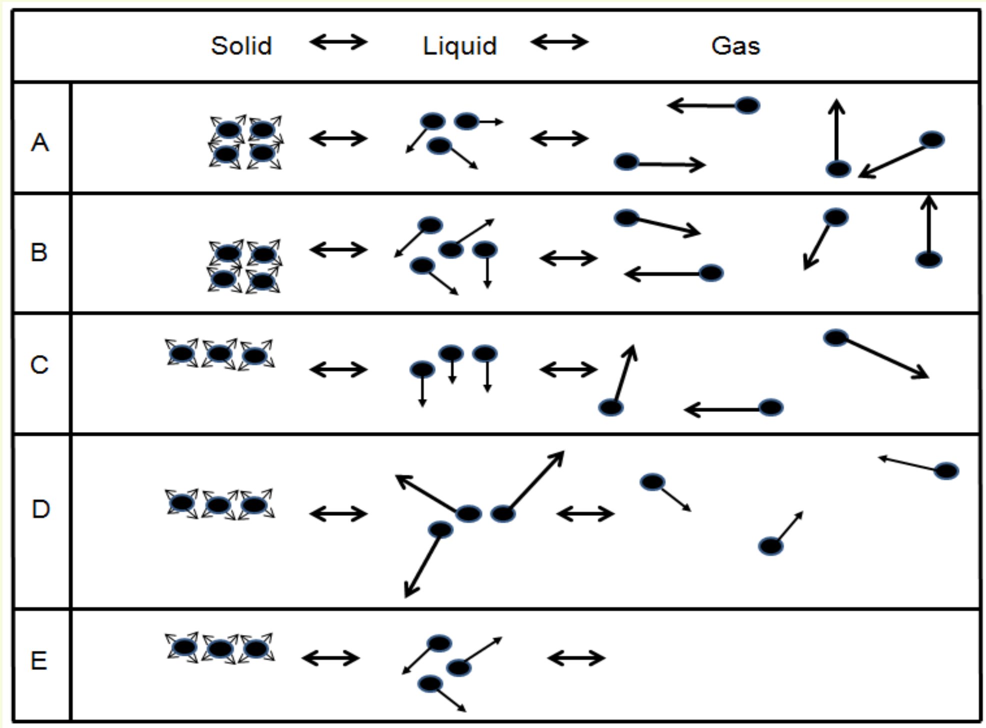
Preferred Pole	Non-Preferred Pole	Critical Differentiation Pole
Full understanding of how to represent an atomic collision.	Full understanding of how to represent an atomic collision excluding future atomic location or accuracy of angle of bounce.	Accuracy of depiction of trajectory within a range of features.
Full understanding of how to represent atomic collision excluding future atomic location or accuracy of angle of bounce.	Alternative understanding of representation of trajectory.	Non-discernible 'Angle of bounce'.
Alternative understanding of representation of accurate trajectory.	Alternative understanding of particulate behaviour involving collision.	Atomic bounce.
Alternative understanding of particulate behaviour involving collision.	Apparent absence of understanding of particulate behaviour involving collision.	No understanding of particulate collision.

Table 6.25: Question 8 Marking Scheme

Grade	Marking Scheme	*Illustrated Example*	
10 mks	Student possesses a clear and detailed understanding of particulate movement in relation to the straight trajectory of an atom, angle of the same trajectory and the subsequent location of an atom in relation to its former trajectory of movement.	 **Figure α1**	
8 mks	• Student is capable of drawing a clear trajectory resulting in a regular shaped definite angle (albeit incorrect) – see Figs. β1, β2, β3, β4, β5. • Student appears to be lacking specific detail e.g. omission of correct symbol (Figs. β1, β2, β3, β4, β5) **Note:** Table continued on page 162	 **Figure β1**	 **Figure β2**
		 **Figure β3**	 **Figure β4**
			 **Figure β5**

4mks	• Student conveys the notion of an ‘atomic bounce’ **but** draws a <u>trajectory</u> that is <u>non-linear</u>. • The nature of the trajectory drawn results in the absence of a definite angle of bounce (albeit incorrect). • Student appears to be lacking specific detail e.g. omission of correct symbol. • Student appears to be lacking the knowledge of the possible location of the atom after collision. (Figure γ1, γ2, γ3, γ4, γ5.)	 **Figure γ2,**  **Figure γ3,**	 **Figure γ1,**  **Figure γ4,**
			 **Figure γ5,**
1mk	• Student appears to display an inability to understand or anticipate particulate movement in relation to an atom meeting other objects. (Figure δ1, δ2.)	 **Figure δ1**	 **Figure δ2**
0mks	Blank		

Analysis of Summative Assessments:

QUESTION 1 *In the table below, there are 5 different representations of matter changing state. Explain beneath the table for each selection (a) to (e) if it is an accurate representation of matter changing state or if it is not.*		
A PARTICLE SUCH AS		**IS INDICATING THAT IT CAN VIBRATE**
A PARTICLE SUCH AS		**CAN MOVE MORE THAN THE VIBRATING PARTICLE**
WHILE A PARTICLE SUCH AS		**IS ABLE TO MOVE EVEN MORE.**
 		
A WHY OR WHY NOT?		
B WHY OR WHY NOT?		
C WHY OR WHY NOT?		
D WHY OR WHY NOT?		
E WHY OR WHY NOT?		

Question 1:

The initial question of the exam requires students to identify accurate representation(s) of matter changing state. It also affords students of the non-intervention cohort with the opportunity to visualize the conventions used to draw states of matter in a dynamic manner. Each individual component, as well as the overall task, is causal in nature as students were being asked to justify their selection as being an accurate presentation or not.

Table 6.26: Summer Exam Question 1(a) Construct System

Increased Comprehension	**SUPERORDINATE CONSTRUCT:**		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
	Complete qualitative understanding of behaviour involving phase change at particulate level.	Full qualitative understanding of behaviour involving phase change at particulate level excluding comparison of models.	Lacks comparative detail.
	Full qualitative understanding of behaviour involving phase change at particulate level excluding comparison of models.	Apparent understanding of particulate behaviour involving phase change.	No reasoning at particulate level.
	Apparent understanding of particulate behaviour involving phase change.	Alternative understanding of particulate behaviour involving phase change.	Alternative understanding.
	Alternative understanding of particulate behaviour involving phase change.	Apparent absence of understanding of particulate behaviour involving phase change.	No particulate understanding of phase change.

Table 6.27: Question 1(a) Marking Scheme

MARKING SCHEME	GRADE
• Students are able to make comprehensive qualitative and quantitative arguments at a particulate level. This involves making a comparison regarding the states of matter they see in terms of the relevant component (number of particles) of the four central elements★. Written Examples: • 'In liquid stage there is one less particle and if 4 particles solid, this implies 4 particles are required for a liquid' or 'All states have to have the same amount of particles'.	**5mks**
• Students are able to make adequate arguments at a particulate level in terms of the relevant component (number of particles) of the four elements★. The answer provided is a basic qualitative explanation[a] and or quantitative explanation[b], which is lacking in comparative detail. Written Examples: • No **and '**Liquid should have 4 particles' [a] or 'Liquid should have more particles' [a]. • No **and** 'Not enough in liquid[b]' or 'Different number of particles in liquid[b]' or 'Liquid is different amount[b]'.	**4mks**
• The student's ability to reason at a particulate level is not at all developed. The argument provided may be a guess. Written Examples: • No **and** no reason given • No **and** 'Liquid looks wrong' (incorrect reason).	**2mks**
• The argument provided may be a guess of 'Yes' (incorrect). Written Examples: • Yes **and** no reason given • Yes **and** 'It is showing the right particles' or 'It is a solid, liquid and gas[Φ]' 'Because solid turns to a liquid gas particles will move more and it being turned to gas makes it even move more freely[Φ]' or Solid is tightly packed. Liquid can move more but not so much. Gas can bounce everywhere' or 'As a solid changes to a liquid and then to a gas[Φ]' or 'The gas is too close together' or 'Because of how the particles are places together' or It keeps changing state of matter[Φ]' (incorrect reasons).	**1mk**
• Blank	**0mks**

QUESTION 1(B)

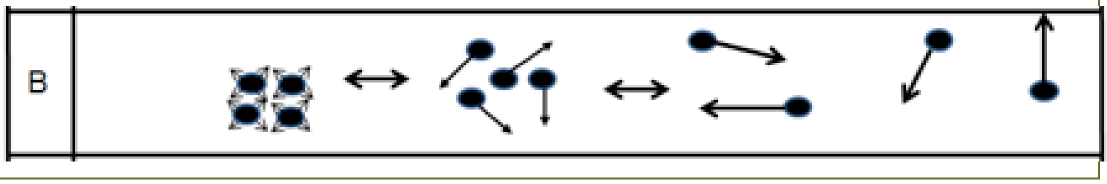


Table 6.28: Summer Exam Question 1(b) Construct System

	SUPERORDINATE CONSTRUCT: The capacity to recognise accurate depictions of phase changes at the particulate level.		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
Increased Comprehension ↑	Full qualitative understanding of behaviour involving phase change at particulate level.	Full qualitative understanding of behaviour involving phase change at particulate level excluding full description of model features.	Limited range of reasoning at particulate level.
	Full qualitative understanding of behaviour involving phase change at particulate level excluding full description of model features.	Apparent understanding of particulate behaviour involving phase change.	Absence of reasoning at particulate level.
	Apparent understanding of particulate behaviour involving phase change.	Alternative understanding of particulate behaviour involving phase change.	Alternative understanding of phase change.
	Alternative understanding of particulate behaviour involving phase change.	Apparent absence of understanding of particulate behaviour involving phase change.	No particulate understanding of phase change.

Table 6.29: Summer Exam Question 1(b) Marking Scheme

MARKING SCHEME	GRADE
• Students are able to make comprehensive arguments at a particulate level, which involves making a comparison regarding the states of matter they see, in terms of 3 or 4 of the central elements★. Written Example: • Yes **and** 'There are 4 in all states and they are random with the right space between particles'.	**5mks**
• Students are able to make adequate arguments at a particulate level, which involves making a comparison regarding the states of matter they see in terms of one or two of the central elements★. Written Examples: • 'Yes' **and** 'There is the same amount in each one' or 'There is the correct space and movement'.	**4mks**
• Student may have an inability to use particulate level arguments. The argument provided may be a guess. Written Examples: • Yes **and** 'It is showing the right particles' or 'Melting then boiling' or 'it's correct as it can vibrate, move more, and then move more again' or 'You can see very clearly that the particles gradually distance themselves' (incorrect reasons).	**2mks**
• Student may have an inability to use particulate level arguments. The argument provided may be a guess of 'No' (incorrect). Written Examples: • No **and** no reason given Yes **and** 'It is showing the right particles' or 'It is a solid, liquid and gas$^{\Phi}$' or 'It looks right' or 'The liquid is too random' (incorrect reasons).	**1mk**
• Blank	0mks

QUESTION 1(C):

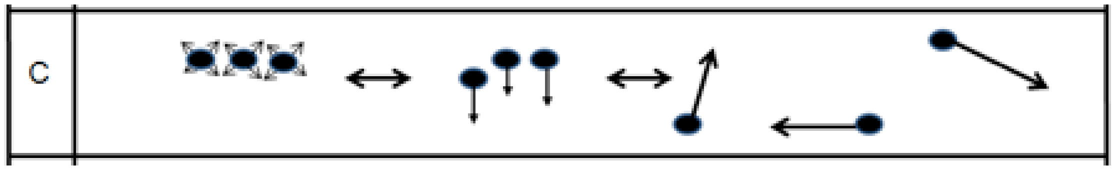


Table 6.30: Question 1(c) Construct System

	SUPERORDINATE CONSTRUCT:		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
Increased Comprehension	Full qualitative understanding of behaviour involving phase change at particulate level.	Full qualitative understanding of behaviour involving phase change at particulate level excluding full description of model features.	Limited range of reasoning at particulate level.
	Full qualitative understanding of behaviour involving phase change at particulate level excluding full description of model features.	Apparent understanding of particulate behaviour involving phase change.	Absence of reasoning at particulate level.
	Apparent understanding of particulate behaviour involving phase change.	Alternative understanding of particulate behaviour involving phase change.	Alternative understanding of phase change.
	Alternative understanding of particulate behaviour involving phase change.	Apparent absence of understanding of particulate behaviour involving phase change.	No particulate understanding of phase change.

Table 6.31: Question 1(c) Marking Scheme

MARKING SCHEME	GRADE
• Students are able to make comprehensive qualitative argument at a particulate level. This involves identifying the state of matter they see as displaying an error, in terms of the relevant component (direction of movement) of the four central elements★, and describing precisely the nature of its flaw. <u>Written Examples:</u> • No **and** 'Liquid moving in same direction and should be random'.	**5mks**
• Students are able to make adequate arguments at a particulate level in terms of the relevant component (number of particles) of the four central elements★. The answer provided is a basic qualitative explanation, which is lacking reference to random movement. <u>Written Examples:</u> • No **and '**liquid moving in same direction' or 'Liquid is going down' or 'Liquid has wrong movement' or 'Liquid doesn't always move downwards'.	**4mks**
• The student's ability to reason at a particulate level is not at all developed. The argument provided may be a guess. <u>Written Examples:</u> • No **and** no reason given • No **and** 'It can move more than a gas' (incorrect reason).	**2mks**
• The argument provided may be a guess of 'Yes' (incorrect). • Student may not have understood the question. <u>Written Examples:</u> • Yes **and** no reason given • Yes **and** 'There is the same amount of particles$^{\Phi}$' or 'There is enough' (incorrect reasons) or 'Solid - liquid - gas$^{\Phi}$' or 'because it's going from vibrating to moving to moving even more' or 'It looks right' 'You can see in the liquid that it flows' or 'It's not tight as a solid, the liquid is liquid is too loose and the gas is okay'.	**1mks**
• Blank	0mks

QUESTION 1 (D):

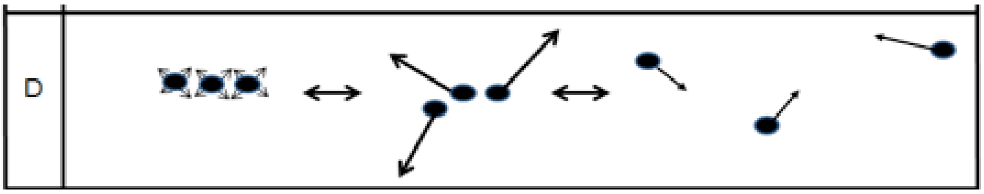


Table 6.32 Question 1(d) Construct System

	SUPERORDINATE CONSTRUCT: The capacity to recognise accurate depictions of phase changes at the particulate level.		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
Increased Comprehension	Full qualitative understanding of behaviour involving phase change at particulate level.	Full qualitative understanding of behaviour involving phase change at particulate level excluding full description of model features.	Limited range of reasoning at particulate level including lack of comparative detail.
	Full qualitative understanding of behaviour involving phase change at particulate level excluding full description of model features.	Apparent understanding of particulate behaviour involving phase change.	Absence of accurate reasoning at particulate level.
	Apparent understanding of particulate behaviour involving phase change.	Alternative understanding of particulate behaviour involving phase change.	Alternative understanding of phase change.
	Alternative understanding of particulate behaviour involving phase change.	Apparent absence of understanding of particulate behaviour involving phase change.	No particulate understanding of phase change.

Table 6.33: Question 1(d) Marking Scheme

MARKING SCHEME	GRADE
• Students are able to make comprehensive qualitative argument at a particulate level. This involves identifying the state of matter they see as displaying an error, in terms of the relevant component (level of movement) of the four central elements★, describing precisely the nature of its flaw and using it to make a comparison with another state of matter. Written Examples: • No **and** 'Level of movement of liquid is too great relative to gas' or 'The liquid is moving too much and the gas too little' or 'The liquid arrows are too big and the gas too small' or 'The liquid don't move freely that much'.	**5 mks**
• Students are able to make adequate arguments at a particulate level in terms of the relevant component (level of movement) of the four central elements★. The answer provided is a basic qualitative explanation, which is lacking in comparative detail. Written Examples: • No **and** 'arrows for liquid inaccurate' or 'Liquid too free' or 'Gas can move more' or 'The liquid arrows are too big' or 'The liquid arrows aren't the right length' or 'The liquid has the wrong movement' or the 'Gas looks wrong'.	**4 mks**
• Student may lack the ability to perceive detail at particulate level and may believe that liquid particles can move more than gas particles. • The student's ability to reason at a particulate level is not at all developed. The argument provided may be a guess. Written Examples: • No **and** no reason given • No **and** 'or 'The solids are too far apart or 'The liquid has the wrong movement' or 'The liquid is too far apart'.	**2mks**
• Student may have been satisfied that she saw a standard conversion of a 'solid to a liquid to a gas' (or vice versa) • Student may have an inability to use particulate level arguments. The argument provided may be a guess of 'Yes' (incorrect). Written Examples: • Yes **and** no reason given • Yes **and** ''A liquid can move more than a gas' or 'There's the same amount of particles' or 'There's lot of space in the gas particles'.	**1mks**
• Blank	0mks

QUESTION 1(E):

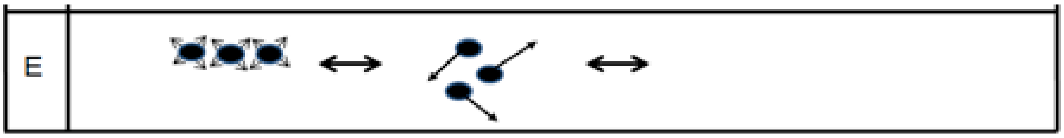


Table 6.34: Question 1(e) Construct System

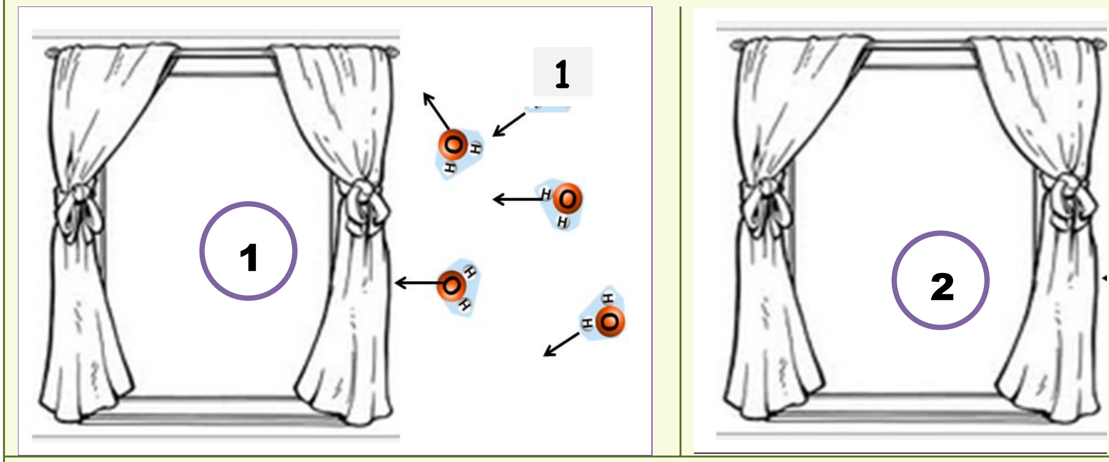
SUPERORDINATE CONSTRUCT: The capacity to recognise accurate depictions of phase changes at the particulate level.

Increased Comprehension

Preferred Pole	Non-Preferred Pole	Critical Differentiation Pole
Full qualitative understanding of behaviour involving phase change at particulate level.	Full qualitative understanding of behaviour involving phase change at particulate level excluding capacity to refer to particulate.	Absence of specific particulate level reasoning.
Full qualitative understanding of behaviour involving phase change at particulate level excluding capacity to refer to particulate.	Apparent understanding of particulate behaviour involving phase change.	Alternative *reasoning*.
Apparent understanding of particulate behaviour involving phase change.	Alternative understanding of particulate behaviour involving phase change.	Alternative *understanding* of phase change.
Alternative understanding of particulate behaviour involving phase change.	Apparent absence of understanding of particulate behaviour involving phase change.	No particulate understanding of phase change.

Table 6.35: Question 1(e) Marking Scheme

MARKING SCHEME	GRADE
• Students are able to make comprehensive qualitative argument at a particulate level. This involves identifying the state of matter they see as displaying an error, in terms of the relevant component (particulate conservation) of the four central elements★, describing precisely the nature of its flaw in terms on a particulate level[a] or using it to make a comparison with another state of matter[b]. <u>Written Examples:</u> • No **and** 'No gas particles present[a]' or 'Liquid particles turned into gas won't make the gas particles disappear[a]' or 'Only two changes of state[b]' or 'Only two forms changing state[b]'. • Yes **and** gas particles now drawn into the empty space representing the gas phase on the exam script.	**5mks**
• Students are able to make adequate arguments at a particulate level in terms of the relevant component (particulate conservation) of the four central elements★. The answer provided is a basic qualitative explanation, with no specific reference to the submicroscopic level. <u>Written Examples:</u> • No **and** 'no gas' or 'There is no gas diagram' or 'There is no gas stage' or 'It's missing gas'.	**4mks**
• The student's ability to reason at a particulate level is not at all developed. <u>Written Examples:</u> • No **and** no reason given • No **and '**Does not represent the accurate representation of matter' 'or 'A gas can move' or 'it should show that it just moves a lot more, not that they have disappeared'.	**2mks**
• Student may have been satisfied that she saw a standard conversion of a 'solid to a liquid to a gas' (or vice versa). Students may believe that their submicroscopic mental model of a gas should conform to their macro view of one i.e. it is colourless and invisible. <u>Written Examples:</u> • Yes **and** no reason given • Yes **and** 'A liquid can move more than a gas' or 'There's the same amount of particles' or 'There's lot of space in the gas particles' or 'Gases can be invisible as well' or 'It is in order' or 'It stayed in a liquid state' or 'Gas cannot be seen' or 'A solid can be changed to liquid and also not be changed to a gas' or 'Yes if you melt a solid it changes to liquid'.	**1mk**
• Blank	**0mks**



Question 2 *Above in diagram 1 are some water particles moving towards a very cold window. Draw what the water particles will look like when they reach the surface of the window in diagram 2.*

Use arrows to show the amount and types of movement they have.
Explain your choice.

Question 2:

The initial part of this question, where students are asked to draw a representation of what will happen the water particles when they meet the surface of the cold window, is procedural. The overall task becomes causal when students are asked to explain their drawing. As there was no indication of the 'level' of coldness of the window, it was acceptable for students to illustrate water particles in both the liquid and the solid phases.

Table 6.36: Question 2 Construct System

SUPERORDINATE CONSTRUCT:
The capacity to apply knowledge of phase changes and interchange between macroscopic and particulate thinking to draw a representation of water vapour cooling accurately.

Increased Comprehension	**Preferred Pole**	**Non-Preferred Pole**	**Critical Differentiation Pole**
	Full qualitative understanding of behaviour involving phase change at particulate level.	Full qualitative understanding of behaviour involving phase change at particulate level excluding full and accurate array of drawn features.	Range of accurate drawing features.
	Full qualitative understanding of behaviour involving phase change at particulate level excluding full and accurate array of drawn features.	Apparent understanding of particulate behaviour involving phase change.	Range of accurate drawing and/or explanatory features
	Apparent understanding of particulate behaviour involving phase change.	Alternative understanding of particulate behaviour involving phase change – largely causal	Written: Alternative Explanation Drawn: Qualitative molecular change or Macro substitution.
	Alternative understanding of particulate behaviour involving phase change – largely due to alternative causal effects (written) and qualitative molecular change or substitutes particulate with macro level (Drawings)	Apparent absence of understanding of particulate behaviour involving application of phase change.	No particulate understanding of application of phase change.

Table 6.37: Question 2 Marking Scheme

<table>
<tr><th>MARKING SCHEME</th><th>GRADE</th></tr>
<tr><td>

Student is able to convey a liquid in a drawing which includes <u>all criteria from:</u> Randomly directed arrows, visible water symbols, arrows smaller than for gas particles in diagram1, similarly sized particles to solids (and other particles in this phase) and the same number of particles as illustrated in Diagram 1, a little inter-particulate space (like within a solid).
Student is able to display a solid in a drawing, which includes <u>all criteria from</u>: Randomly directed arrows, a small level of movement that is vibrational in nature and smaller than for a liquid, visible water symbols, similarly sized particles and a little inter-particulate space (between approximately 75% of particles).

<u>Written Examples:</u>

Liquid: ‘Condensation’ or ‘Changes to liquid’ or similar.
Solid: ‘Freezing’ or ‘Changes to solid’ or similar.

<u>Illustrated examples below</u>:
Figures : α1 (representing condensation),
α2 (representing freezing),

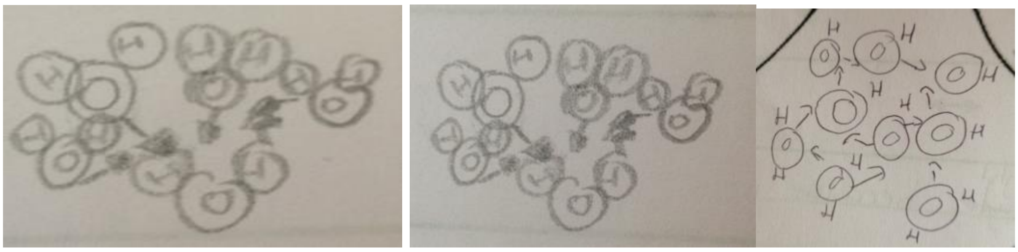
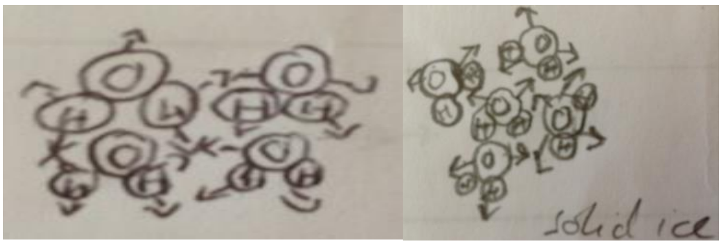



Figure α1


Figureα2
</td><td>10mks</td></tr>
</table>

Table 6.37(contd): Question 2 Marking Scheme

<table>
<tr>
<td>

- Student is able to convey a liquid in a drawing which includes <u>all criteria from:</u> **Randomly directed arrows** or **in the direction of gravity**, visible water symbols, arrows larger than for solid particles, similarly sized particles to solids (and other particles in this phase) and the same number of particles as illustrated in the gas phase **but wrongly indicates an inter-particulate space that is larger than a solid** (actually incorrect in absolute terms) **and much less than a gas**.

- Student is able to display a solid in a drawing, which includes <u>all criteria from</u>**:** Randomly directed arrows, a small level of movement that is vibrational in nature and smaller than for a liquid, visible water symbols, similarly sized particles **but no** inter-particulate space (actually incorrect in absolute terms) – see Figs. β1 & β2.

<u>Written Examples:</u>

- Liquid: 'Condensation' or 'Changes to liquid' or similar.
- Solid: 'Freezing' or 'Changes to solid' or similar.

<u>Illustrated examples below</u>:
Figures α1 (representing condensation),
α2 (representing freezing),

</td>
<td>

8mks (Good Drawing)

5mks

(Very Good Explanation)

</td>
</tr>
<tr>
<td colspan="2">

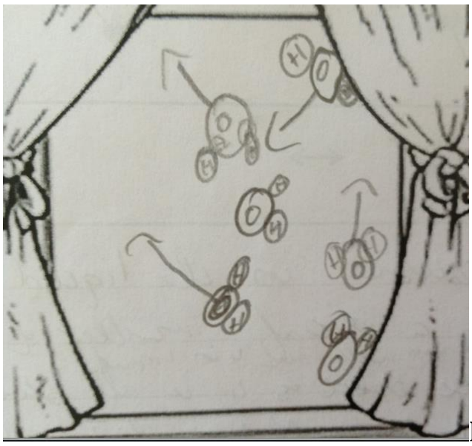


Figure α 1

</td>
</tr>
</table>

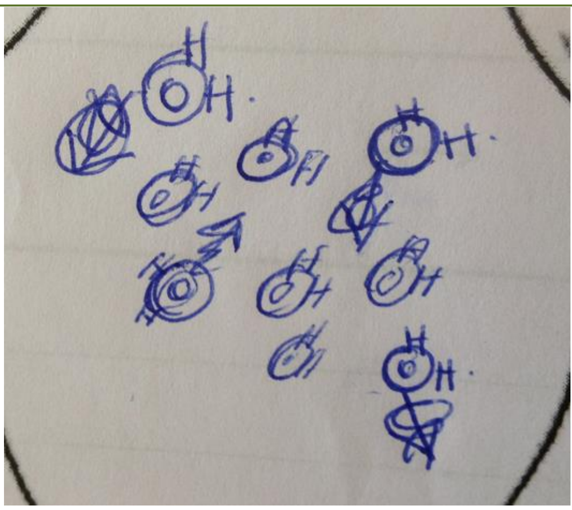
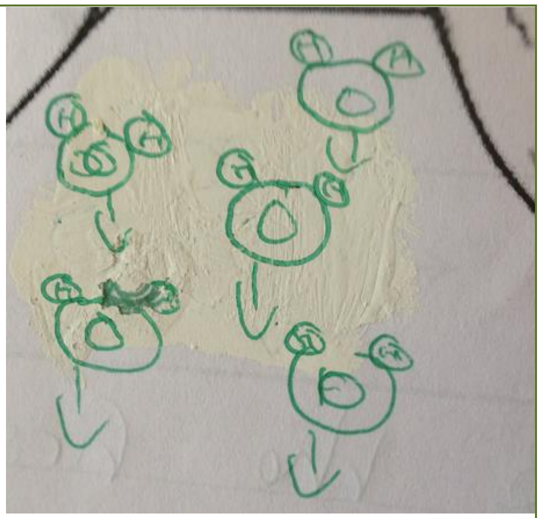
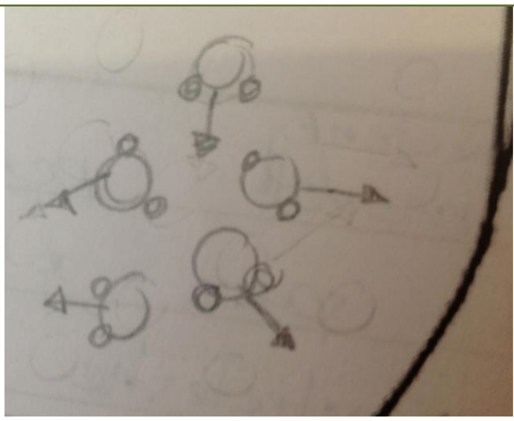
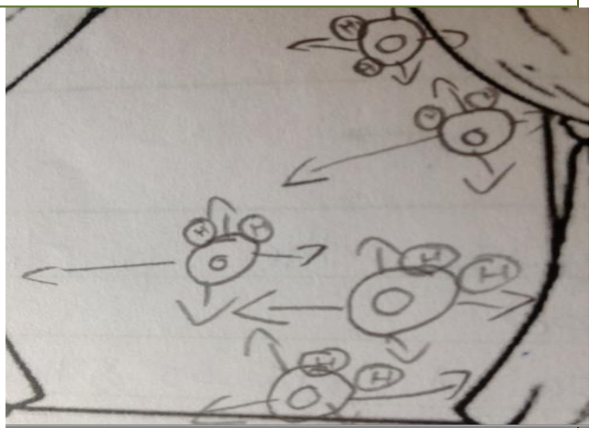
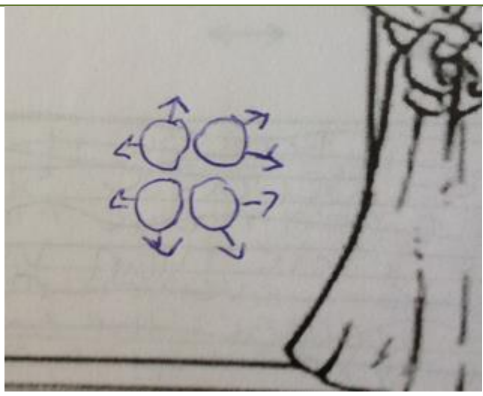
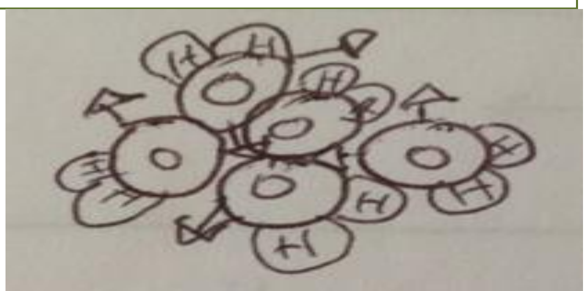
 **Figure α** 1	 **Figure α** 1
 **Figure α1**	 **Figure α1**
 **Figure α2**	 **Figure α2**

Table 6.37(contd): Question 2 Marking Scheme

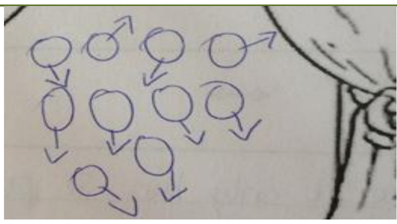
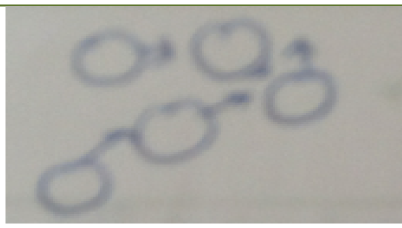
The grade of 'Average' is obtained if the student provides: • A 'Very Good' or 'Good' drawing with no, or an incorrect, explanation. Examples of Good and Very Good drawings are given in Tables 6.38 and 6.39. • An average standard drawing of a liquid (as a result of condensation) or a solid (as a result of freezing) only or accompanied by a Very good', 'Good' or 'Basic' explanation. Characteristics of 'Average Drawings' can be obtained in this table (in the subsequent paragraph to that which follows) with examples at the bottom of this table. Examples of 'Average' explanations are given in the final paragraph in this table. Examples of 'Basic' explanations are given in below. • A basic standard drawing (see Table 42) with a 'Very good, 'Good' or an 'Average' explanation. Examples of 'Average' explanations are given in the final paragraph in this table. The grade of 'Average' is obtained from the following drawn answers for the liquid or solid: • Liquid: An incorrect inter-particulate distance which appears to be approximately at an intermediate distance between a solid and a gas and any two of the following criteria: Randomly directed arrows, visible water symbol included, similarly sized particles as solids (and other particles in this phase) and the same number of particles as illustrated in the solid phase –see Figure γ1. • Solid: Student drawing illustrates **no** inter-particulate space or **a little** inter-particulate space and includes **any one of the following criteria:** randomly directed arrows, a small level of movement that is vibrational in nature and smaller than for a liquid, visible water molecules, similarly sized particles – Written 'Average' Explanations: • For liquids - 'Turns into water droplets', 'It creates fog', 'it will moisturize the window', 'It can turn into steam', 'water got stuck and our dripping off the window',' they are droplets, 'If it gets warmer the water in one drip down', 'All the particles drip down', 'Window will fog up'. 'they don't vibrate but don't move as far apart as a gas'. • For solids – 'The cold window made the water and stick. 'They will turn to ice'. • For both solid and liquid: It changes state of matter	**10mks Very Good Drawing** **8mks Good Drawing** 10/8+0/1: 8-11 **4mks Average Drawing** **5mks Very Good Explanation/ 4mks Good Explanation/ 2mks Average Explanation /1mks Basic Explanation** 4 +5/4/2: 6-9 **2mks Basic Drawing** **5mks Very Good Explanation/** **4mks Good Explanation/** **2mks Average Explanation: 2+5/4/2: 4-7**
 Figure γ1  Figure γ1	

Table 6.37 (contd): Question 2 Marking Scheme

<table>
<tr><td>The grade of ‘Basic’ is obtained if the student provides: Written ‘Basic’ explanations <u>only</u>, ‘Basic’ drawings <u>only</u> or <u>both</u> ‘Basic’ explanations and drawings.

For the purposes of analysis, ‘Basic’ explanations are divided into
• General
• Liquid
• Solid

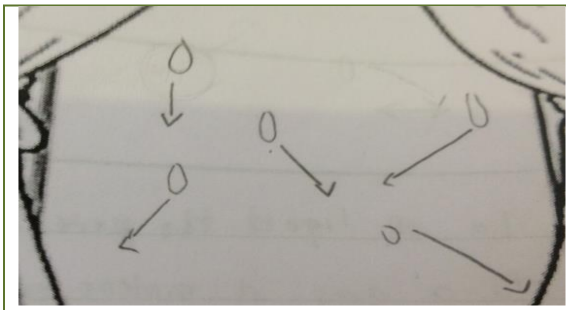
Also, for the purposes of analysis, ‘Basic’ drawings are divided into
• Macro level drawing (Liquid)
• Macro level drawing (Solid)
• Water molecule splitting into O atoms
• Water molecule splitting into H atoms
• Water molecule splitting into H and O atoms
• Water molecule remains in gaseous form</td><td>2mks Basic Drawing / 1mksBasic Explanation
2+1/0: 2-3
or 0 + 1:1
Range: 1→ 3</td></tr>
<tr><td><u>Written ‘Basic’ Explanations:</u>
General Basic: ‘Because the window is cold, water particles will react to it’, ‘Particles will be at this closer to each other’, It changed state of matter’, ‘They can move away from the window’, ‘(particles) Will go to the top because it is colder up there’, ‘They will be blown down once they reach the window’, ‘Water particles are loosely together and move a lot’, ‘They want to get out to the air and the light’, ‘The liquid turns into oxygen’ ‘Hot and cold’, They will evaporate’, ‘They are moving away because it touches cold and will disappear’, ‘It can move much more, ‘It loosens even more and becomes a gas’, ‘They have hit the window and come closer together’, ‘When water particles hit the surface of the window the water starts to build up on top of other particles’, ‘Water will go out of the window’, They are all apart from each other and pointing out the window..

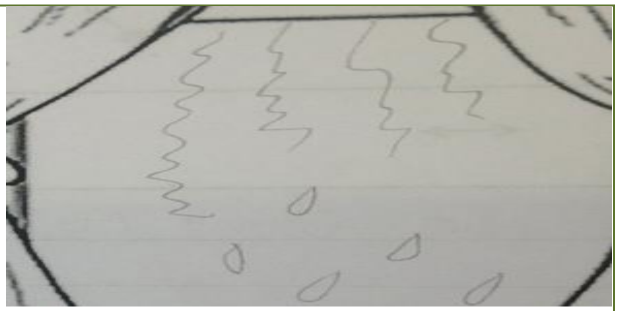
Liquid Basic: ‘Water would land on the window’, ‘They will cool down when they hit the window’, ‘Will make a puddle on the window’, ‘Will start to slip down the window’, ‘Water will meet the cold air and fall down’, ‘Water will fall down’

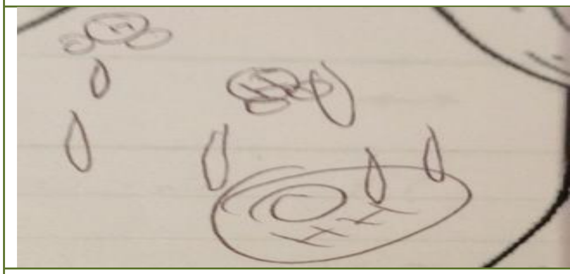
Solid Basic: ‘When the particles gets closer they break up and freeze’, ‘

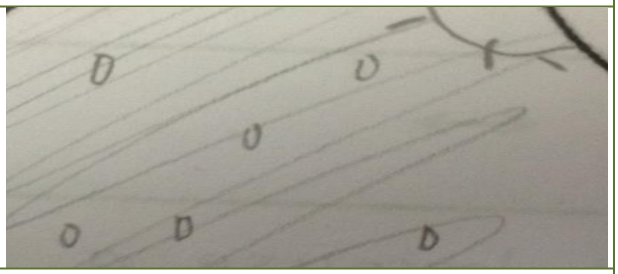
<u>Examples:</u> include the drawing of: the incorrect state, overlapping molecules of water, a distorted particle shape, the macro version (ice or water) or a solid lattice or liquid lattice, the splitting of the water molecule into Hydrogen molecules, Hydrogen atoms, Oxygen atoms or both Hydrogen and Oxygen atoms.</td><td>1 mark</td></tr>
<tr><td>Blank</td><td>0mk</td></tr>
</table>

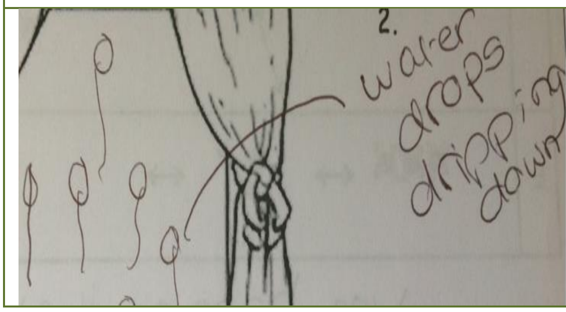
Macro Level Drawing (Liquid)

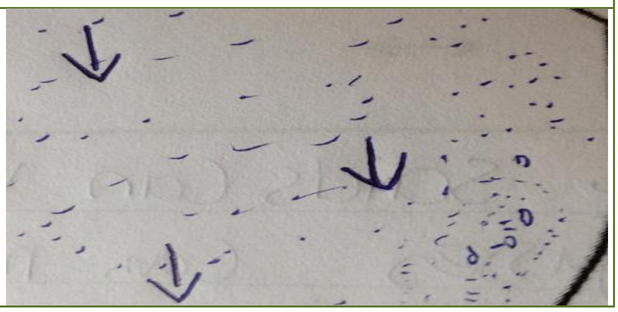




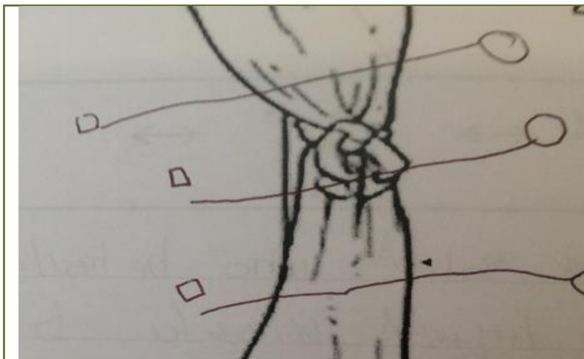


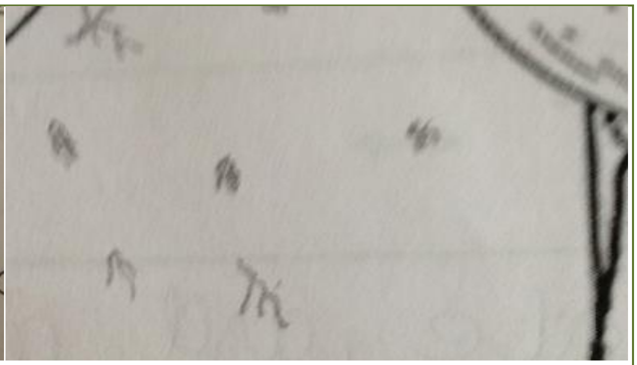




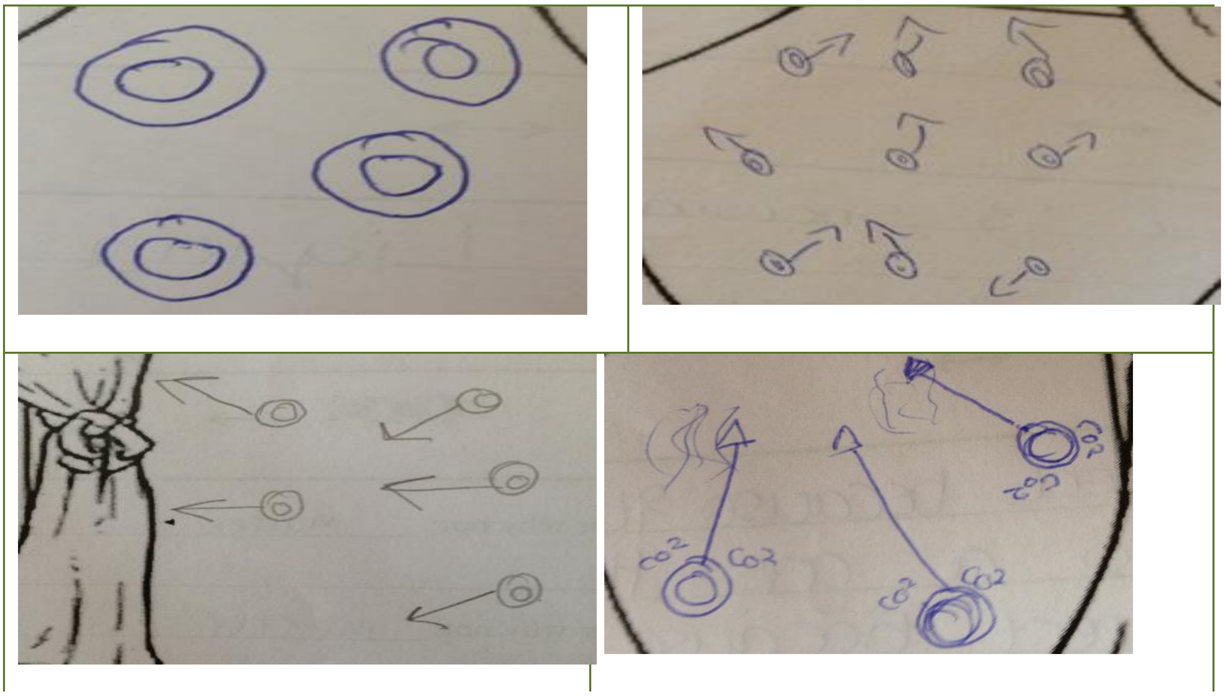


Macro Level Drawing (Solid)

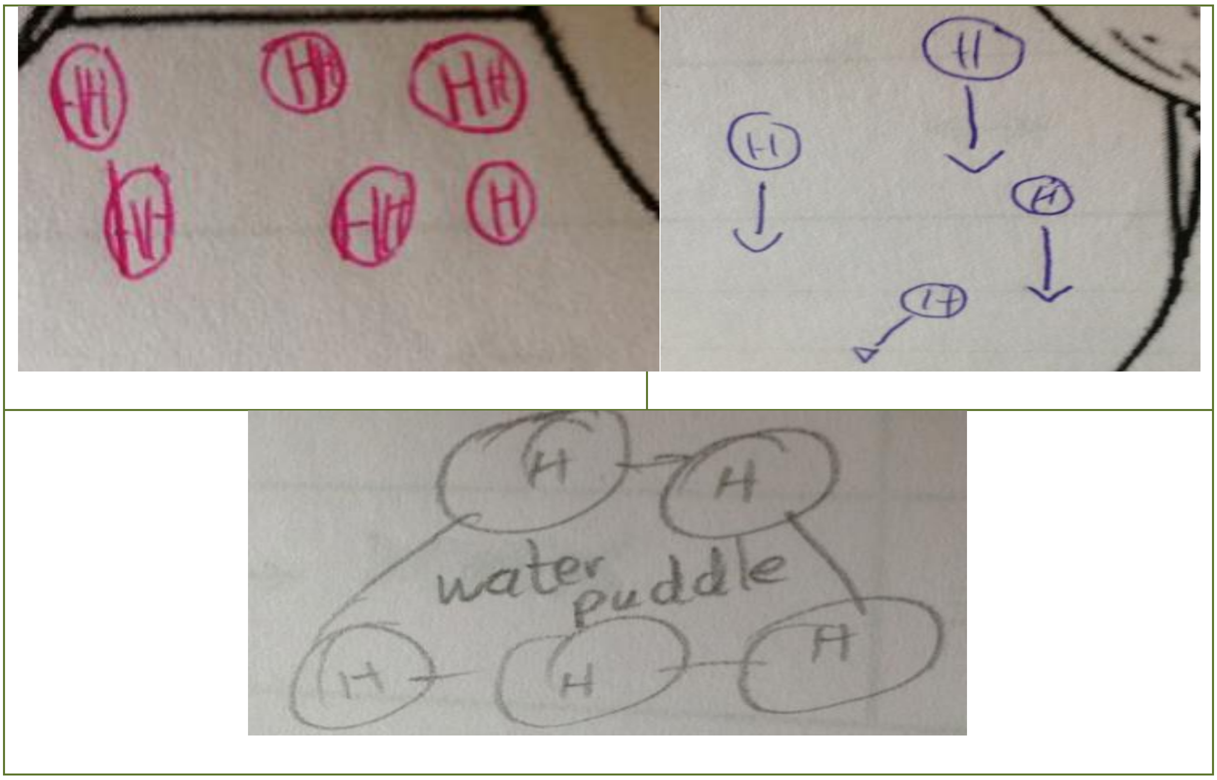




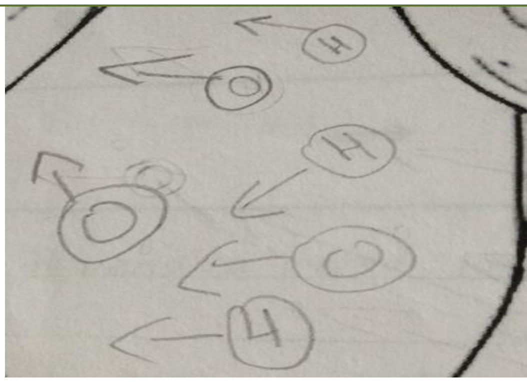
Water Molecule Splitting to O atoms



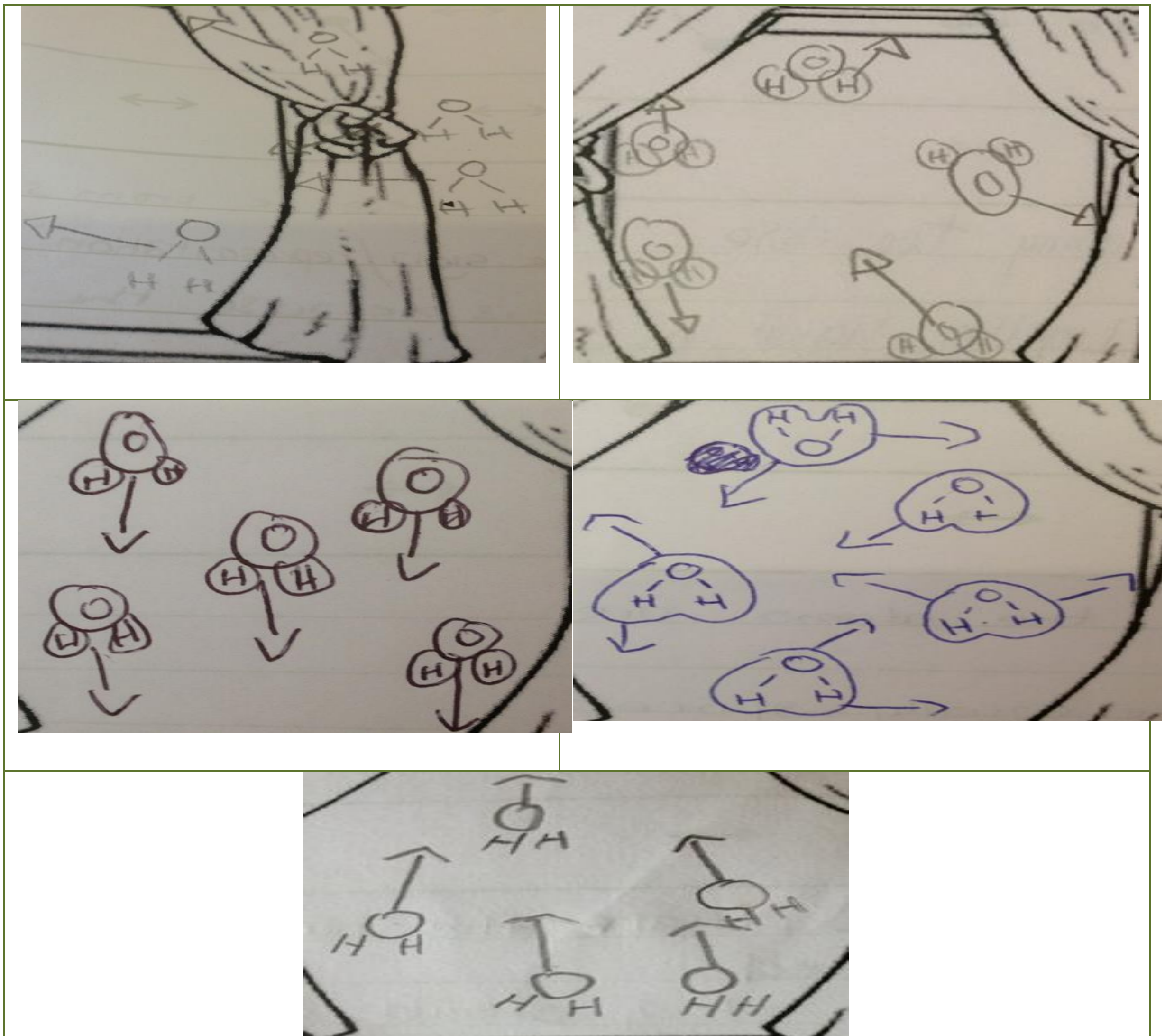
: Water Molecule Splitting to H atoms



Molecule Splitting to H and O atoms

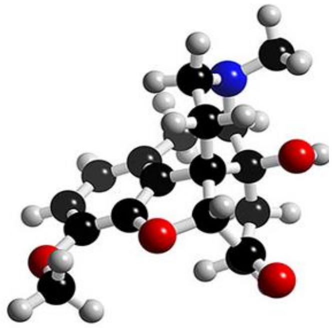


Water Molecules Remain in Gaseous Form



QUESTION.3 *Shown below is a picture of some paracetamol tablets next to a model of what a particle of paracetamol looks like.*

The blue sphere represents a nitrogen atom, the black spheres, carbon atoms, the white spheres hydrogen atoms and the red spheres represent oxygen atoms



(a) Explain why you think that paracetamol is either an atom or a molecule

(b) Explain why you think that the tablets of paracetamol represent an element or a compound.

Question 3:

This question asks students to look at a previously unseen (complex) molecule and choose whether it is an example of an atom or molecule and subsequently whether it is an element or compound. In terms of each part and the overall task students are asked to explain their thinking so the question is causal in nature.

Table 6.38: Question 3(a) Construct System

	SUPERORDINATE CONSTRUCT: The capacity to visualise a molecule.		
Increased Comprehension ↑	**Preferred Pole**	**Non-Preferred Pole**	**Critical Differentiation Pole**
	Full qualitative understanding of the atomic level.	Full visual understanding of the atomic level.	Limited range of (accurate) particulate language.
	Full visual understanding of the atomic level.	Apparent understanding of the atomic level.	Absence of qualitative detail at atomic level.
	Apparent understanding of the atomic level	Alternative understanding of the atomic level	Absence of reasoning at atomic level.
	Alternative understanding of the atomic level	Absence of understanding of the atomic level	No atomic level understanding.

Table 6.39: Question 3(a) Marking Scheme

MARKING SCHEME	GRADE
• Students were able to use the plural term 'atoms'. • Some students may have reasoned from the diagram in the question that a molecule is made from 'more than one <u>type</u> of atom'. <u>Written Examples:</u> • 'Molecule' (Correct answer) **and** 'More than one type of atom' or 'Many different atoms' or 'More than one atom' or 'More than one element present'.	**5mks**
• Students' answer was lacking in qualitative detail. They may have omitted the word 'atom' from their answer but visually understood the term 'molecule'. • Some indicated that 'atoms were mixed'. • Others used the term 'particles' in their explanation. <u>Written Examples:</u> • 'Molecule' (Correct answer) **and** 'Different kinds of particles' or 'Different kinds of colours' or 'Different kinds of dots' or 'They are not all the same'.	**4mks**
While writing the answer, student failed to adequately, or accurately explain their reason for selection. <u>Written Examples:</u> • Molecule (Correct answer) **and** 'different things' or 'is not an element' (inaccurate reason) or no reason given (which may signal the possibility that the student is guessing.	**2mks**
• Some students see multiple individual atoms as 'adding up to an atom' but do not see a resultant molecule. <u>Written Examples:</u> • Atom	**1mk**
• Blank	**0mks**

QUESTION 3 (B)
(b) Explain why you think that the tablets of paracetamol represent an element or a compound.

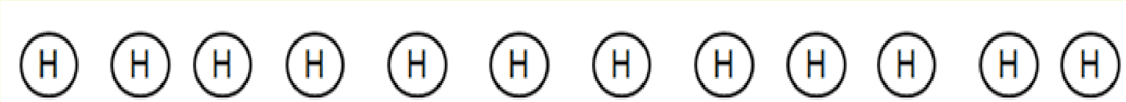
Table 6.40 Question 3(b) Construct System

Increased Comprehension	**SUPERORDINATE CONSTRUCT:** The student understands the particulate components of an element and compound.		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
	Full qualitative understanding of the particulate components of a compound.	Full visual understanding of the particulate components of a compound.	Limited range of (accurate) particulate language.
	Full visual understanding of the particulate components of a compound.	Apparent understanding of the particulate components of a compound.	Absence of integrated concepts.
	Apparent understanding of the particulate components of a compound.	Alternative understanding of the particulate components of a compound.	Absence of reasoning at atomic level.
	Alternative understanding of the particulate components of a compound.	Absence of understanding of the particulate components of a compound.	No atomic level understanding.

Table 6.41: Question 3(b) Marking Scheme

MARKING SCHEME	GRADE
• Students can both visualize a compound and convey a comprehensive qualitative written explanation of what it is. <u>Written Examples:</u> • Compound **and** more than 'One type of element' or 'Many different elements' or 'Different types of atoms'.	**5mks**
<u>Written Examples:</u> • Compound and 'As not in periodic table' or 'Made up of different things' or 'Makes up 'something new', 'there are a different number of atoms'.	**4mks**
<u>Written Examples:</u> • Compound **and** inaccurate reason e.g. 'As it has oxygen in it', 'mixture of elements'.	**2mks**
• Student was confusing the terms 'element' and 'compound'. <u>Written Examples:</u> Element **and** an inaccurate reason e.g. 'Since they are all atoms' or no reason given.	**1mk**
• Blank	**0mks**

QUESTION 4 *How many particles of hydrogen (symbol = h2) could you make from the following (shown in the box below)?*



Number of Particles =

Explain your answer:

Question 4:

This question required students to link the symbolic to the particulate and explain how many Hydrogen molecules could be made from the 12 atoms illustrated. The application of the knowledge that Hydrogen is a diatomic molecule was required to solve this problem, which is procedural. The question then becomes causal as the second line requires students to explain how they arrived at their answer.

Table 6.42: Question 4 Construct System

Increased Comprehension ↑	**SUPERORDINATE CONSTRUCT:** The capacity to apply knowledge of the meaning of a chemical symbol.		
	Preferred Pole	**Non-Preferred Pole**	**Critical Differentiation Pole**
	Completion of arithmetic operation based on a full qualitative understanding of the symbolic level.	Completion of arithmetic operation based on full qualitative understanding of the symbolic level excluding full description of model features.	Limited range of (accurate) particulate language.
	Completion of arithmetic operation based on full qualitative understanding of the symbolic level excluding full description of model features.	Apparent understanding of the symbolic level.	Absence of integrated concepts
	Apparent understanding of the symbolic level.	Alternative understanding of the symbolic level.	Selective application of cues in question (Associative Activation).
	Alternative understanding of the symbolic level.	Absence of understanding of the symbolic level.	No symbolic level understanding

Table 6.43: Question 4 Marking Scheme

MARKING SCHEME	GRADE
Written Examples: • 6 (correct interpretation of the formula) **and** 'There are two Hydrogens in one particle' or, 'H + H = H_2' or 'Every 2 'H' makes 1 'H_2' or 'You put two 'H' together' or 'The Hydrogens come in twos' or 'Keep putting two H'S together' or 'I put two H's together and made it as one' or 'The symbol is H_2 so every 2H's is a particle' or 'Because there is 2 'H' in H_2 so that's why there's six'.	**5mks**
• Students did not respect the scientific protocol of referring to a H atom specifically, in their written explanation[a]. • Students incorrectly used the 2 in the formula, for Hydrogen, in their explanation as a superscript, instead of a subscript[b]. • They may not have understood the true meaning of the terms 'atom' or 'molecule' and referred to molecular units as 'particles[c]'. Written Examples: • 6 (correct interpretation of the formula) **and** • 'They join together'[a] or '6 pairs of 2'[a] or 'Pair them up'[a] or 'You need pairs'[a] or 'There's two in each'[a] or 'You need 2 each'[a]. • 'Two H's make H^2'[b] or 'H^2 is 2 Hydrogen so you count how many there is and divide by 2'[b] • 'Every particle has to have two'[c].	**4mks**
2mks obtained if the correct answer **or** the correct reason (if no answer given in first part) is provided.	**2mks**
Written Examples: • 24 Molecules: '24 - One 'H' = 'H_2' – it goes in twos, '24 – all the H's add up to 12 and multiply by 2.' Note: There is the presence of the alternative conception that H_2 =**2**H_2 [working on the premise that the subscript indicated that there should in fact be two molecules of hydrogen]. • 12 molecules: 'Because there are 12 (H) and it is hydrogen', '12 – There are 12 H's', 'I counted them', • 4 Molecules: '4 – Get three H's and put them together'.	**1mk**
• Blank	**0mks**

QUESTION 5 *If a particle of nitrogen can be represented by…*

And a particle of hydrogen can be represented by…

Draw in the box below what the symbol NH_3 means if it used to represent ammonia gas:

Question 5:

The penultimate question of the exam asks students to apply their knowledge of the symbolic to draw the corresponding particulate representation. It is therefore procedural in nature.

Table 6.44: Question 5 Construct System

	SUPERORDINATE CONSTRUCT: The capacity to apply knowledge of the meaning of a chemical symbol to a molecular drawing.		
Increased Comprehension	**Preferred Pole**	**Non-Preferred Pole**	**Critical Differentiation Pole**
	Full understanding of symbolic in relation to particulate.	Full understanding of symbolic in relation to particulate excluding structural nature of molecule.	Partial qualitative understanding of molecular structure
	Full understanding of symbolic in relation to particulate excluding structural nature of molecule.	Alternative understanding of the relation between the symbolic and particulate.	Selective application of cues in question (Associative Activation).
	Alternative understanding of the relation between the symbolic and particulate.	Alternative understanding of the symbolic level.	Activation of the number 3. (Associative Activation).
	Alternative understanding of the symbolic level.	Absence of understanding of the symbolic level.	No symbolic level understanding

Table 6.45: Question 5 Marking Scheme

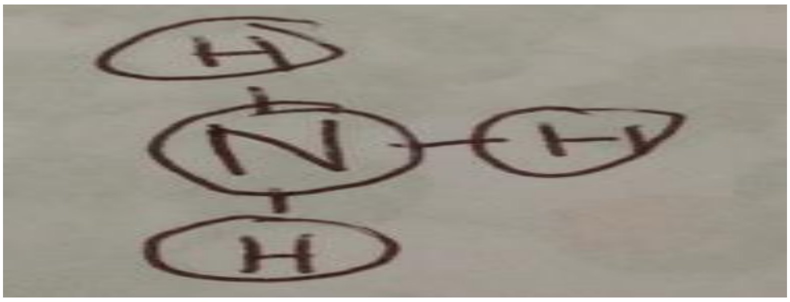
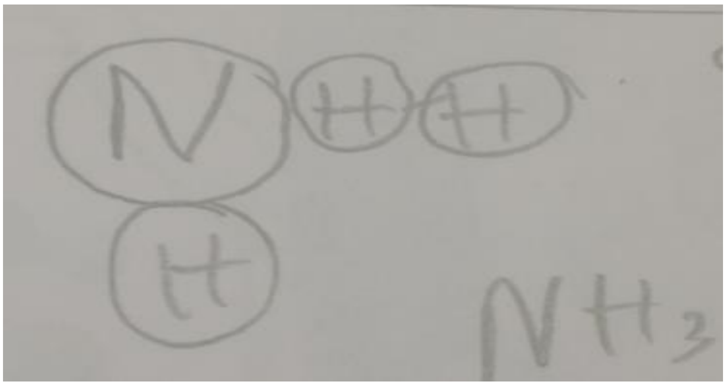
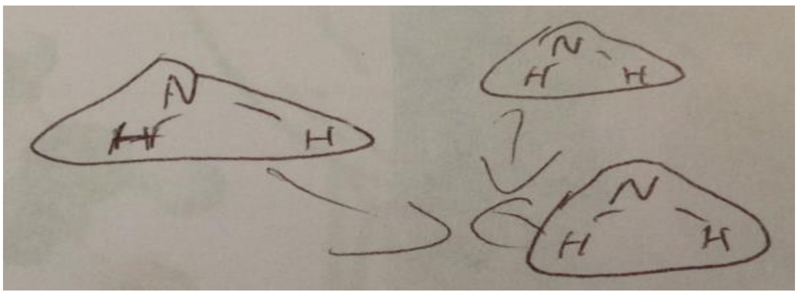
MARKING SCHEME	**GRADE**
Central N with 3 H's around it.	**5mk**
	
N not central to three H's or 3H's are not all connected to N. This type of representation is an additive one where students understand the number of atoms in the molecule but are unaware of the structure.	**4mks**
	
NH_2 or NH_4 drawn. The structures they draw are additive representations of their mental models and they may have no understanding of the formula symbol informing them of the appropriate combination of atoms in the molecule.	
	**2mks**

Table 6.45(contd): Question 5 Marking Scheme

<table>
<tr><td colspan="3">

- Some students chose not to deconstruct the formula and put atoms of NH_3 in the gaseous state – see Figure δ5.
- Some students multiply both atoms by three – see Figs. δ2, δ3.
- The structures other students drew are additive representations of their mental models Figs δ4, δ5.
- Some students provided inappropriate atomic combinations– see Figs δ6, δ7.
- Some students may have had difficulty transferring the symbolic model of ammonia to the submicroscopic - see Figs δ8.
- Other students represented their interpretation of the formula in the form of three NH single atomic units. – see Figs δ9, δ10.
- Some students offered inappropriate atomic combinations. Each component of the formula was therefore assigned to an atom of its own – see Fig. δ11.

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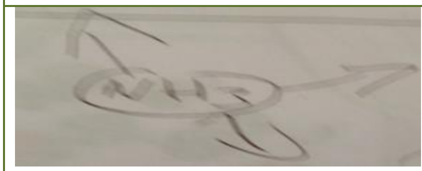
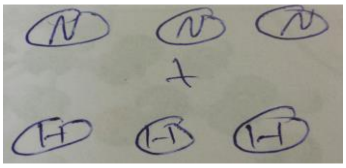
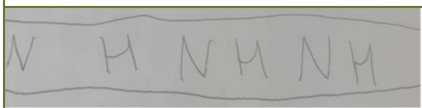
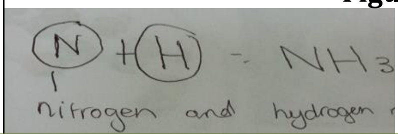
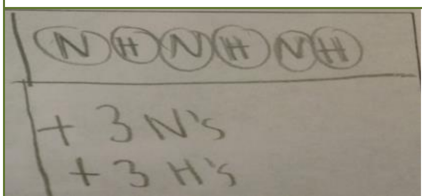
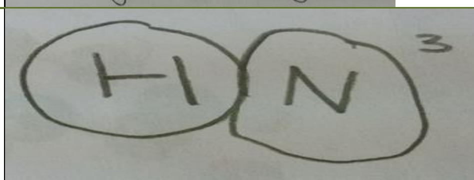
<tr><td>
Figureδ1</td><td></td><td>**Figure**δ4
</td><td></td></tr>
<tr><td>
Figureδ2</td><td></td><td>**Figureδ5**
</td><td></td></tr>
<tr><td>
Figureδ3</td><td></td><td>
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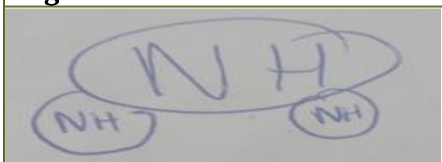
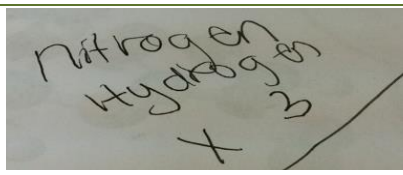
<tr><td>
Figureδ7</td><td></td><td>
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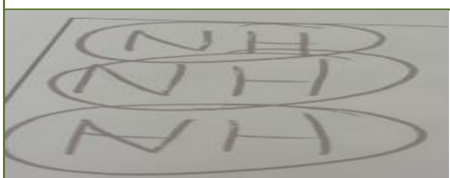
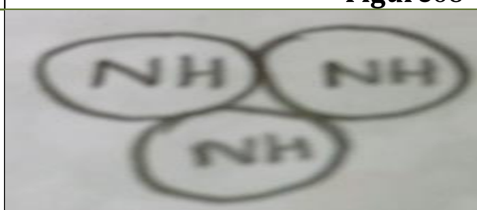
<tr><td>
Figureδ9</td><td></td><td>
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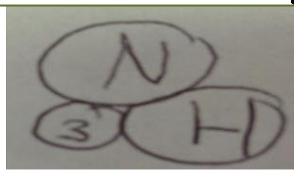
<tr><td colspan="2"></td><td>
Figureδ11</td><td></td></tr>
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</table>

6.5 Results of Diagnostic and Summative Assessments

Table 6.46 displays the results to the diagnostic assessment of phase 3. Each column denotes a category from 'Very Good' to 'Basic'. It is a scale that captures answers with quality explanations where maximum marks were awarded to an indecipherable or blank answer where zero marks were awarded. The same scale applies to the summative exam, which is described in the next section. The 'Mean Score %' is the percentage score received in each component of a question.

Table 6.46: Phase 3 Diagnostic Assessment Results (N=17)

Question/ Category	Very Good	Good	Average	Basic	Zero	Mean Score %
1	23.5	35.2	17.6	17.6	5.9	61.8
2	5.9	23.5	0.0	58.8	11.7	30.5
3 (a- solid)	5.8	58.8	11.7	17.6	5.9	61.1
3 (a- liquid)	5.8	29.4	41.1	17.6	5.9	49.4
3 (a- gas)	41.1	11.8	17.6	23.5	5.9	62.4
3b	58.8	5.9	23.5	11.8	0.0	75.2
4(a)	35.3	17.6	17.6	29.4	0.0	62.4
4(b)	17.6	5.9	58.8	11.8	5.9	45.3
5 (frozen)	11.8	35.3	35.3	11.8	5.9	56.4
5 (unfrozen)	29.4	5.9	5.9	52.9	5.9	47.0
7	11.8	0.0	5.9	76.5	5.9	21.8
8	11.8	35.3	35.3	17.7	0.0	63.5

Students were seen to perform best in questions 1 and 3 while their poorest levels of success were in questions 2 and 7. Question 2 was an abstract question involving the relation between heat energy and increased particulate speed. A visual cue was not provided which may have hindered students. Question 7 related to the inter-particulate distance between liquids and was designed to be counter-intuitive so was probably the most difficult question on the exam.

Table 6.47 indicates the average scores that the student cohort attained in each question of the summative exam. The 'Mean Score/Q' is the percentage score attained in a question taken in its entirety. 'C' indicates the control group while 'I' indicates the intervention cohort. Statistical significance is based on a Welch Two Sample t-test.

Table 6.47: Phase 3 Summative Assessment Results [Intervention (N=20); Control (N = 99)]

Question		Category	Very Good	Good	Average	Basic	Zero	Mean Score %	Mean Score /Q
1	1 (a)	I	10.0	15.0	10.0	50.0	15.0	36.0	I* = 51.8% C*= 25.5 % *= Sig. diff.
		C	0.0	7.1	3.0	66.7	23.2	20.2	
	1 (b)	I	10.0	35.0	15.0	25.0	15.0	49.0	
		C	0.0	8.1	27.3	38.4	26.3	25.0	
	1 (c)	I	15.0	40.0	20.0	5.0	20.0	20.2	
		C	0.0	7.1	16.2	47.5	29.3	56.0	
	1 (d)	I	30.0	20.0	25.0	5.0	20.0	60.0	
		C	6.1	7.1	22.2	37.4	27.3	28.0	
	1 (e)	I	25.0	40.0	10.0	5.0	20.0	62.0	
		C	4.0	19.2	14.1	34.3	28.3	31.9	
2	2 (a)	I	15.0	10.0	15.0	50.0	10.0	40.0	I* = 40.0% C*= 21.3 % *= Sig. diff.
		C	1.0	0.0	2.0	77.8	19.2	16.0	
	2 (b)	I	20.0	5.0	10.0	60.0	5.0	40.0	
		C	12.1	8.1	13.1	39.4	27.3	32.0	
3	3 (a)	I	50.0	5.0	10.0	30.0	5.0	64.0	I* = 65.0% C*= 40.0 % *= Sig. diff.
		C	22.2	4.0	13.1	48.5	12.2	40.4	
	3 (b)	I	40.0	25.0	0.0	30.0	5.0	66.0	
		C	22.2	40.0	14.1	47.5	12.1	40.0	
4	4	I	75.0	15.0	5.0	5.0	0.0	90.0	I* = 90.0% C*= 53.0 % *= Sig. diff.
		C	28.3	17.2	6.1	42.4	6.1	52.9	
5	5	I	70.0	0.0	5.0	25.0	0.0	77.0	I* = 77.0% C*= 35.4 % *= Sig. diff.
		C	19.2	2.0	2.0	59.6	17.2	35.4	

The intervention group is seen to outperform the control group in all questions and each result is statistically significant at a 0.05 level. The poorest performances on average were Questions 1 and 2 by both cohorts while the intervention group performed best in Question 4**.** All parts of Question 1 relate to the particulate behaviour of matter requiring a detailed written explanation. This may have proved more difficult than a drawn explanation. Question 2 involved the concept of condensation which students had found difficult throughout the previous two phases.

6.6 Repertory Grid Analysis

This section presents and discusses results from the repertory grid analysis. Section 6.6.1 presents the basis of the analysis of repertory grids while sections 6.6.2-6.6.4 represent the results of the three grids generated. The data from each of three sets of grids were subjected to analysis with the objective of discovering (i) how the students in the intervention cohort saw themselves as scientists, (ii) the affective nature of the IBL module and the (iii) cognitive nature of the IBL module. The analysis was conducted using OpenRepGrid and in each case, the following is produced:

(i) a basic grid;
(ii) a principal-component analysis plot.

6.6.1 The Basis of Repertory Grid Analysis

(i) A Basic Grid:

From the dichotomous nature of concepts (Kelly, 1955/1991), as discussed in Section 3.4.3, it is possible to say that a construct is bipolar. This nature of a construct permits elements to be located between the poles of a construct, and rating formulations of responses in grids take advantage of this. Kelly's 'Organisation Corollary' posits that relationships between constructs used to construe a set of elements do exist. Fransella et al. (2003) note that analyses of this relationship such as principal-component analysis are based on measures of association between constructs, such as correlations, distances etc. They build on the fact that such measures are essentially symmetrical i.e. the relationship between Construct A and Construct B is the same as the relationship between

Construct B and Construct A.

(ii) Principal Components Analysis (PCA)

There are patterns of variability that exist in a repertory grid: the number of different ways in which the values of the ratings vary. According to Fransella et al. (2003), PCA works by looking at the variability within a grid and identifying any distinct patterns of variability. This is carried out by following procedures that calculate the extent to which ratings in each row of a grid are similar to one another. Correlation between each row and each other row are used to identify each distinct pattern.

The process is iterative. Firstly, the pattern accounting for the largest amount of variability is identified, reported, and removed (or statistically set aside). The next pattern is identified likewise, and so on, until all of the variability has been accounted for. These patterns of variability are called 'components' and can be graphed. The plots for components that, when added together, account for 80% or more of the variance are usually examined. Percentage variance is a measure that determines the validity of the analysis. The majority of the variance should be accounted for in the first two components for a two dimensional plot to be viable. This allows one to plot the way in which the elements and the constructs within a repertory grid are arranged with respect to two principal components. By convention, the *horizontal* axis represents the *first* component and the *vertical* axis the *second*. They are set at right angles to each other, because they represent maximally distinct patterns in the data. The constructs are plotted as straight lines. Jankowicz (2004) indicates that the angle between any two construct lines reflects the extent to which the ratings of elements on those constructs are correlated: the smaller the angle, the more similar the ratings. Also, the angle of a construct or group of constructs with respect to each component line reflects the extent to which the construct is represented by the component: the smaller the angle, the greater the extent. Fransella et al. (2003) explain that each component may be viewed as a statistical invention, whose purpose is to represent one of the different patterns in the grid. As each component 'stands for' several constructs, the elements can be positioned along each component, in place of their original position along each construct; there they are plotted. The resulting plot is an illustration of patterns of similarity. With respect to the location of elements on a plot, Jankowicz (2004) indicates that the distance between any two elements reflects the ratings each element received on all the constructs. Any two elements close together in the graph received similar ratings, whereas any which are located far apart would tend to be rated differently on the original grid. To link the colloquial nature of the names assigned by respondents to the emergent/preferred and implicit/non-preferred poles of constructs, a term from PCP and/or the science education literature is assigned to the preferred pole. This is undertaken to give the construct or group of constructs in question a context regarding issues in cognitive research. These labels include the PCP corollaries of 'Construction', 'Sociality' and 'Choice'. They also include the name of 'Permeability' given to describe aspects of a construct (Fransella et al., 2003). Lastly, to acknowledge the nature of conceptual change, the transitional construct of 'Aggression' is used. It is referred to in this section as 'Kellyian Aggression'. Finally, the term of 'Metacognition' from the science education literature is employed.

6.6.2 Results: How I as a Student See Myself as A Scientist

The constructs in Table 6.48 were identified by students in phase 3 regarding 'How I See Myself as a Scientist'. The table illustrates the preferred pole of the construct group on the left hand side and the non-preferred pole on the right side.

Table 6.48: Phase 3: Constructs in relation to 'How I see Myself as a Scientist'

Preferred Pole	**Non-Preferred Pole**
Use experiments to prove theories	Guessing instead of testing theories
Kept trying to solve the problem	Just gave up
Tested problems for themselves	Influenced by what other people told them
Risk taker	Play it safe

These constructs were rated according to seven elements deemed related to the work of a scientist by students in the intervention group. The resultant aggregate repertory grid forms a 4x7 matrix shown in Table 6.49

Table 6.49: Phase 3: Repertory Grid 'How I see Myself as a Scientist' (N=11)

Rating = 1	Fleming	Galilleo	Frankland	Lotrenux	Redux	How I see myself as a scientist now	How I see myself as a scientist Ideally	Rating = 5
Use experiments to prove theories	2.8	1.6	1.3	3.5	3.6	2.4	1.9	Guessing instead of testing theories
Kept trying to solve the problem	2.8	2.0	1.5	4.0	4.0	2.6	1.9	Just gave up
Test problem for themselves	2.8	1.5	1.5	4.2	4.0	2.8	2.5	Influenced by what other people told them
Risk Taker	2.5	2.1	1.4	2.6	2.6	3.0	2.7	Play it safe

The scientist who receives the average ratings that are consistently closest to the preferred poles of the constructs is Bill Frankland. Gallileo received an equivalent rating along the construct 'Tested problems for themselves---Influenced by what other people told them'. In terms of the element 'How I see myself as a Scientist', students scored themselves on average along these constructs in the range of 2.4 to 3.0. This element received its highest rating along the construct: 'Use experiments to prove theories---Guessing instead of testing theories'.

A PCA of this grid was then generated and is illustrated in Figure 6.2(a). The PCA of the same constructs when organised by theme is given in Figure 6.2(b).

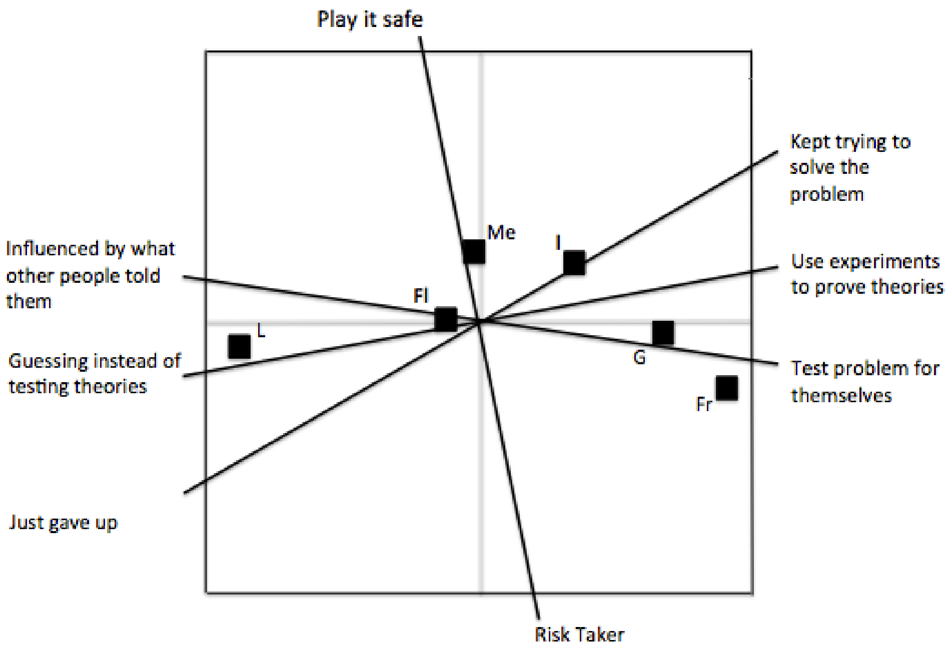


Figure 6.2(a): Phase 3: PCA of 'How I see Myself as a Scientist' (N=11)
(Variation accounted for by Component 1 is 92.7% while component 2 accounts for 5.2%)

Key

R= Redux Pharmaceuticals
L = Lotrenux Pharmaceuticals
Fl = Alexander Fleming (Scientist)
Fr = Bill Frankland (Scientist)
G = Gallileo (Scientist)
Me = How I see myself now as a Scientist / I = How I see myself ideally as a Scientist

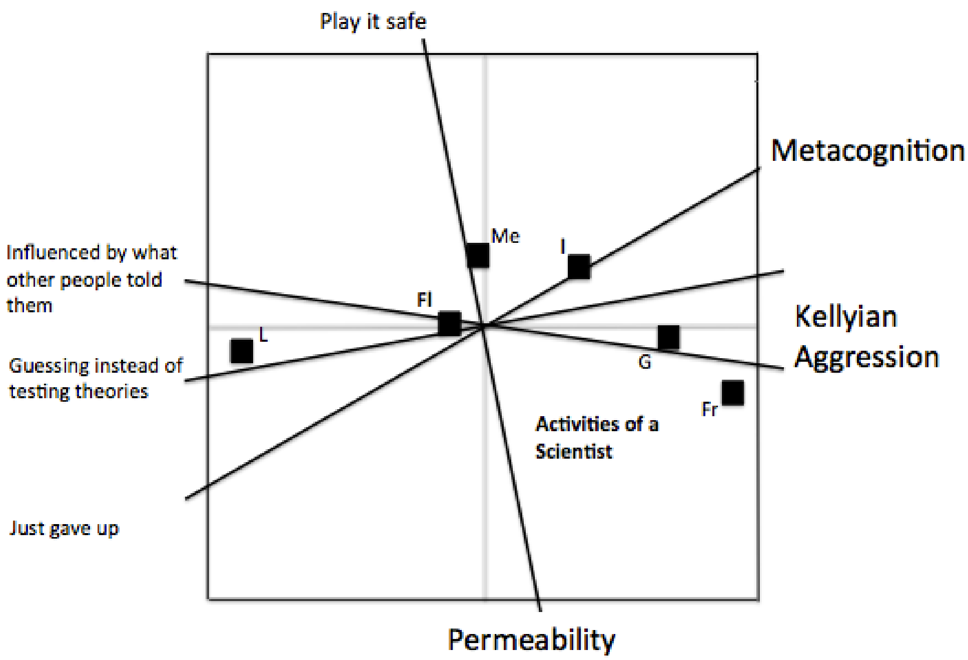


Figure 6.2(b): Phase3: PCA of 'How I see Myself as a Scientist' by Construct Set (N=11)

The poles corresponding to the 'Activities of a Scientist' appear on the right-hand side of the PCA. These traits in these poles enable a student to behave like a scientist according to Kelly's Fundamental Postulate (see Section 3.4.3). Component 1 (horizontal axis) and Component 2 (vertical axis) account for approximately 98% of the variance of the ratings. There is a pair of constructs that lie near the first component. These are:

> 'Use experiments to prove theories--- Guessing instead of testing theories'
>
> and
>
> 'Tested problems for themselves--- Influenced by what other people told them'.

Together, their positive poles may be described by the PCP corollary of '*Kellyian Aggression'* (see Section 3.4.3), which is to actively experiment in order to check the validity of construing so that one's construct system may be elaborated. The construct 'Use experiments to prove theories---Guessing instead of testing theories' is almost orthogonal to the construct 'Risk taker---Play it safe' which is distinct from this pair. The latter is related to the idea of '*Kellyian Permeability'* (see Section 3.4.3). This corollary describes the capacity of an individual to re-construct their construct system following invalidation so that a new theory may be generated. The element 'How I see myself now as a Scientist' lies towards the 'Play it safe' pole. It is also located closest to the element Alexander Fleming and is nearby another element; 'How I see myself ideally as a Scientist'. According to the PCA, the 'Ideal element' (How I see myself as a scientist ideally) sits on the construct:

'Kept trying to solve the problem---Just gave up'.

It is located towards the preferred pole of this construct, which may be described by the theme of '*Metacognition*'. This term relates to thinking about one's ideas and formulating an opinion.

6.6.3 Results: How I as a Student See the Pedagogy

During the second part of the interview, the constructs were generated as per phase 2. The PCA plot of the resultant repertory grid that was produced was cluttered and difficult to interpret so it was decided to divide the constructs into two separate groups: those relating to the *cognitive* aspect of understanding and the cohort that represented the *affective* nature of learning. The affective constructs are shown in Table 6.50 in italics.

Table 6.50: Phase 3: Constructs resulting from Repertory Grid Interviews related to the Pedagogy

	Preferred Pole	Non-Preferred Pole
Cognitive Perspective	Models look realistic	Molecules are not represented properly
	Gives me a visual aid that tells me what a molecule is like	Can't picture what a molecule looks like
	I can see how states of matter behave	I don't really know how states of matter behave
	Working in groups allows me to see what others are thinking	I only have my opinion
	I get to make my own notes and drawings	Just given notes that I might want to word differently
	Allows me to express my own way of understanding	Just given the information and I have to give it back exactly
	I actually get to figure things out for myself	I just look at and read the information that is given
	Allows me to think about what I have learned so that I can figure out and remember	I just read over someone else's thoughts
	I understand better if I make or model something	Just learn off notes and pictures
Affective Perspective	*I feel more confident as I know what atoms can make up a molecule*	*I would not be sure if I understand how to make a molecule with the right atoms*
	I feel I get to help someone who is confused (during group-work)	*I don't feel helpful*
	I know I understand and so I feel more confident	*I feel pressure as I'm not sure when I work on something on my own if it is enough to solve the problem*
	I use my own information to learn and I know from others the group that it is not wrong	*It's like maths where there is only one way of getting the answer*
	Get the opportunity to say what I think	*Just given notes that I might want to word differently*

The aggregate ratings that the element received along the cognitive constructs are illustrated in the Repertory Grid in Table 6.51 and forms a 9 x 4 matrix.

Table 6.51: Phase 3: Repertory Grid of how Students see the Pedagogy from a Cognitive Perspective (N = 20)

Rating = 1	Modelling	Textbook	Workbook	Ideal	Rating = 5
Models look Realistic	2.4	2.4	2.1	1.8	Molecules are not represented properly
Gives a visual aid that tells me what a molecule is like	1.8	2.3	2.0	1.8	Can't picture what a molecule looks like
I can see how states of matter behave	2.0	2.2	1.7	1.6	I don't really know how states of matter behave
Working in groups allows me to see what others are thinking	1.8	2.6	2.3	1.7	I only have my opinion
I get to make my own notes and drawings	2.0	3.1	2.1	2.0	Just given notes that I might want to word differently
Allows me to express my own way of understanding	1.5	3.1	2.2	1.6	Just given the information and I have to give it back exactly
I actually get to figure things out for myself	2.0	3.2	2.4	1.8	I just look at and read the information that is given
Allows me to think about what I have learned so that I can figure out and remember	2.0	3.0	2.4	2.0	I just read over someone else's thoughts
I understand better if I make or model something	1.6	3.2	2.3	2.0	Just learn off notes and pictures

The grid in Table 6.51 illustrates that the 'Ideal' element ('How I would like to see the workbook ideally') was nearest to the preferred pole along seven of the nine constructs. The element 'Modelling' received an identical rating to that of the 'Ideal' element along three constructs. A PCA of this grid was then generated and is illustrated in Figure 6.43(a). The PCA of the same constructs when organised by theme is given in Figure 6.43(b).

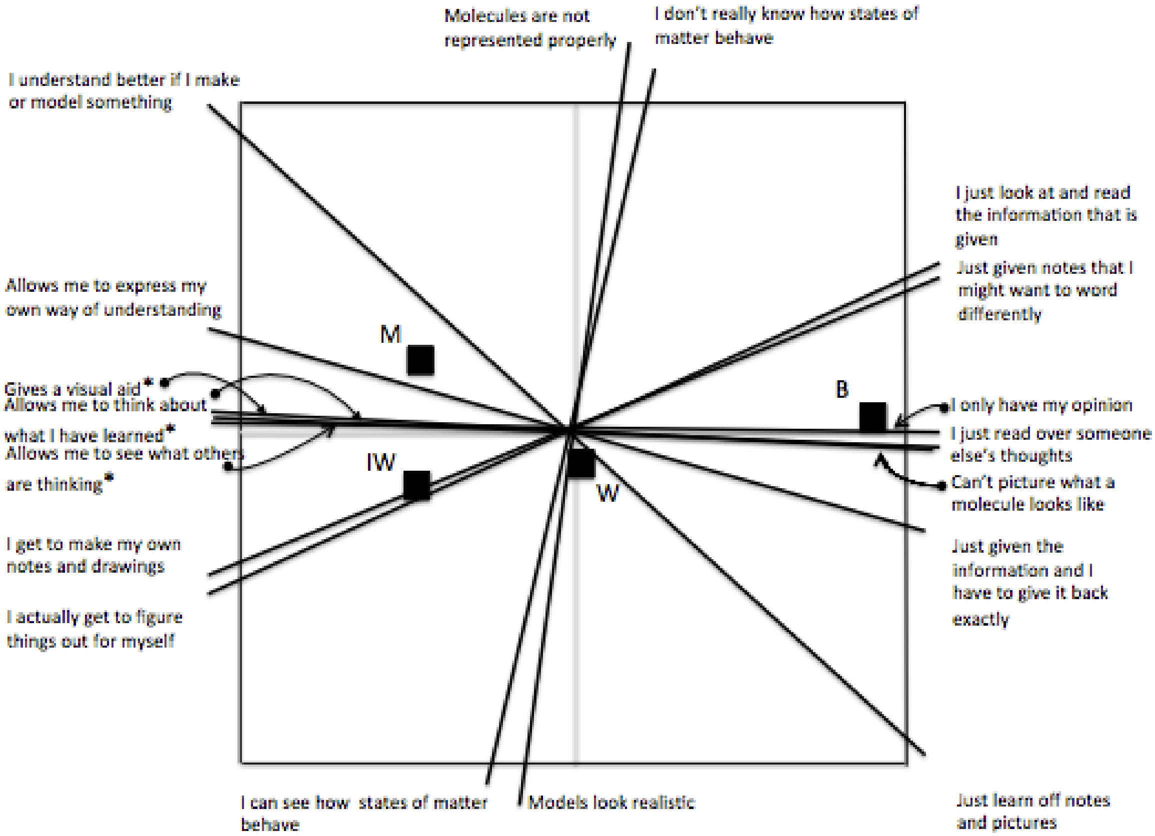


Figure 6.3 (a): Phase 3: PCA of 'How I as a Student see the Pedagogy' from a Cognitive Perspective (N = 20)

(Variation accounted for by Component 1 is 92.1% while Component 2 accounts for 5.8%)

Key:

M = Modelling;
T = Textbook;
W = Workbook;
IW = Ideal Workbook;
** = Truncated construct pole name for presentation purposes (see Table 6.51 for complete construct)*

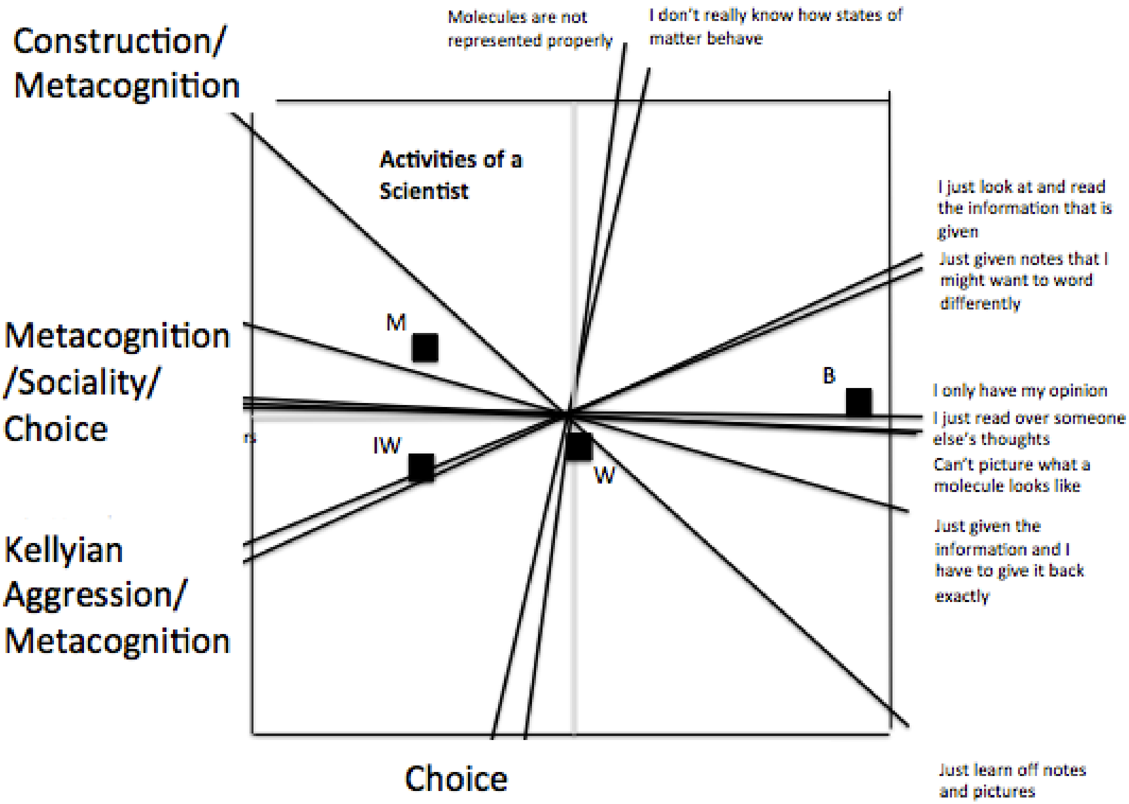


Figure 6.3(b): Phase 3: PCA of 'How I as a Student see the Pedagogy' from a Cognitive Perspective by Construct Set (N = 20)

Both components account for over 97% of the variance of the ratings. The constructs appear to be arranged in 4 main groups including one containing a single construct: 'I understand better if I make or model something---Just learn off note and pictures'. This appears to lie between the two principal components and relates to the PCP corollary of '*Construction*' (see Section 3.4.3) and the learning characteristic of *'Metacognition'*. The corollary involves being able to construe replications of events (such as submicroscopic models) in order to better recognise themes that are re-current. Metacognition in this case describes being aware of how one can put their ideas into operation.

The pair of constructs,

> 'I can see how states of matter behave---I don't really know how states of matter behave' and
>
> 'Models look realistic---Molecules are not represented properly'

form another group in a clockwise direction.

The PCP corollary that relates to these constructs appears to be '*Choice*' (see Section 3.4.3) whereby there are more possibilities for a student to develop preferences that allow for the greatest possibility of the elaboration of their construct system. In this case, their construct system would be growing in terms of the ability to choose re-current themes so that they can understand at a submicroscopic level. The next group is arranged close to the first component of the PCA and contains four constructs:

'I actually get to figure things out for myself---I just look at and read the information that is given';

'I get to make my own notes and drawings---Just given notes that I might want to word differently';

'Working in groups allows me to see what others are thinking---I only have my opinion' and

'Gives me a visual aid that tells me what a molecule is like---Can't picture what a molecule looks like'.

This cluster of constructs is characterized by a tight fan shape. The shared meaning underpinning this grouping may be related to the PCP corollaries of '*Sociality'* (see Section 3.4.3), '*Choice'* and to the idea of '*Metacognition*'. *'Sociality'* indicates that secondary construal is possible, which creates the opportunity for the development of a consistency of meaning of the topic by construing the views of others. *'Choice'* arises from the presence of a greater number of ways to visualise in order to understand. *'Metacognition'* involves thinking about one's ideas so they can be put into operation. The 'Book' element lies towards the non-preferred poles of this construct set. The final group is formed by a pair of constructs:

'Allows me to express my own way of understanding---Just given the information and I have to give it back exactly' and

'Allows me to think about what I have learned so that I can figure out and remember---I just read over someone else's thoughts' .

These appear to be related to the transitional construct of '*Kellyian Aggression*' (see Section 3.4.3) and *'Metacognition'*. The former construct involves leaving the security of the known and actively validating one's ideas in order to grow in understanding. The 'Ideal' element lies towards the preferred pole on this group of constructs. Drawing from advice by Jankowicz (2004), that it is necessary to examine the constructs along which movement would need to occur for a convergence of any element with the ideal, it appears that in order for the 'Workbook' element to move closer to the Ideal element it must do so along this group. It currently lies along the second component nearest the construct set, which also may be described by the PCP corollary of '*Choice*'/Metacognition'. The 'Modelling' element appears to allow for the formation of opinions as it lies between the sets of constructs defined by '*Metacognition/Sociality/Choice'* and 'Construction/*Metacognition*' themes. The theme of '*Construction/Metacognition'* appears to depend approximately equally on the '*Metacognition/Sociality/Choice'* and '*Choice'* groups of constructs. It also appears that the constructs related to *'Kellyian Aggression/ Metacognition'* in the third quadrant depend to a large degree on *'Choice'* allied with '*Sociality'* and '*Metacognition'*. It appears that construct poles most related to the 'Activities of a Scientist' appear on the left hand side of the PCA.

6.6.4 Results: How I as a Student See the Pedagogy from an Affective Perspective

In relation to how students view the pedagogy from an affective perspective, Table 6.52 illustrates the repertory grid of the five constructs that were generated.

Table 6.52: Phase 3: Repertory Grid of 'How I as a Student see the Pedagogy from an Affective Perspective' (N=20)

Rating = 1	Modelling	Textbook	Workbook	Ideal	Rating = 5
I feel more confident as I know what atoms can make up a molecule	2.2	2.2	2.0	1.6	I would not be sure if I understand how to make a molecule properly with the right atoms
I feel I get to help someone who is confused (during groupwork)	2.4	3.1	2.3	2.3	I don't feel helpful
I know I understand and so I feel more confident	2.1	3.2	2.2	2.1	I feel pressure as I'm not sure when I work on something on my own if it is enough to solve the problem
I use my information to learn and I know from the group that it's not wrong	2.1	2.9	2.1	2.1	It's like maths where there is only one way of getting the answer
I get the opportunity to say what I think	2.1	3.5	2.4	1.8	I'm just given the notes that I might want to word differently

The grid in Table 6.52 illustrates that the ratings for the 'Ideal' element (How I would like to see the workbook) fall at or between 1.6 and 2.3. The average ratings for this element were nearest to the preferred pole of all constructs. Two of these ratings were matched by the element 'Modelling' along two constructs.

A PCA of this grid was then generated and is illustrated in Figure 6.4(a). Component 1 and Component 2 account for over 98% of the variance in the ratings. The PCA of the same constructs when organised by theme/set is indicated in Figure 6.4(b).

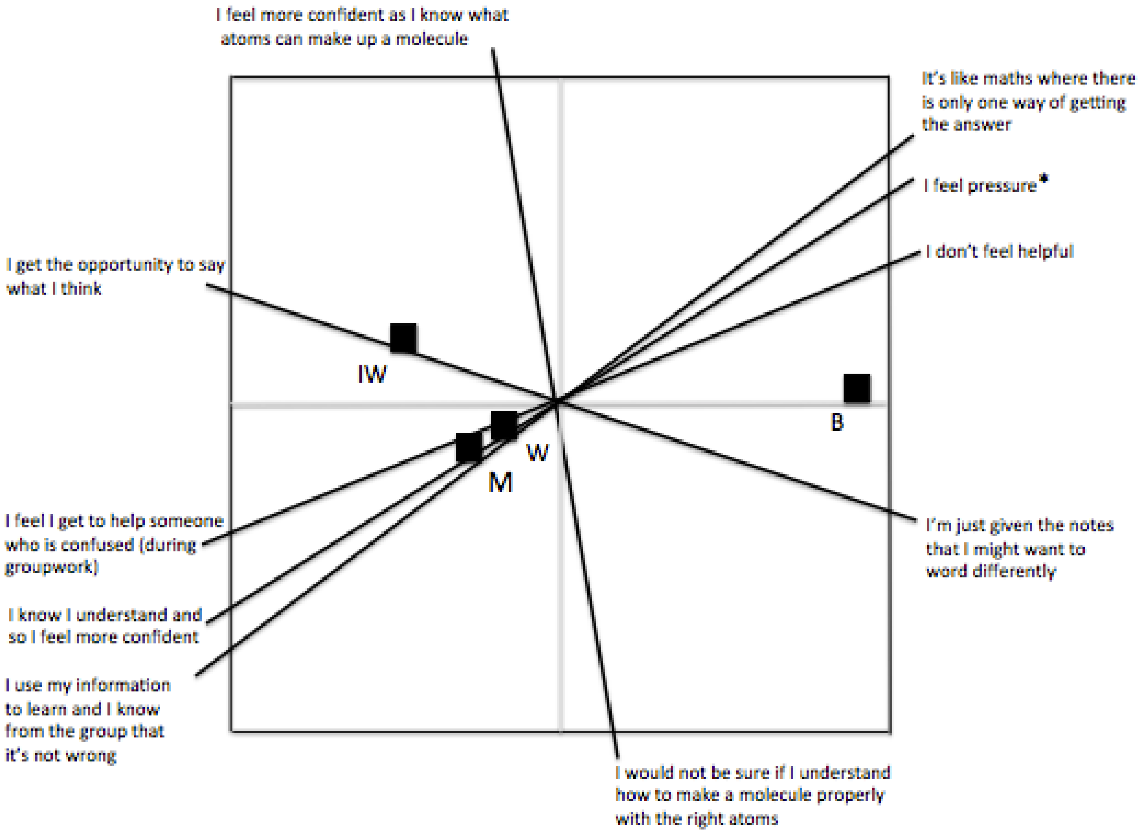


Figure 6.4(a): Phase 3: PCA of 'How I as a student see the Pedagogy' from an Affective Perspective (N = 20)
(Variation accounted for by Component 1 is 93.3% while Component 2 accounts for 5.2%)

Key

M = Modelling (tool used within pedagogy);
B = Textbook (recommended for students);
W =Workbook (pedagogical instrument);
IW = Ideal Workbook
** = Truncated construct pole name for presentation purposes (see Table 6.52 for complete construct).*

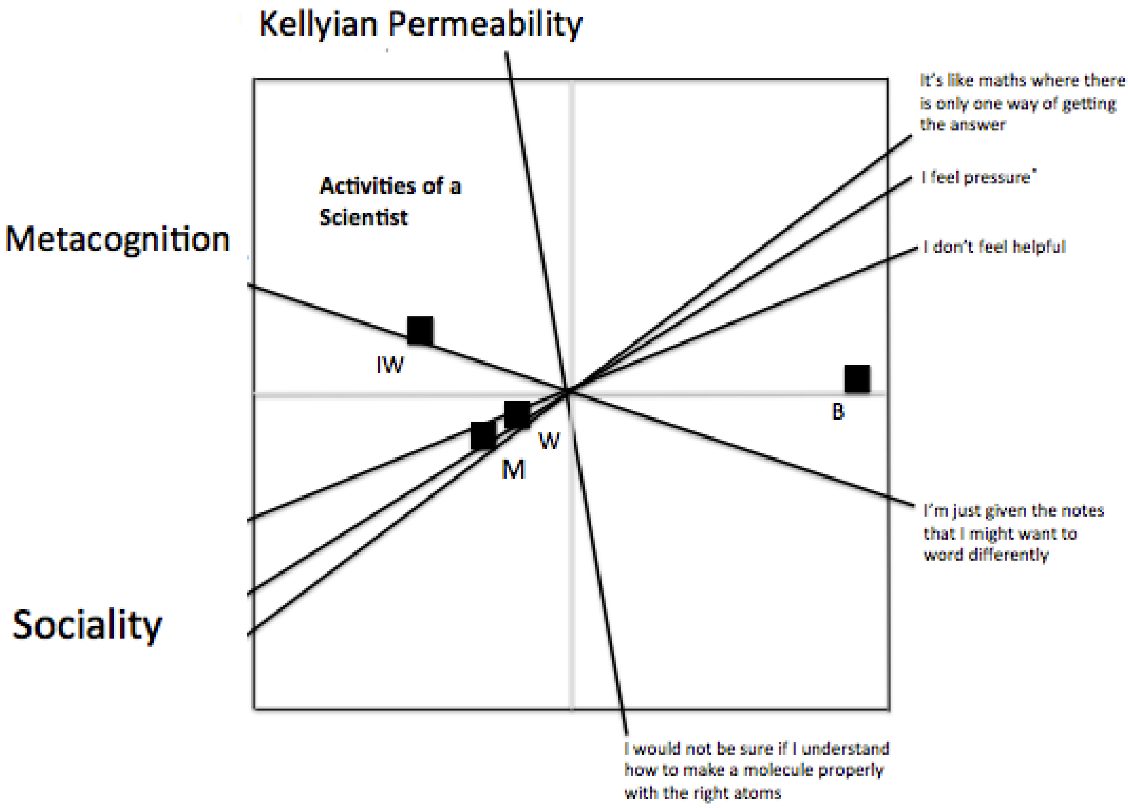


Figure 6.4(b): Phase 3: PCA of 'How I as a student see the Pedagogy' from an Affective Perspective by Construct Set (N = 20)

The Ideal element ('How I would like to see the workbook') is located near the preferred pole of the construct:

> 'I get the opportunity to say what I think--- Just given notes that I might want to word differently'.

This construct appears to be related to the idea of '*Metacognition*' involving the conscious monitoring of ideas by students in order to use them to express an opinion. The other,

> "I feel more confident as I know what atoms can make up a molecule---I would not be sure if I understand how to make a molecule with the right atoms'

lies near the second component.

This construct is related to the PCP construct aspect of 'Kellyian Permeability' as it involves the freedom to undergo conceptual change by re-constructing one's construct system so as to generate new theories (in this case on the submicroscopic level). A sheaf of constructs intersecting both components, complete the set of constructs in the grid.

This set appears to have the shared meaning related to the PCP corollary of '*Sociality'* and include the constructs:

> 'I feel I get to help someone who is confused (during group-work)--- I don't feel helpful';
>
> 'I know I understand and so I feel more confident--- I feel pressure as I'm not sure when I work on something on my own if it is enough to solve the problem' and
>
> 'I use my own information to learn and I know from others in the group that it is not wrong--- It's like maths where there is only one way of getting the answer'.

This corollary relates to a pedagogy that offers the opportunity for a student to carry out a secondary construal of another pupil or group of students in order to attempt to impose a consistency of meaning on their learning.

The 'Modelling' and 'Workbook' elements receive similar ratings and are located close to one another along the construct :

> 'I know I understand and so I feel more confident---I feel pressure as I'm not sure when I work on something on my own if it is enough to solve the problem'

which is towards the preferred pole (in the '*Sociality'* grouping). In order for the workbook to move towards the 'Ideal' element, students need to be given further opportunities to move towards the preferred pole of the construct:

> 'I get the opportunity to say what I think--- Just given notes that I might want to word differently'.

It seems to be equally dependent on the construct:

> 'I feel more confident as I know what atoms can make up a molecule--- I would not be sure if I understand how to make a molecule with the right atoms'

(which can be described by *'Kellyian Permeability'*) and the construct set with the possible shared meaning of '*Sociality*'.

6.7 Adaptations and Implications for Phase 4

Under the frameworks of understanding that were developed in relation to all questions, it appears that the most common Critical Differential Poles are: 'Understanding of the Particulate' and 'Range'. Range is related to implicit knowledge element of 'Processing fluency' (not indiscriminately selecting question cues to the answer because of range of convenience). While 'Processing Fluency' was not identified as a learning gap, because it was not within this author's range of convenience of understanding at the time, there are two implicit knowledge characteristics that were apparent (see Section 3.3.3.1). Of the twenty-two component parts to all questions in phase 3 of the diagnostic and summative exams, the following features were noted:

- Attribute Substitution in six of the twenty-two questions;
- Associative Activation of knowledge, in three of the twenty-two questions (not necessarily in questions requiring a response involving drawings).

The presence of these characteristics appeared to justify the use of the question asked at the beginning of phase 4: "Can I continue to use IBL as pedagogy to increase student competence in comprehending the area of PNM while developing an analysis tool that has the potential to reveal core implicit knowledge components within students' drawings?"

Currently, in relation to how they see themselves as scientists, students display a modest disposition by gauging themselves as being along the 'play it safe pole' of the construct. They rate themselves as being most similar to the scientist, Alexander Fleming. The location of the 'How I see myself as a Scientist' element on the PCA is close to how they wish to see themselves as a scientist in future (the 'Ideal' element).

Ideally, students would like to become scientists who are capable of greater levels of metacognition. In this regard they would prefer on average to be better at persevering at 'trying to solve' problems rather than 'just giving up'.

In respect of the affective aspects of learning, in terms of the workbook and modelling elements, students feel more confident as they come to believe they understand the PNM topics. Since related learning activities involve group-work, students may get to 'help someone who is confused'. This is echoed in a recording that '*there was plenty of intra group debate during the exercise and this was followed by the correction of the answers. Students were able to debate against an answer if they thought it was incorrect*' (Teaching Journal, 2013). Also, if necessary regarding the selection of appropriate information during decision making, they are able to 'know from the group that it is not wrong'. An example in the observation notes (Teaching Journal, 2013), serves to illustrate this point i.e. *'Students constructively criticised each other's drawings to the class and displayed a keen eye in terms of the criteria they used to decide if a drawing was up to the mark or not. Issues such as the size of particles being inconsistent and lack of arrows to depict random movement were pointed out (by themselves)*'. An example of drawings under consideration at this point is illustrated in Figure 6.5.

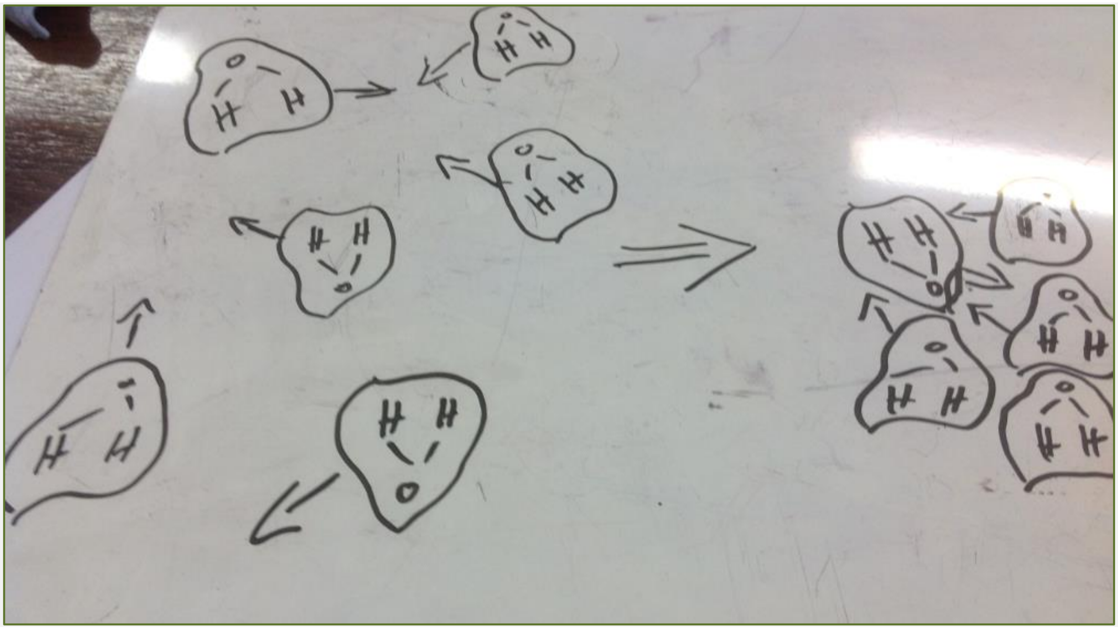


Figure 6.5: A Student Drawing Providing a platform for Debate

This allows students on average to rate themselves as likely to 'know I understand and feel more confident'. These feelings are in direct contrast to feeling pressure due to working in isolation where doubts might emerge as to the capacity to work through a problem by oneself. An example of such an occasion was provided when, during a recapitulation exercise when another student asked "*if liquids while they might look still, had particles that were always moving?" The majority of the class confidently said that "they did*" (Teaching Journal, 2013). Also in relation to confidence, there is a teacher observation entry that states '*I (the teacher) also felt during this lesson that students were willing to explain things or take on explanations - there may have been an increase in confidence allowing this to happen. It was interesting to watch the reasoning and the beliefs evolve or dissolve and evolve (again) as this began'* (Teaching Journal, 2013). These emotions are in contrast to those at the non-preferred poles of the constructs that have been cited above. Hence students are less likely to experience 'not feeling helpful' or that there is 'only one way of getting the answer'.

Ideally, students rate themselves as wishing for greater metacognitive activity in relation to the 'opportunity to say what I think'. This is opposed to 'just being given notes that I might want to word differently'.

In terms of the cognitive aspects seen by students as delivered by the pedagogical instrument (the workbook element) 'choice' in relation to the submicroscopic levels of molecules and the behaviour of the states of matter is apparent. Students are more likely to see/visualise how the states of matter behave. The modelling component of the pedagogy also appears to provide 'choice' in relation to how new knowledge is acquired ('Gives me a visual aid that tells me what a molecule is like'). The modelling element is located on the PCA beside the poles of a construct set where the learning environment appears to offer opportunities to interact with others while engaging in metacognitive activities ('Allows me to think about what I have learned', 'Allows me to see what others are thinking' and 'Allows me to express my own ways of understanding'). Therefore, it is likely to go towards providing a positive context for learner engagement, so the student experience echoes the work of a real scientist.

However, students would like to see the workbook move towards having further opportunities to attempt to elaborate one's construct system by figuring 'things out for myself' and making 'my own notes and drawings'. Specifically, this idea contrasts with '<u>just</u> looking at and reading the information that is given' and 'reading over someone else's thoughts'. Given that (i) the summative analysis proved statistically significant in all questions favouring the intervention group when compared to its counterpart and (ii) repertory grid analysis scored the pedagogy consistently near the preferred pole of all constructs, it seemed reasonable to continue with the work into phase 4. The answer to the original question posed at the start of phase 3 'Can I continue to use IBL as a pedagogy to increase student competence in comphrending the nature of PNM, while developing a framework of understanding that has the potential to reveal learning gaps in students' knowledge?' has been fully answered in a positive light given the construct systems developed in this phase.

6.8 Conclusion:

The question posed at the beginning of phase 3 was "Can I continue to use IBL as a pedagogy to increase student competence in comprehending the PNM while, developing a framework of understanding that has the potential to reveal learning gaps in students' knowledge?" Having posed the question, a plan was developed with the intention of trying to answer it in the best interests of the school community. Ideas from PCP were invoked to acknowledge that, as is the case of IBL, the student is viewed as an active meaning-making individual. PCP ideas were also used since it is a theory that recognises learning in unrestricted terms as opposed to those that are restrictive. PCP allows that concepts introduced in school are not too abstract for students to deal with at their stage of cognitive development. It does view students as being able to contribute to class discussion. Theory from PCP was later applied to student explanations in an attempt to model reasoning patterns evident in student explanations. A 'Dialogic' approach was utilised in the classroom to attempt to have genuine conversations about learning and understanding during teacher-student and student-student interactions. This approach, used in conjunction with modelling and visualization tools, involved the teacher in facilitating the construction and refinement of representations (of phenomena) through coordinated public discussion of their explanatory adequacy. Literature was surveyed and used to inform the development of the workbook pedagogical instrument in conjunction with qualitative and quantitative analysis of phase 2. Following exams, frameworks of understanding were developed in relation to all exam questions in phase 3. This was undertaken by focusing on characteristics of responses by students. All explanations, including drawings, were categorised and used to build a hierarchical construct system that attempted to capture beliefs and concepts held by students. 'Critical Differentiation Poles' were identified to make inferences about gradations of understanding within these frameworks and reveal learning gaps. In this way, it was intended to see if answers due to cognitive processes operating in the minds of students might be harnessed to inform a future iteration of the pedagogy. It was apparent that the main critical differential poles evident were 'Understanding of the Particulate' and 'Range'. While it was subsequently established that 'Range' is related to the implicit knowledge element of 'Processing fluency', it was noted at the time of analysis that there were two implicit knowledge characteristics which were <u>directly</u> apparent. These features were:

- Attribute Substitution;
- Associative Activation of knowledge.

In phase 3 the comparison of intervention to control cohorts regarding the summative exam favoured continuation of the unit as results of all exam questions were statistically significant in favour of the intervention group. Therefore, it seems reasonable to continue with this work and allow it to be carried on into phase 4 of this work. Here, the development of an instrument to capture the nature of implicit knowledge elements potentially arising in students' answers will be pursued. This links to their presence in the critical differential poles of this phase. Hence, Phase 4 will pose the question:

'Can I continue to use IBL as a pedagogy to increase student competence in comprehending the area of PNM while developing an analysis tool that has the potential to reveal core implicit knowledge components within students' drawings?'

CHAPTER 7: FINAL ANALYSIS: PHASE 4

Introduction

The previous chapter focused on how the practical development of an educational intervention over the third of four phases was carried out. It involved quantitative and qualitative analyses, which were triangulated so that the conceptual understanding of the PNM among junior second level school students could be enhanced. PCP was applied as an adjunct to action research methodology in phase 3. Students who undertook IBL demonstrated a greater conceptual understanding of the PNM than their counterparts who did not. This chapter also uses the same methodological approach to focus on the practical nature of the further development and delivery of the pedagogical instrument rooted in IBL. It details how the artefact, used as this instrument, has evolved over the course of the final phase. The development of a novel (exploratory) evaluation tool to analyse student understanding in relation to their drawn explanations is also provided. This is done using the lens of PCP, with a view to the provision of better feedback to learners regarding their thinking around PNM.

Phase 4 seeks to answer the question: 'Can I continue to use IBL as a pedagogy to increase student competence in comprehending the area of PNM while developing an analysis to that has the potential to reveal core implicit knowledge components within students' drawings?' Specifically, it involves adapting Talanquer's heuristics stance to situate responses from questions and give a context to automatic cognitive processes which may constrain learning. It draws from the idea that analysis has the potential to highlight elements that can support teachers in developing activities based on students' drawing analogies that could improve their learning (Mozzer and Justi, 2012).

By attempting to model the conceptual reasoning of students against a backdrop of PCP, it is possible to notice re-current themes in relation to what helps and hinders students' learning. Hence, a secondary question can now be posed: 'Can I develop a model of conceptual change and learning in relation to my students?' By extending the evaluation of student data to determine understanding, the remark by Yenawine (2012) may be borne out that determining achievements should only be one intention of testing. It also has to help the student understand themselves and what they can do to grow conceptually. This question represents a construct that will be prone to validation or otherwise at the end of this phase. If validated, it may serve to facilitate the teaching of chemistry at a conceptual level for teachers and learners.

7.1 Reflections and Adaptations for Phase 4

The following section describes the nature of the planning and adaptations implemented for phase 4.

It is deemed desirable to continue to support students in terms of their modelling (planned in Phase 2). The teacher supports the students in this. It is important that this work seeks to build on that of Phase 3 where a dialogic approach, used to frame areas of discussion around a variety of activities (including doing hands-on explorations, writing, drawing, discussing), is employed. This is intended to solidify the "synergistic relationship" that Siry (2013) indicates can occur during this process. In addition, Mozzer and Justi (2012) remind us that with regard to making analogies, the teacher has to take on a role (a) in supporting the students in evaluating their analogies and (b) in favouring students' involvement in the modification of their analogies. This work also drew from suggestions by Yenawine (2012) on visual paraphrasal to assist students make analogies.

Building on the workbook used in phase 3, a more structured space for students to take their own notes was provided at the end of each chapter of the phase 4 workbook. This note-taking section now included a five-point sequence of questions that were designed to scaffold the metacognition exercise for the students. These are:

- What I thought about the topic in question e.g. solids and liquids and gases at the beginning of the chapter?
- What have I learned or think about it now?
- What made me change my mind?'
- Which bit did I find difficult?
- How can I make sure I understand this before the next lesson?

This note-taking space was re-designed as a consequence of the location of the ideal element in the repertory grids on how the intervention group of students viewed the pedagogy (cognitively and affectively) and how they saw themselves as scientists. Wishes were expressed, from an affective viewpoint, to voice their own opinion based on what they think rather than 'just being given notes that I might want to word differently'. This is aligned, from a cognitive perspective, with the desire to 'figure things out myself' and 'make my own notes and drawings' rather than 'just looking at information that is provided and reading over someone else's thoughts'.

Informed by the Teaching Journal, some modifications were made to the assigned problems in the workbook, e.g. in workbook-chapter 2, the photograph of a kettle boiling was exchanged for that of a gas pipe leaking in all directions as the former may have given rise to students believing gas is only moving in an upwards direction. Observations by the teacher note: '*Students then mentioned that a diagram of a kettle (where water boils) prompted students to mix up phase change with the behaviour of a gas. They indicated during discussion that gas particles appeared to be close together and move upwards in specific lines as this is what they witnessed at the macroscopic level. On this occasion a different group of students, argued that gases have particles that are far apart. On balance, while the diagram cultivated debate, it was decided to exchange it for one deemed less ambiguous macroscopically*' (Teaching Journal, 2013).

There is an increased emphasis on allowing students write down their own thoughts on the behaviour including that of the liquid state at particulate level (this idea relates to Question 2 in the summative exam).

An attempt to develop a coherence involving the visualization of atoms was made. All were depicted as hard spheres with symbols in their centre and without associated colour effects. Hence the emphasis on distinguishing features of the atoms moved to symbols rather than colour.

An increased opportunity of cohesion regarding the visualization of concepts of atoms, molecules, elements and compounds was provided. Freezer bags of Styrofoam balls of various colours and sizes were provided to students. Some were single entities while some have been glued to other balls of the same size and colour or to others of different sizes and colour. Groups of glued Styrofoam balls of up to three in size were provided for modelling activities.

A number of areas exist within the workbook where instructions were clarified, questions were re-phrased to aid reading by students, and activities were re-sequenced to enhance the overall structure of the module.

7.2 Implementation and Evaluation of Phase 4

The following section describes the implementation of the teaching instrument aimed at increasing the knowledge of students in the PNM in phase 4. Figure 7.1 emphasises the continued implementation of the practitioner action research cycle. The fourth phase consisted of 111 mixed ability students. Thirty-nine students were taught by the author. Two other teachers taught fifty-two students. This represented the intervention group. The remaining 20 students were taught by one teacher in a traditional way and this represented the control group.

A fourth iteration of the workbook was developed as discussed in Section 7.1. The three teachers of the first year student cohort were asked if they wished to teach their students using the workbook that was developed. Two of the three teachers felt comfortable with this opportunity to try an alternative approach to the textbook. A basic teacher manual was developed to allow these colleagues anticipate the methodology and materials involved in the lessons and serve as a platform for discussion with the author.

Written observations of classroom events in relation to students' engagement with the pedagogical instrument were recorded in a reflection journal by the author while teaching the intervention cohort.

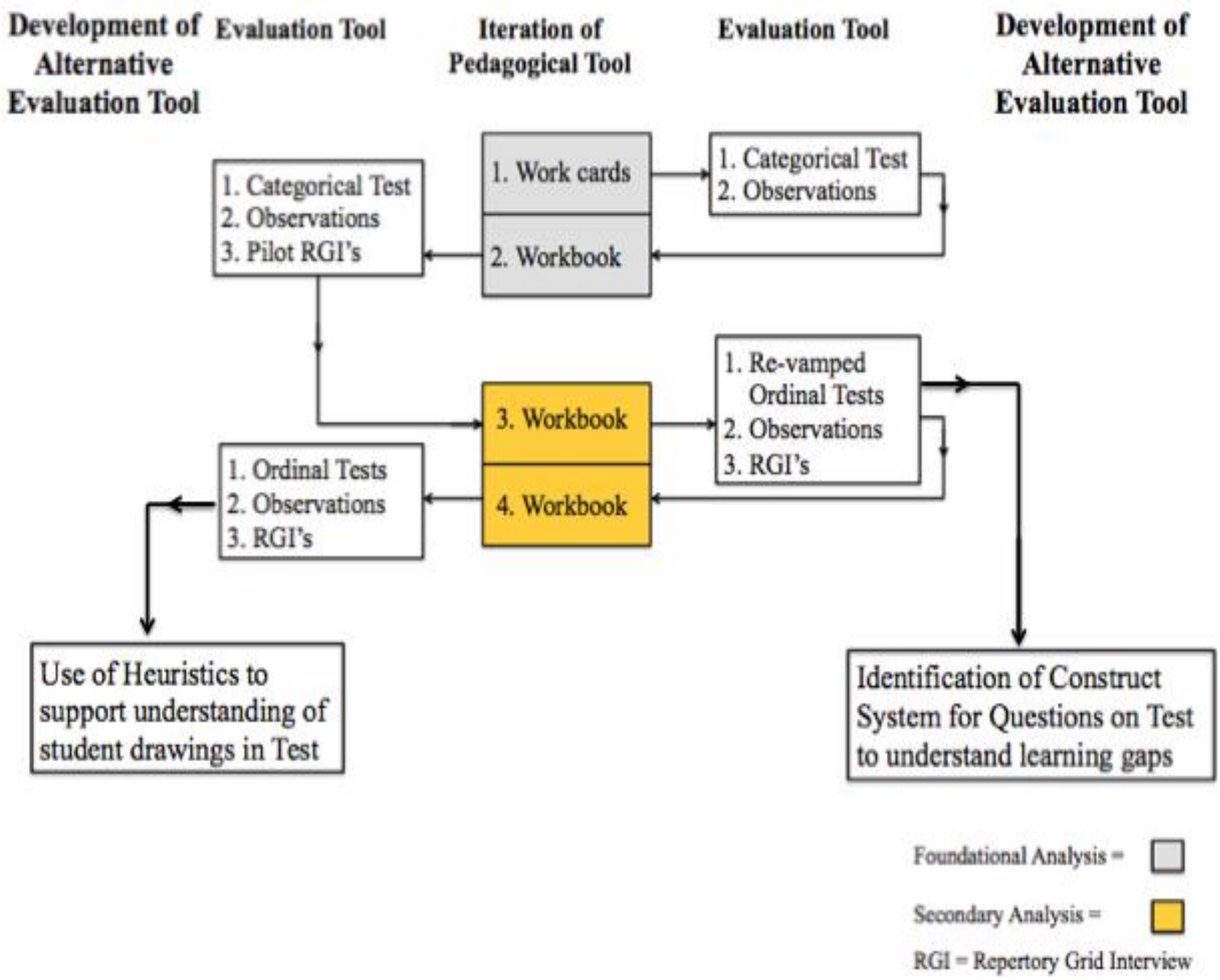
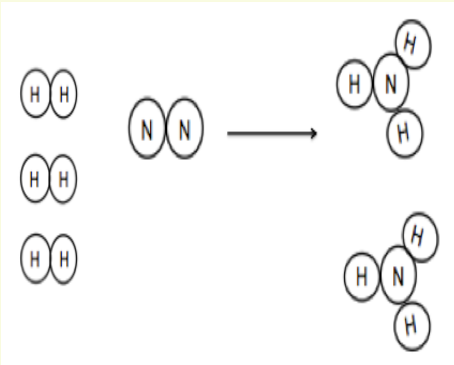


Figure 7.1 Practitioner Action Research Cycle Phase 4

There was evaluation of student learning through assessment tools already discussed in Section 6.3. The diagnostic assessment was identical to the one used in phase 3 and marked as already described in Section 6.4. It was taken by three of the four classes of the intervention group. The summative exam (as described in Sections 6.3 and 6.4) was taken by all students at the end of the year but also had another question included. Question 6 was introduced on the summative exam to examine if students could relate the symbol or formula of an element or compound to its particulate representation (see Figure 7.2).

Results of the evaluations are presented and discussed in Sections 7.3 and 7.4.

Q.6 **Circle** *clearly an equation below the broken line that best represents the chemical reaction represented by the particles above the broken line*



$2N + 6H \rightarrow 2NH_3$

$N^2 + 3H^2 \rightarrow 2NH^3$

$N_2 + 3H_2 \rightarrow 2NH_3$

$N + H \rightarrow NH$

Figure 7.2 Question 6 of the Summative Exam - Phase 4

7.3 Results of Diagnostic and Summative Assessments

Table 7.1 displays the results to the diagnostic assessment of phase 4. Each column denotes a category from 'Very Good' to 'Basic'. It is a scale that captures answers with quality explanations where maximum marks were awarded. Zero marks were awarded to an indecipherable or blank answer. The same scale applies to the summative exam, which is described in the next section. The 'Mean Score %' is the percentage score received in each component of a question.

Table 7.1: Diagnostic Assessment Results (N=77)

Question/ Category	Very Good	Good	Average	Basic	Zero	Mean Score %
1	18.3	23.9	22.5	28.2	7.0	49.2
2	12.7	36.6	5.6	33.8	11.3	47.6
3 (a- solid)	36.6	30.9	21.1	11.2	0.0	72.0
3 (a- liquid)	14.1	45.1	23.9	16.9	0.0	63.0
3 (a- gas)	47.9	29.6	4.2	18.3	0.0	76.0
3b	80.3	4.2	2.8	11.3	1.4	87.0
4(a)	7.0	66.2	21.1	4.2	1.4	69.2
4(b)	2.8	7.0	83.1	4.2	2.8	42.0
5 (frozen)	36.6	18.3	18.3	19.7	7.0	62.4
5 (unfrozen)	14.1	12.7	25.4	42.3	5.6	42.8
7	8.5	12.7	2.8	69.0	7.0	26.6
8	40.8	28.2	8.4	16.9	5.6	69.0

Question 3 scored the highest percentage mark. There had been an emphasis in the workbook on modelling the dynamic particulate models of matter that may have prompted this high performance. This was carried out with an acknowledgement of the relationship between particle movement and energy, which forms part b of the question. Conversely, Question 7 was the question in which students achieved the lowest percentage mark (26.6%). The movement of liquid particles in different volumes of vessel remains a conceptual difficulty for students. The performance of students at depicting the unfrozen area indicates the challenge posed to draw a liquid when not asked to do so directly. There was no statistical difference between the results in this phase and their counterparts in phase 3.

Table 7.2 indicates the average scores that the student cohort attained in each question of the summative exam. The 'Mean Score/Q' is the percentage score attained in a question taken in its entirety. 'C' indicates the control group while 'I' indicates the intervention cohort. Statistical significance is based on a Welch Two Sample t-test.

The highest average total achieved by the intervention group was in Question 4 involving the identification of a gas and a description of its associated behaviour at the particulate level. The lowest mark achieved in the exam by the intervention group was in Question 2. Once again, this question involved the indirect request to draw a liquid and highlights the consistent difficulty students in this phase have at correctly generating a drawn answer in these cases. There is a significant difference between the results (in favour of the intervention group) in questions 1, 2, 4 and 5. There is no significant difference between overall marks of the intervention groups in the summative test between phase 3 and phase 4. Also there is no significant difference in achievement in questions 1, 2 and 3. However, in questions 4 and 5, phase 3 intervention groups scored significantly higher. The background to this difference in understanding related to the use of PhET simulations. In this regard, some groups in phase 4 lacked access to computers because of resourcing constraints. Therefore, the importance of the use of simulations is underscored as regards future implementations. It is important to ensure that students have access to all necessary software resources where possible.

Table 7.2 Summative Assessment Results

Question		Category	Very Good	Good	Average	Basic	Zero	Mean Score %	Mean Score /Q
1	1 (a)	I	9.9	15.4	17.6	53.9	3.3	41.7	I* = 55.5% C*= 33.2% * =Sig diff
		C	0.0	10.5	5.2	63.1	21.0	23.0	
	1 (b)	I	4.4	38.5	27.5	26.4	3.3	51.4	
		C	0.0	10.5	52.6	31.6	5.3	35.8	
	1 (c)	I	9.9	43.9	16.5	20.9	8.8	55.8	
		C	0.0	15.8	5.3	73.7	5.3	29.4	
	1 (d)	I	15.4	40.7	19.8	17.6	6.6	59.2	
		C	5.3	26.3	26.3	31.6	10.5	43.2	
	1 (e)	I	29.7	50.5	6.6	6.6	6.6	69.6	
		C	15.8	36.8	0.0	42.1	5.3	34.7	
2	2 (a)	I	9.9	25.3	14.3	46.2	4.4	45.0	I* = 49.4% C*= 30.8% * =Sig diff
		C	0.0	0.0	10.5	73.7	15.8	18.9	
	2 (b)	I	33.0	19.8	7.7	31.9	7.7	58.2	
		C	42.1	5.3	0.0	42.1	10.5	54.7	
3	3 (a)	I	52.7	1.1	11.0	25.3	9.9	63.1	I = 59.7% C= 49.5% No Sig diff
		C	36.8	10.5	26.3	21.1	5.3	54.7	
	3 (b)	I	44.0	5.5	15.4	25.3	9.9	56.4	
		C	26.3	0.0	26.3	36.8	10.5	44.2	
4	4	I	51.6	12.1	0.0	34.1	2.2	68.0	I* = 68.0% C*= 30.5% * =Sig diff
		C	5.3	10.5	0.0	84.2	0.0	30.5	
5	5	I	42.9	3.3	5.5	41.8	6.5	56.0	I* = 56.0% C*= 28.4% * =Sig diff
		C	15.8	0.0	0.0	63.2	21.1	28.4	
6	6	I	28.6	22.0	28.6	28.6	9.9	58.0	I = 58.0% C= 57.9% No Sig diff
		C	31.6	21.1	21.1	5.3	21.1	57.9	

I = intervention group (N=91); C = Control group (N = 19)
* Indicates significant differences, based on 95% significance level

7.4 Repertory Grid Analysis

Element selection, student interviews, teacher interviews and element evaluation were undertaken regarding repertory grids as described in Section 4.5.3. The following section illustrates the repertory grids produced and the principal component analysis used on them. The student participants represent the part of the intervention group taught by the author. Further grid analysis relates to both teachers who taught intervention groups.

7.4.1 Results: How I as a Student see Myself as A Scientist

The constructs illustrated in Table 7.4 were generated as per phase 3. The resultant aggregate repertory grid forms a 5x7 matrix shown in Table 7.3.

Table 7.3: Phase 4: Repertory Grid: 'How I see Myself as a Scientist' (N=36)

Rating = 1	Fleming	Galileo	Frankland	Lotrenux	Redux	How I see myself as a scientist now	How I see myself as a scientist ideally	Rating = 5
Question what is being taught	2.9	2.5	2.3	3.4	3.2	3.2	2.6	Agree with what is being taught but can't see for myself
Learned by figuring out	3.7	1.8	2.2	3.1	3.2	2.6	2.3	Learned by accident
See if you could improve the experiment	3.5	2.5	2.1	3.8	3.7	2.5	2.0	Accept without testing
Not afraid to take a risk in the lab	2.6	2.2	1.6	3.7	3.5	2.9	2.7	Accept the rules but don't think
Open to others' opinions	4.0	2.8	2.2	3.2	3.6	2.1	2.0	Not open to others' opinions

The scientist who receives average ratings that are consistently closest to the preferred poles of the constructs is Bill Frankland. However, Galileo is viewed as nearest to how students see themselves as a scientist ideally. The PCA that illustrates this grid is shown in Figure 7.3(a). A revised version of the PCA by construct theme is shown in Figure 7.3(b). The poles that best describe the 'Activities of a Scientist' appear on the right-hand side of the PCA.

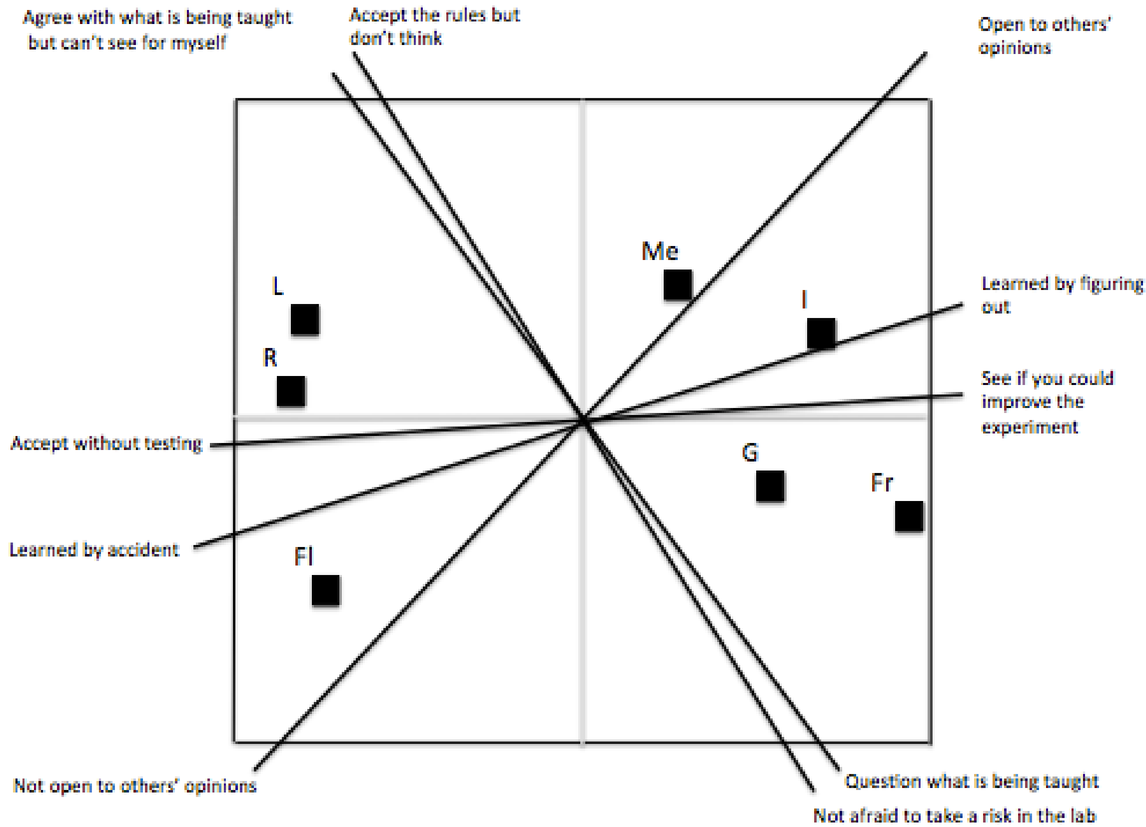


Figure 7.3(a): Phase 4: PCA of 'How I as a Student see Myself as a Scientist' (N = 36)
(Variation accounted for by Component 1 is 77.6% while Component 2 accounts for 16.4%)

Key:

R= Redux Pharmaceuticals;
L = Lotrenux Pharmaceuticals;
Fl = Alexander Fleming (Scientist);
Fr = Bill Frankland (Scientist);
G = Galileo (Scientist);
Me = How I see myself now as a Scientist;
I = How I see myself ideally as a Scientist

It may be inferred from looking at Figure 7.3(b) that the constructs form three main groups with one group composed of a single construct. The group of constructs close to Component 1 contains:

'Learned by figuring out---Learned by accident', and

'See if you could improve the experiment--- Accept without testing'

The shared meaning of this pair of constructs appears to relate to the PCP transitional construct of '*Kellyian Aggression'* (see Section 3.4.3) as they involve actively elaborating one's construct system. The construct set that bisects the first and third quadrants is composed of:

'Question what is being taught---Agree with what is being taught but can't see for myself', and

'Not afraid to take a risk in the lab--- Accept the rules but don't think'.

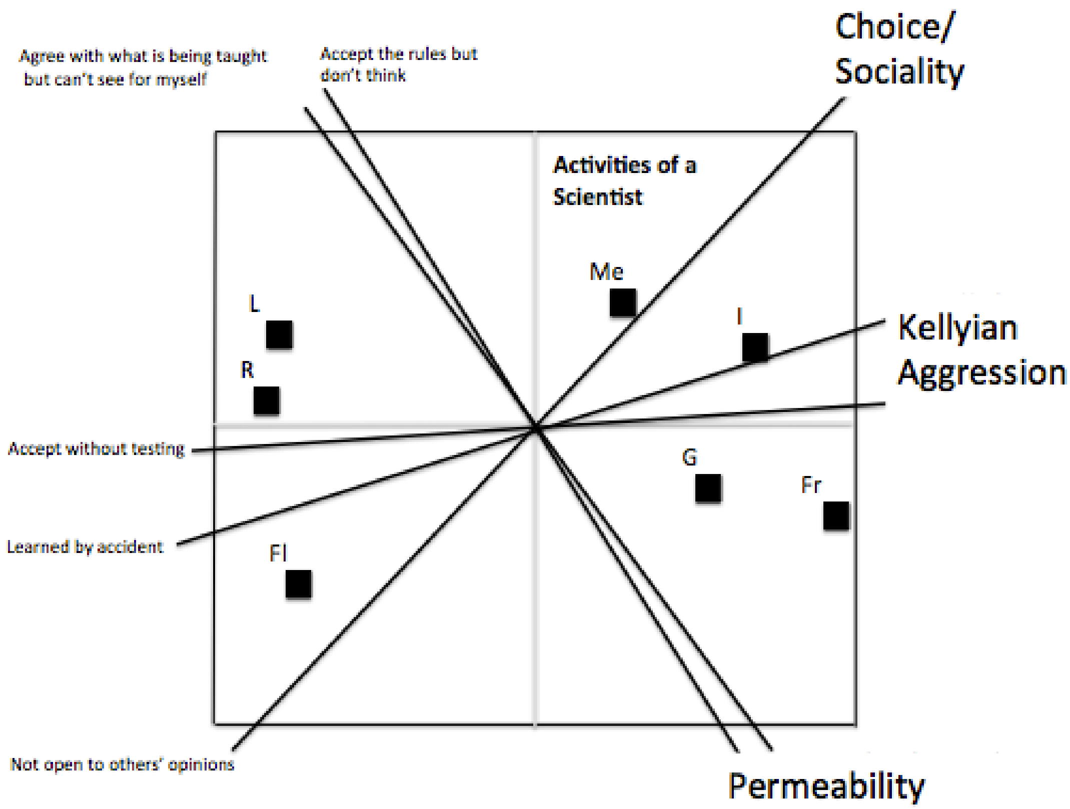


Figure 7.3 (b): Phase 4: PCA of 'How I as a Student see Myself as a Scientist' by Construct Set (N = 36)

The meaning that appears to be common to this pair of constructs is the PCP idea of '*Kellyian Permeability*' (see Section 3.4.3), which relates to the freedom to undergo conceptual change by generating new theories.

Finally, the construct bisecting the first and third constructs is:

'Open to others' opinions --- Not open to others' opinions'.

This construct relates to the PCP corollary of '*Sociality*' (see Section 3.4.3) whereby secondary construal (of others) is possible. Simultaneously, students may attempt to develop a consistency of meaning regarding a topic within their construct system. It also involves the PCP corollary of *'Choice'* whereby there is an increased range of information available during learning from which it is possible to develop a preferred idea for the optimum elaboration of one's understanding. The elements Frankland and Gallileo received similar ratings to one another and are in the third quadrant. Also, the elements 'How I see Myself as a Scientist now' and 'How I see myself as a Scientist Ideally' are rated similarly and appear close to one another in the second quadrant. Both are closest to the element 'Galileo'.

The former is located very close to the construct

'Open to others' opinions---Not open to others' opinions'

while the Ideal element lies along the construct:

'Learned by figuring out---Learned by accident'.

It would seem that in order to move towards the Ideal element, students would need to move along this construct towards the preferred pole.

7.4.2 Results: How I as Student see the Pedagogy from a Cognitive Perspective

The aggregate repertory grid was generated as per phase 3 and is shown in Table 7.4.

Table 7.4: Phase 4: Repertory Grid: 'How I as a Student see the Pedagogy from a Cognitive Perspective' (n=35)

Rating = 1	Modelling	Textbook	Workbook	Ideal	Rating = 5
Put what is important in your own words	2.2	3.4	2.1	2.3	Learn off something that I don't understand
Get a realistic 3D view of what a molecule should be like	1.7	3.3	2.7	2.0	Having a 2D view (of a molecule) makes it harder to understand
I get to think about what I'm doing or trying	1.9	3.0	2.3	2.0	I'm randomly guessing about things
I get to make models myself so its easier to remember	1.6	3.4	2.5	1.9	I just learn things off
I experience other peoples' point of views while solving problems	2.0	3.3	2.7	2.1	I'm just being told or copying an answer
It's easier to study for a normal exam	2.8	2.4	2.9	2.7	It's easier to study for an Inquiry exam

Notably, the ideal element received no average ratings that represented those closest to the preferred pole. 'Modelling' received an average rating nearest to the preferred pole of four constructs while the Ideal element received the next preferred rating in all cases. The PCA that explains this grid is shown in Figure 7.4(a). A revised version of the PCA appears is shown in Figure 7.4(b).

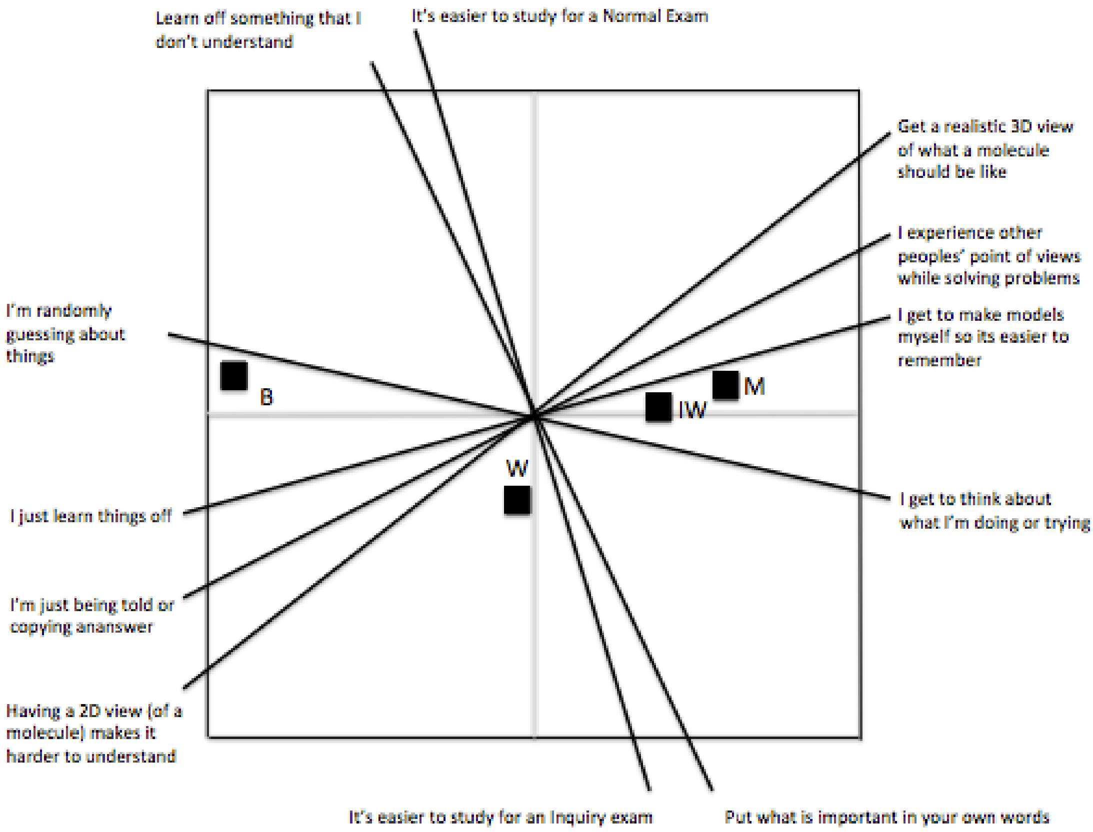


Figure 7.4(a): Phase 4: PCA of 'How I as a student see the Pedagogy' from a Cognitive Perspective (N = 35)
(Variation accounted for by Component 1 is 93.3% while Component 2 accounts for 6.5%)

Key:

M = Modelling (tool used within pedagogy)
B = Textbook (recommended for students);
W =Workbook (pedagogical instrument);
IW = Ideal Workbook
** = Truncated construct pole name for presentation purposes (see Table 7.4 for complete construct)*

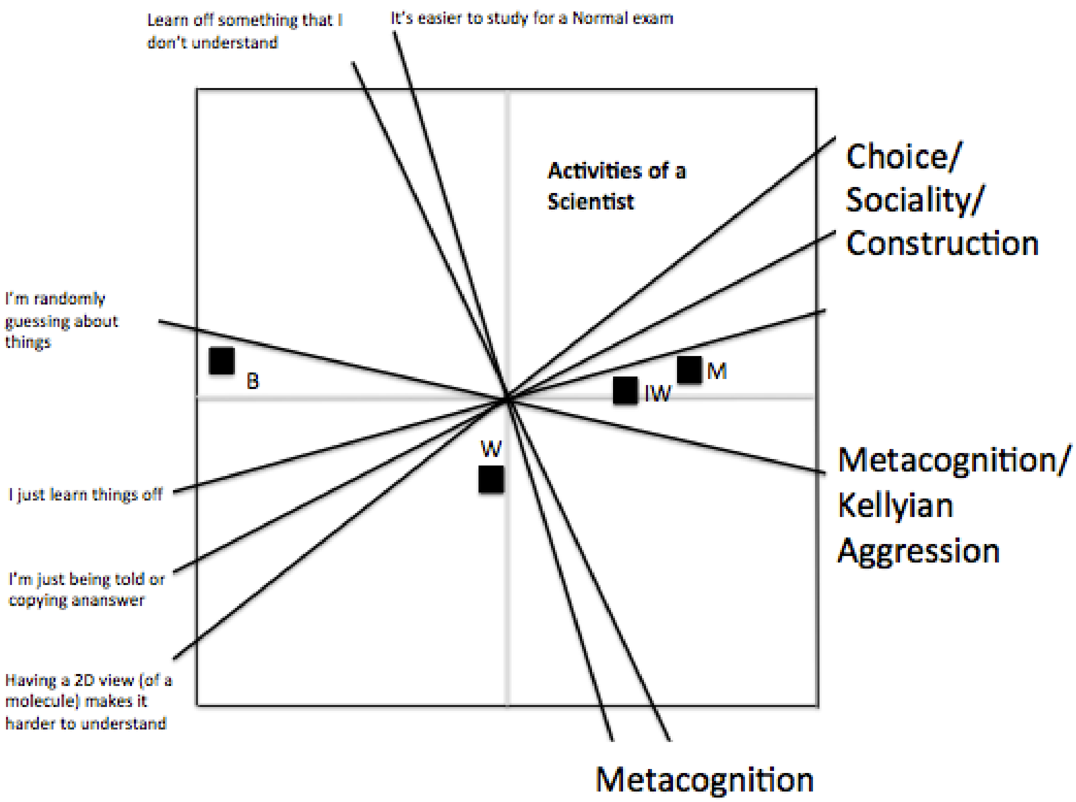


Figure 7.4(b): Phase 4: PCA of 'How I as a Student see the Pedagogy' By Construct Set from a Cognitive Perspective (N = 35)

The constructs in the above PCA are represented by three distinct groups and one grouping is composed of a single construct.

This is the construct

> 'I get to think about what I'm doing or trying --- I'm randomly guessing about things'

which lies nearest the first component.

It appears to be almost equally dependent on the construct groups either side of it and relates to '*Kellyian Aggression*' (see Section 3.4.3) whereby there are active attempts to elaborate one's construct system. It is also related to *'Metacognition'* which relates to thinking about how your ideas may be put into operation. One of these is a group of two constructs that runs between the first and third quadrants consisting of the constructs:

> 'It's easier to study for a normal exam--- It's easier to study for an Inquiry exam' and
>
> 'Put what is important in your own words--- Learn off something that I don't understand'.

It appears that the shared meaning of these constructs may be '*Metacognition'* as they relate to being conscious of how to put one's ideas into operation in order to attempt to perform intelligently rather than mechanically. On the other side of the single construct, and lying between the first and second component, is a set composed of the following:

> 'Get a realistic 3D view of what a molecule should be like--- Having a 2D view (of a molecule) makes it harder to understand';
>
> 'I get to make models myself so it's easier to remember--- I just learn things off' and
>
> 'I experience other peoples' point of views while solving problems--- I'm just being told or copying an answer'.

This grouping may be underpinned by the common meaning of the PCP corollaries of *'Choice'*, *'Sociality' and 'Construction'* (see Section 3.4.3). The presence of *'Choice'* arises from the greater variety of ways a student can attempt to make meaning in order to choose a preferred view to grow their construct system. *'Sociality'* relates to having the opportunity for secondary construal in order to develop a consistency of meaning from the information that is perceived. '*Construction'* indicates the opportunity to increase understanding by recognising recurrent themes within the learning environment. The Ideal element is located on the first component and is almost equidistant from the constructs:

> 'I get to think about what I'm doing or trying--- I'm randomly guessing about things' and
>
> 'I get to make models myself so it's easier to remember---I just learn things off'.

The nearest element to the Ideal element is that of 'Modelling' which is located very close to and towards the preferred pole of the latter construct.

The 'Workbook' element is almost located along the second component nearest the group of constructs with a shared meaning of '*Metacognition'.* The workbook needs to move towards the preferred pole of the construct, 'I get to make models myself so it's easier to remember--- I just learn things off' in order to move towards the 'Ideal Workbook' element.

7.4.3 Results: How I as Student see the Pedagogy from an Affective Perspective

The elements were rated against the constructs as per phase 3 to generate the aggregate repertory grid illustrated by Table 7.5.

Table 7.5: Phase 4: Repertory Grid: How I as a Student see the Pedagogy from an Affective Perspective (n=35)

Rating = 1	Modelling	Textbook	Workbook	Ideal	Rating = 5
Figuring out how to make models gives me confidence	1.5	3.4	2.5	2.0	I am told the answers and don't get a chance to figure them out
I get confidence trying to learn from my mistakes	1.6	3.2	2.3	1.8	I feel lost
I get confidence from trying to tackle a new problem I have never seen	2.1	2.9	2.5	2.0	I just copy off someone else
I get a chance to be motivated by a challenge	2.0	2.7	2.3	1.8	I am just being told or copying an answer
It gives you confidence for normal exams	2.6	2.6	2.7	3.0	It gives you the confidence to be a scientist

The ideal element received two ratings that represented those closest to the preferred pole along two constructs, while the 'Modelling' element received ratings nearest the preferred pole of three constructs. The PCA that corresponds to Table 7.5 is shown in Figure 7.5(a). A revised version of the PCA appears in Figure 7.5(b). The 'Activities of a Scientist' can be seen to occur predominantly on the right-hand side of the PCA.

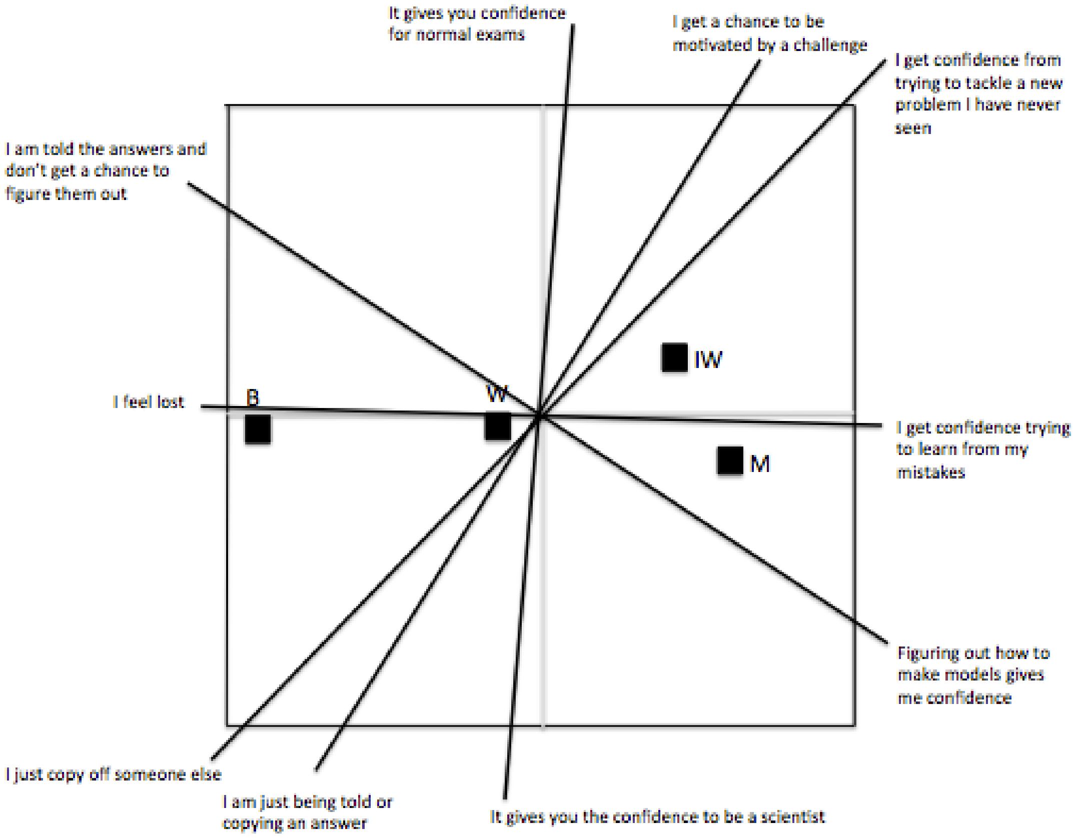


Figure 7.5(a): Phase 4: PCA of 'How I as a Student see the Pedagogy' from an Affective Perspective (N = 35)

(Variation accounted for by Component 1 is 95.4% while Component 2 accounts for 4.4%)

Key:

M = Modelling (tool used within pedagogy);
B = Textbook (recommended for students);
W =Workbook (pedagogical instrument);
IW = Ideal Workbook
** = Truncated construct pole name for presentation purposes (see Table 7.5 for complete construct)*

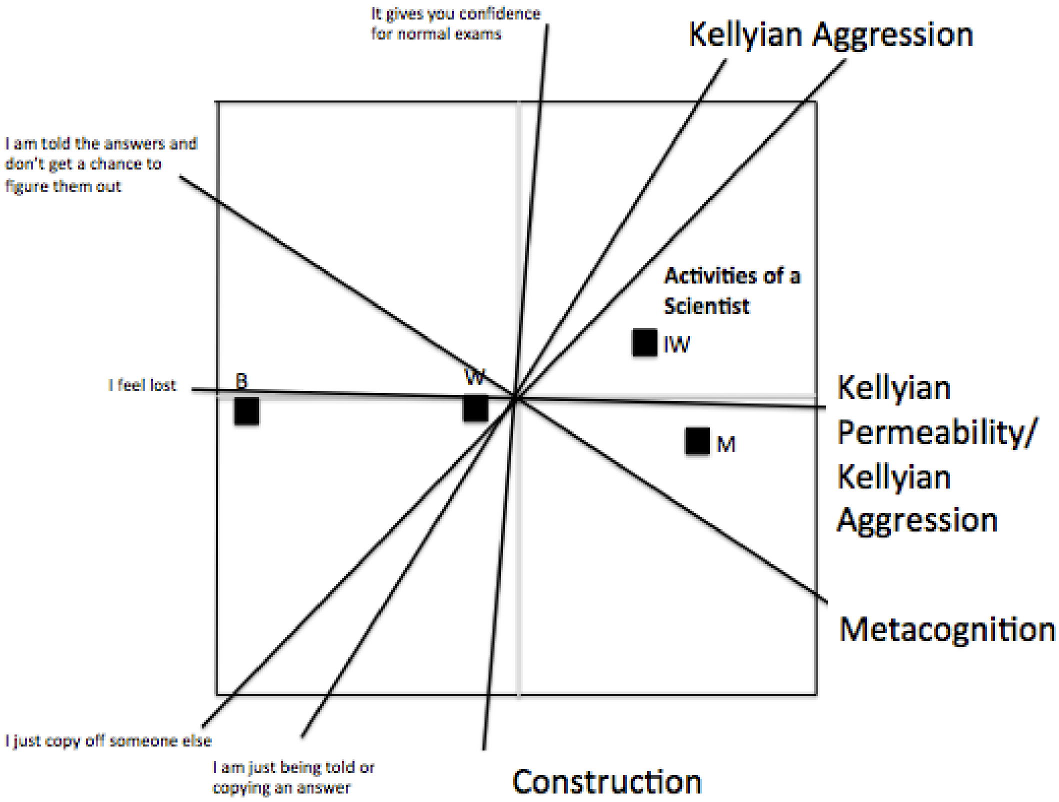


Figure 7.5(b): Phase 4: PCA of 'How I as a Student see the Pedagogy' by Construct Set from an Affective Perspective (N = 35)

The constructs in the above PCA are represented in four distinct groups and three groupings are composed of a single construct.

One such construct is

'I get confidence trying to learn from my mistakes ---I feel lost'

which lies nearest the first component.

This construct is related to the PCP idea of '*Kellyian Permeability'* (see Section 3.4.3), which involves the degree of freedom a student has to undergo conceptual change and generate a new theory. It also involves '*Kellyian Aggression'* (see Section 3.4.3) which involves actively trying to test the validity of new hypotheses.

A second such singular construct is

'It gives you confidence for normal exams---It gives you the confidence to be a scientist'

which lies close to the second component.

This may be related to the PCP corollary of 'Construction' (see Section 3.4.3) whereby students can develop internal representations or constructs and therefore recognise re-current themes and patterns in what they perceive in order to derive a meaning, which is more elaborate than before. A third single construct bisects the second and fourth quadrants and is 'Figuring out how to make models gives me confidence --- I am told the answers and don't get a chance to figure them out'.

This construct appears to be almost equally dependent on the two previous constructs and might be characterised by the idea of '*Metacognition*'. This is because, one is attempting to put their ideas into operation by formulating the information they perceive. The group containing a construct pair consists of:

> 'I get confidence from trying to tackle a new problem I have never seen --- I just copy off someone else', and
>
> 'I get a chance to be motivated by a challenge---I am just being told or copying an answer'.

It appears that the shared meaning of these constructs is the PCP transitional construct of '*Kellyian Aggression*'. This construct involves leaving behind the security of the known in order to check the validity of one's construing and actively grow in the understanding of a topic.

The 'Modelling' element lies almost between the preferred poles of 'Figuring out how to make models gives me confidence' and 'I get confidence trying to learn from my mistakes'. It is the element that is closest to the 'Ideal Workbook' element. The 'Workbook' element lies along the second component and almost along the construct

> 'I get confidence trying to learn from my mistakes --- I feel lost',

slightly towards its non-preferred pole.

To move towards the 'ideal' element it needs to move towards the pole

> 'I get confidence from trying to tackle a new problem I have never seen'.

Summary of Student Perspective of the Pedagogy

Currently students gauge themselves in terms of how they view themselves as scientists, as being towards the preferred pole of the construct 'Open to others' opinions---Not open to others' opinions'.

An example is recorded in the Teacher Journal where '*Class discussion was useful when the groups presented their tasks because it allowed students recognise the connection between heat and particulate movement'*, and, '*I (the teacher) circulated* *but did not intervene as students negotiated the problems*' (Teaching Journal, 2014). Hence, a consistency of meaning regarding conceptual understanding can be developed by students whereby other students may play a metacognitive role in relation to them. However, according to the 'Ideal' element, students wish to move towards having further opportunities to learn by "figuring out".

From a cognitive viewpoint, in terms of the modelling element, students view the pedagogy as affording them the opportunity to make models and remember concepts more easily. Meanwhile, they view the workbook as making it easier to study for an inquiry-type exam rather than a normal exam. Ideally, they would like it to give greater opportunity to engage with models so that it would be easier to remember concepts that are encountered. This may be the approach that is required to bridge the gap between studying for an inquiry exam and a normal exam.

From an affective perspective, modelling gives students 'confidence trying to learn from my mistakes'. However, the workbook element *does* make students 'feel lost' very slightly. There is a slight tension in these ideas. Ideally, students would like to see the workbook move towards greater opportunity 'to get confidence from trying to tackle a problem I have never seen'. In this way, any sense of feeling lost might be reduced.

7.4.4 Results: How Teachers See the Pedagogy

Using the same set of elements contained in the <u>student</u> repertory grids, two teachers other than the author who taught using the pedagogy in 2014, were interviewed individually using the same triadic method which was used in student interviews. For presentation purposes, these teachers are referred to as 'Teacher 1' and 'Teacher 2'.

Teacher 1

During the repertory-grid interview, the constructs indicated in Table 7.6 were generated. These constructs were then rated against the elements provided and the following repertory-grid illustrated in Table 7.6 was produced.

Table 7.6: Phase 4: Repertory Grid: How I as Teacher 1 see the Pedagogy

Rating = 1	Modelling	Textbook	Workbook	Ideal	Rating = 5
Generate answers and Ideas	1	5	1	1	Repitition of answers given
Formulate and apply information	1	4	2	1	Passively regurgitating but not engaging
Picking up learning skills	1	5	2	2	Rote learning
Students need to construct the material themselves	1	5	2	2	The information is provided in a clean and perfect way
Make decisions regarding presenting information	2	5	1	1	Never their own work
Correcting each other and explaining conjectures	1	4	2	1	Recalling from memory the perfect diagram
Giving rationale for the answer	3	5	2	1	Saying: 'That's what the book said'
Work could look messy but is their interpretation	2	5	1	1	Present you with something that looks polished
To facilitate the acquisition of learning skills	1	5	1	1	Filling students with information to pass an exam

The 'Ideal' element (How I would like to see the workbook ideally) received a rating nearest the preferred pole along all but two constructs. The 'Modelling' element received an equivalent rating to the ideal element along four constructs. The PCA of this repertory grid is shown in Figure 7.6(a). A revised version of the PCA by construct set appears in Figure 7.6(b). The 'Activities of a Scientist' appear on the right-hand side of the PCA.

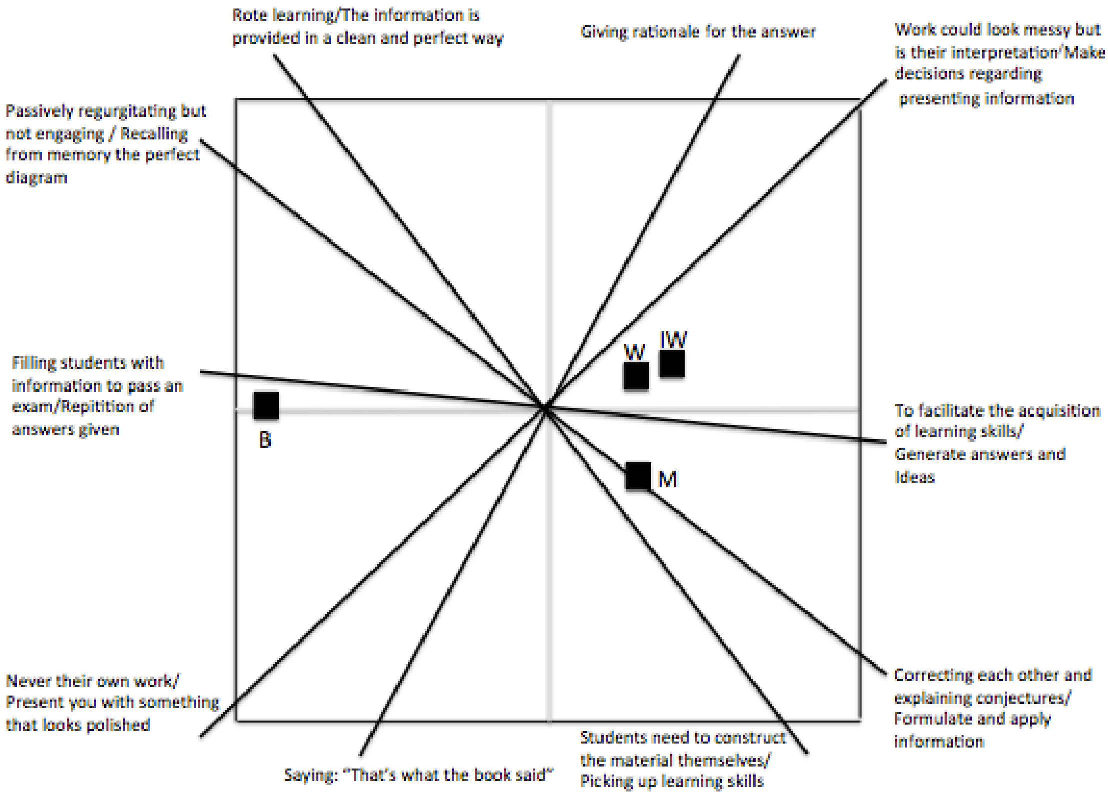


Figure 7.6(a): PCA of 'How I as Teacher 1 see the Pedagogy'
(Variation accounted for by Component 1 is 93.3% while Component 2 accounts for 5.3%)

Key:

M = Modelling (tool used within pedagogy);
B = Textbook (recommended for students);
W =Workbook (pedagogical instrument);
IW = Ideal Workbook
** = Truncated construct pole name for presentation purposes (see Table 7.6 for complete construct*)

The constructs in the PCA appear to be in three groups. The first group is located very close to component 1 and forms a pair including:

> 'To facilitate the acquisition of learning skills---Filling students with information to pass an exam' and
>
> 'Generate answers and Ideas---Repetition of answers given'

which were rated identically according to the elements provided.

The shared meaning linking these constructs could be attributed to '*Metacognition'* and '*Kellyian Permeability'*. The label of '*Metacognition'* occurs because of the inclination towards acquiring learning skills (rather than simply being a receptor of information) exists. The presence of '*Kellyian Permeability*' highlights the capacity of students to generate ideas and risk failure rather than repeat the worked example answers as in a textbook learning scenario. This pair appears to be equally dependent on the groups of constructs on either side of it.

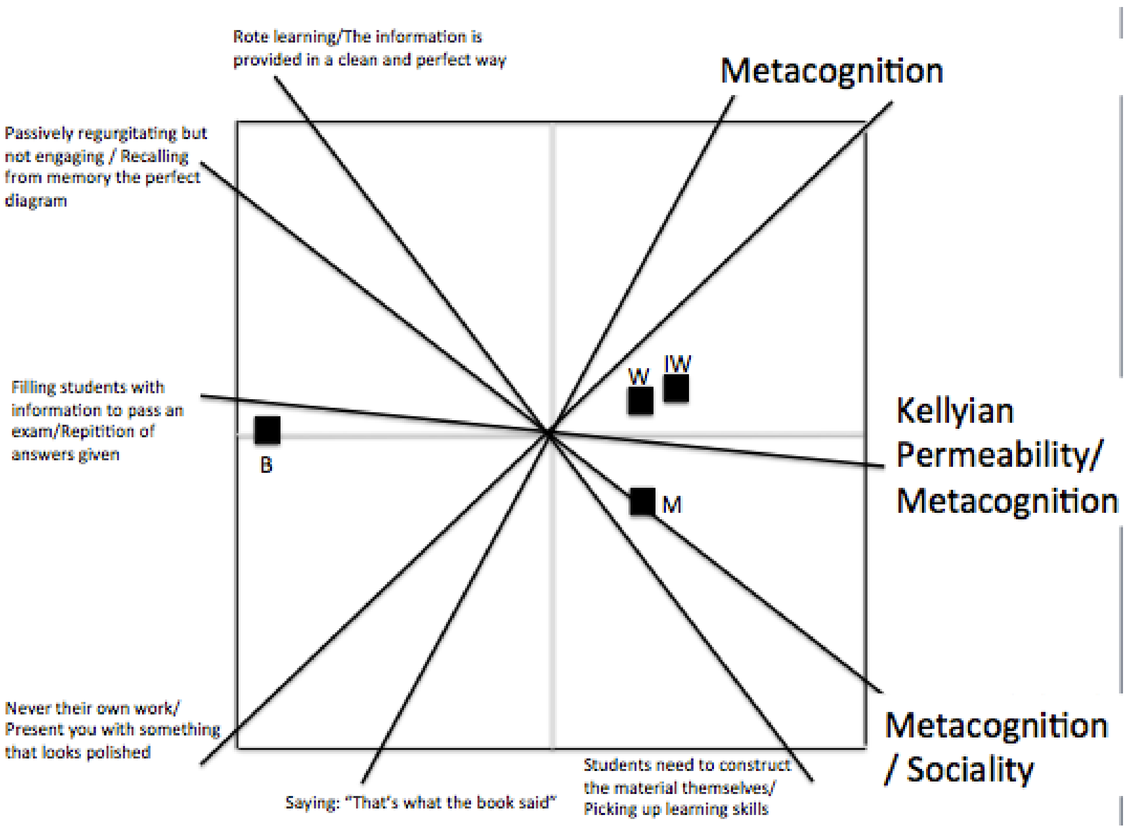


Figure 7.6(b): Phase 4: PCA of 'How I as Teacher 1 see the Pedagogy' by Construct Set

One such construct grouping bisects the first and third components and consists of:

> 'Correcting each other and explaining conjectures---Recalling from memory the perfect diagram';
>
> 'Formulate and apply information---Passively regurgitating but not engaging';
>
> 'Picking up learning skills---Rote learning', and
>
> 'Make decisions regarding presenting information---Never their own work'.

This construct set may be underpinned by the shared meaning of '*Metacognition*' and the PCP corollary *'Sociality'*. *'Metacognition'* also relates to the formulation and presentation of information (including constructing models) while *'Sociality'* relates to the capacity to undertake secondary construal and develop a consistency of meaning in terms of what is perceived. The final group of constructs that appears almost orthogonal to this set includes:

> 'Work could look messy but is their interpretation*---Present you with something that looks polished';

'Students need to construct the material themselves---The information is provided in a clean and perfect way' and

'Giving rationale for the answer---Saying: *That's what the book said*'

This construct set are likely to have a shared meaning with the PCP corollaries of *'Construction'*/ *'Metacognition'*. *'Construction'* describes the nature of developing more sophisticated constructs/internal representations by getting the opportunity to recognise re-current themes and patterns in information. *'Metacognition'* is the capacity to formulate ideas so they can be presented. The 'Workbook' element is positioned closest to the Ideal element. Both are in the second quadrant and lie between the positive poles of the construct groups deemed to have shared meanings of '*Kellyian Permeability*'/*'Metacognition'* and '*Construction*'/*'Metacognition'*.

To move closer to the Ideal element, the workbook needs to move slightly closer to the preferred poles of all constructs. The 'Modelling' element lies on the pair of constructs:

'Correcting each other and explaining conjectures---Recalling from memory the perfect diagram', and

'Formulate and apply information---Passively regurgitating but not engaging'

and towards their positive poles.

The 'Book' element lies towards the non-preferred poles of the group of constructs with the possible shared meaning of '*Kellyian Permeability*'. Due to its position near these poles, it can better be described as leading to 'Kellyian Hostility' (the opposite to Permeability) and/or non-metacognition. Incentives and barriers this teacher saw in terms of teaching with the pedagogical tool were identified. These are discussed in the conclusion of this chapter (Section 7.6).

Teacher 2

Twelve constructs were generated and rated in the repertory-grid interview. The resultant repertory grid is illustrated in Table 7.7. The Ideal element received a rating nearest the preferred pole along all but four constructs. In these cases, it received a rating of 2. Along nine of the twelve constructs, the Workbook received an identical rating to the 'Ideal Workbook'. The PCA of this repertory grid is shown in Figure 7.7(a). A revised version of the PCA by construct set appears in Figure 7.7(b). The 'Activities of a Scientist' appear on the right-hand side of the PCA.

Table 7.7: Phase 4: Repertory Grid: 'How I as Teacher 2 see the Pedagogy'

Rating = 1	Modelling	Textbook	Workbook	Ideal	Rating = 5
Active ways of figuring out learning outcomes	2	4	2	2	Just given learning outcomes
Students questioning with resource to work from	3	5	2	2	Quiet classroom
Remember better if working stuff out for themselves even if they are wrong	1	5	1	1	Just being told
They get to do their own work	3	5	2	2	Information just transmitted
Better retention longer-term	2	4	2	1	Rote-learning but not understanding
They need to be given the opportunity to be thinking	1	5	1	1	Just copying but not thinking
Debating over challenging questions involving peer learning	3	5	2	1	Being asked questions that don't involve thinking but regurgitation
Student led	2	5	2	2	Teacher making assumptions about student limitations
Can communicate with someone their own age and argue their point	3	4	2	2	Just teacher-based questioning where not everyone is involved
Gives confidence to talk out in a group	2	4	2	1	Stay shy
Molecules are coloured to promote understanding	1	2	2	1	2D and black and white
They get a chance to know if they understand something	1	4	1	1	Students think they know it but don't get an opportunity to test themselves

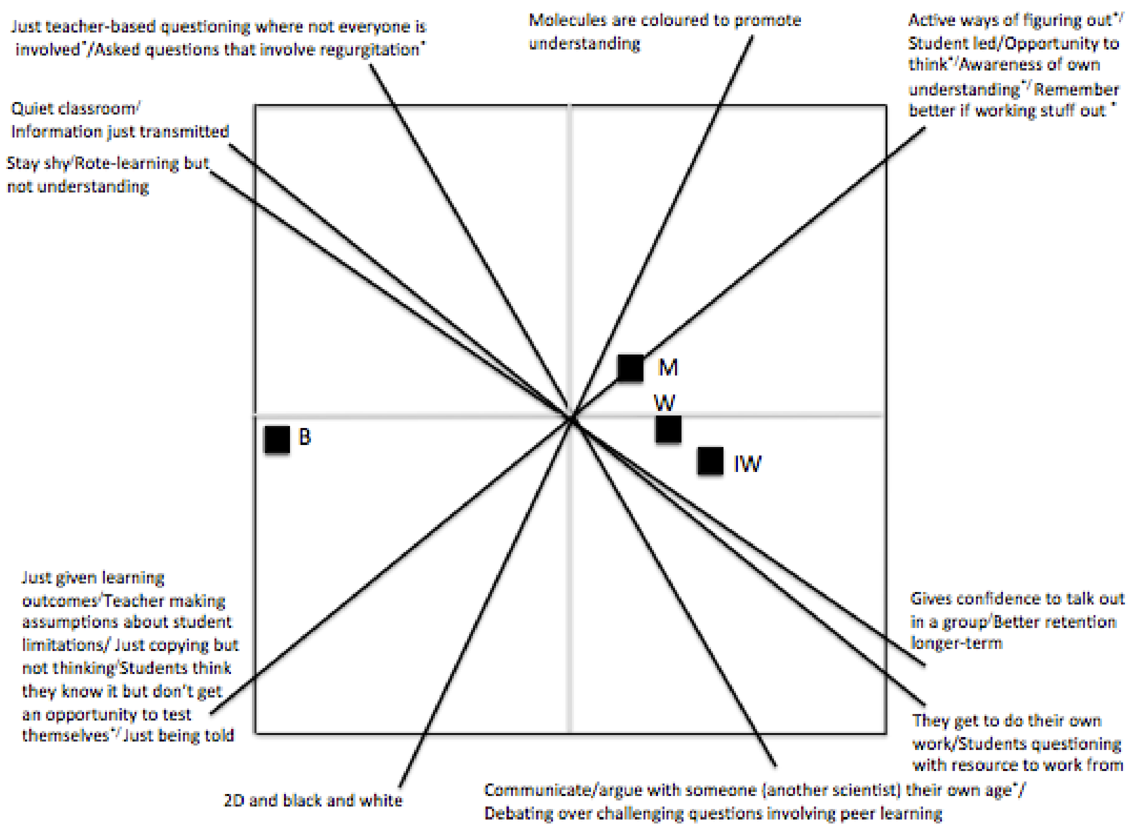


Figure 7.7(a): PCA of 'How I as Teacher 2 see the Pedagogy'
(Variation accounted for by Component 1 is 94.3% while Component 2 accounts for 3.7%)

Key:

M = Modelling;
T = Textbook;
W = Workbook;
IW = Ideal Workbook;
** = Truncated construct pole name for presentation purposes (see Table 7.7 for complete construct)*

The constructs in the PCA appear to be in three main groups. The set of constructs that bisects quadrants two and four consists of:

'Active ways of figuring out learning outcomes--- Just given learning outcomes';

'Remember better if working stuff out for themselves even if they are wrong--- Just being told';

'They need to be given the opportunity to be thinking--- Just copying but not thinking';

'Student led--- Teacher making assumptions about student limitations' and

'They get a chance to know if they understand something--- Students think they know it but don't get an opportunity to test themselves'.

The shared meaning that may be ascribed to this group of constructs is *'Construction'*, *'Kellyian Aggression'* and *'Metacognition'*. *'Kellyian Aggression'* is related to the capacity for active construal in order to check the validity of conceptual choices made. *'Metacognition'* refers to the conscious nature of how ideas are formulated and operationalised. *'Construction'* refers to working through patterns in an attempt to see recurring themes.

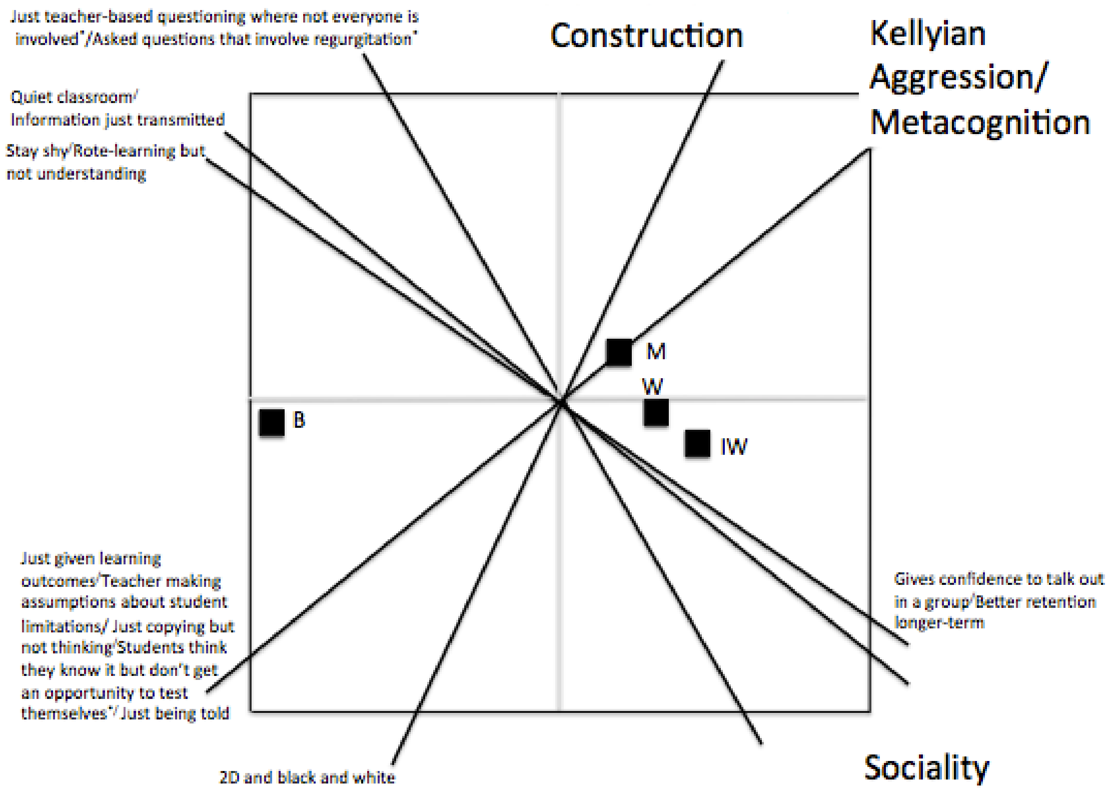


Figure 7.7(b): Phase 4: PCA of 'How I as Teacher 2 see the Pedagogy' by Construct Set

Next to this set is a singular construct which is related to the PCP corollary of *'Construction'. 'Construction'* in this case is on the submicroscopic level. Finally, the group of seven constructs that bisect the first and third quadrants are related to the PCP corollary of *'Sociality'* and *'Metacognition'.* In relation to *'Sociality'* some preferred poles represent an acknowledgement the teacher sees for students to get an opportunity to undertake secondary construal and develop a consistency of meaning in their understanding.

This group of constructs includes:

'Debating over challenging questions involving peer learning--- Being asked questions that don't involve thinking but regurgitation', ‘Can communicate with someone their own age and argue their point---Just teacher-based questioning where not everyone is involved’

‘Gives confidence to talk out in a group---Stay shy’

‘Students questioning with resource to work from---Quiet classroom’

‘They get to do their own work--- Information just transmitted’, and

‘Better retention longer-term---Rote-learning but not understanding’.

Incentives and barriers were identified by this teacher in terms of teaching with the pedagogical tool. These are discussed in the conclusion of this chapter (Section 7.6).

Summary of Teacher Perspective of the Pedagogy

In the opinion of the first teacher interviewed (Teacher 1), modelling was seen as allowing students the opportunity to ‘correct each other’ and consider alternatives by explaining conjectures. The modelling approach was also viewed by this teacher as invoking the metacognitive skill of ‘formulating and applying information’. Also, ‘Students communicated better than otherwise (e.g. using a traditional pedagogical style) and enacted a better use of language’. This led the teacher to note that ‘students had confidence in explanations and wording in both student-student and student-teacher interactions’. Teacher 1 observed, regarding student activity, ‘it also improved note-taking which was a big advantage. In this regard, it also compels students metacognitively to ‘make decisions regarding presenting information’. Teacher 1 would like to see the workbook move slightly further in this direction.

In the view of Teacher 2, the workbook element imbued students with a ‘confidence to talk out in a group’ and perceived that such aspects of metacognitive skill development related to ‘better retention longer-term’ of information. According to the ‘Ideal’ element, Teacher 2 would like to see the workbook move even further in these directions. With regard to the activity of modelling, Teacher 2 saw it as a strategy that allows for ‘active ways of figuring out learning outcomes’ and providing students with an ‘opportunity to think’ rather than ‘just copying but not thinking’. In relation to the nature of models, an entry in the Teacher Journal reads ‘*I (the teacher) spoke with some students about the possible advantages of* *models and they explained that having something to physically touch was important. It was also important that the models were coloured. They cited the book as a counter example'* (Teaching Journal, 2014).

Teacher 2 believed that 'visual aids' enabled visual paraphrasal by the teacher. This links with an entry in the Teacher Journal recording that '*a group modelled a solid, liquid and gas with mass necklaces around their necks and this helped the majority of students to resolve the problem (that mass is conserved) as they debated it*' (Teaching Journal, 2014).

Regarding the structure of the unit, Teacher 2 believed that the repetition of themes within it served to benefit student understanding. Also in relation to student understanding within the structure of the pedagogy, Teacher 1 believed that the student knowledge achieved was more comprehensive.

Regarding those students perceived as non-academic by the teachers interviewed, Teacher 2 believes that (apparently) weaker students found the first iteration of modelling hard going but really got into the understanding of it afterwards in (further) other attempts. An example of the ability of seemingly weaker students to engage with modelling is recorded in the Teaching Journal, '*The afore mentioned less-able student indicated that we could think of the elements (in relation to compounds) as different coloured markers and when you mixed the colours together you got a different colour to the original colours e.g. green and red to give pink. This was an excellent analogy in my view and far better than I as a teacher could have come up with'* (Teaching Journal, 2014). Teacher 2 indicates that '(so-called) weaker students get more of a structured flow – everything is linked and they get to choose what is important to know (note taking)'.

7.4.5 Analysis of Implicit Knowledge

The following section discusses how a tool that could analyse the implicit knowledge of students was developed and used to identify how heuristics were employed during reasoning.

It was decided to apply the ideas of Sevian et al. (2014) on heuristics as a lens in order to provide a theoretical framework for examining student drawings and their relation to reasoning. By dichotomizing each idea, thereby converting them into constructs, it allows commentary on student explanations. Thus it may point in a more meaningful way to dominant forms of explanation or ways of construing that students use to make predictions in order to make sense. A repertory grid was generated using the ten heuristics that Talanquer (2014) proposes as possibly affecting student judgment and decision making. The cluster is converted into ten constructs by dichotomizing each concept and so it can enable the secondary construal of students' drawings through their prism. These are given in Table 7.8.

Table 7.8: Implicit Knowledge Judgement Ideas as Constructs (Talanquer, 2014)

	Preferred Pole	Least Preferred Pole
1.	Activation of relevant associated knowledge	No distinction made between relevant and irrelevant
2.	Fluently selects appropriate features of exam question	Tentatively selects features of exam question
3.	No substitution ('Actual' question answered)	Attribute substitution activated
4.	Open to new interpretations	One reason decision making
5.	Surface Similarity	Discern differences
6.	Unlimited perception	Recognition
7.	Discrimination	Generalisation
8.	Permeable	Rigidity
9.	Reasonable doubt of a good scientist	Over-confident
10.	Amenable to elaborating one's theory	Affect

Some poles are similar despite being on separate constructs. The least preferred poles are not necessarily the conventional opposites to the preferred poles and this allows constructs to be more easily distinguished. For simplicity, the constructs appear with the preferred pole to the left hand side of the table. Numbers 1→3 describe the construing of alternatives in an order to actively see the world. Numbers 4→ 8 relate to the capacity of a student to test or reflect on the validity of their hypothesis (if it works, I don't change it). Finally, numbers 9 → 10 relate to transitional constructs where students might fall back on rigid constructs rather than elaborate their construct system.

Two researchers observed carefully, compared, and tentatively assigned a rating to 8 sets of student responses to drawing questions from the Diagnostic and Summative exams (10% of student cohort) of phase 4. The rating scale used was 1-5 which is consistent with all other rating scales in the study. One researcher then coded the entire data set. The other researcher then checked over the codes against students' work to ensure that their drawings were properly coded. Any disagreements were resolved through discussion. Both researchers have strong backgrounds in chemistry. Once all of the answers to the five questions were categorised, all of the drawings were observed again to ensure consistency in the definition of each class and to verify their rating along each construct. This inductive process on occasions led to the reassignment of some ratings. It was found that there was a large amount of repetition along certain constructs regarding the ratings students received for their efforts. Based on these results, the spectrum of constructs was condensed from ten. Hence, they were re-arranged slightly to capture the variety of results. They are now given in Table 7.9.

Table 7.9: Condensed version of Implicit Knowledge Judgement Ideas as Constructs

	Preferred Pole	Least Preferred Pole
1.	Activation of relevant associated knowledge	No distinction made between relevant and irrelevant
2.	Fluently selects appropriate features of exam question	Tentatively selects features of exam question
3.	No substitution ('Actual' question answered)	Attribute substitution activated
4.	Permeable	Rigidity

The first three constructs in Table 7.9 are linked with previously mentioned ideas in this work as being, in the view of (Talanquer, 2014), those which underpin most heuristic reasoning. They are: 'Associative Activation', 'Fluency', and 'Attribute

Substitution'. The fourth construct in this table of 'Permeability---Rigidity' is chosen as it is deemed to be beyond the range of convenience of the first three. Hence, this construct was seen as having the capacity to enhance the second iteration of the repertory grid in capturing student judgments that might allow us anticipate the way in which they make sense using drawings of new ideas with which they are confronted. Thus, a revised repertory grid based on these constructs was generated whereby it could be seen to draw upon recently established knowledge in the Chemistry education field and add value to it as a resource by elaborating it with Kellyian ideas. This grid had the elements 'Solid', 'Liquid', 'Gas', 'Frozen', 'Unfrozen' and 'Condensation'. These represent respective student answers to questions 3(a) and 5(a) from the Diagnostic exam and Question 2 of the Summative exam. It also included an 'Ideal' element which is an answer that receives optimum ratings along all constructs.

Drawings across both the diagnostic and summative exams were considered in relation to students in the intervention cohort. This amounted to a total of responses to six questions in 68 cases. The elements represent a one-word description of the task involved in each question. The ratings obtained for each question were averaged and appear along each of the four constructs pertaining to implicit knowledge in Table 7.10.

Table 7.10 Students Answers in terms of Implicit Knowledge to Questions requiring Drawing (n=68)

Rating = 1	Solid	Liquid	Gas	Frozen	Unfrozen	Condensation	Ideal	Rating = 5
Activation of Relevant Knowledge	1.9	2.2	1.7	2.3	2.9	3.0	1.0	Active of Irrelevant Kowledge
Fluently selects question features	1.6	2.0	1.6	2.1	2.7	2.8	1.0	Tentatively selects question features
No Substitutrion	1.5	2.0	1.4	1.9	3.2	3.2	1.0	Substitution of Actual Question
Permeable	1.1	1.1	1.1	1.5	1.7	2.1	1.0	Rigid

The 'Ideal' element was placed at the preferred pole as this represented the optimum drawn answer that could be provided in response to the questions. The elements 'Solid', 'Liquid' and 'Gas' receive average rating closest to the 'Ideal' along the construct 'Permeable---Rigid'.

The element with average ratings closest to the 'Ideal' along all four constructs is 'Gas'. The PCA corresponding to this repertory grid appears in Figure 7.8.

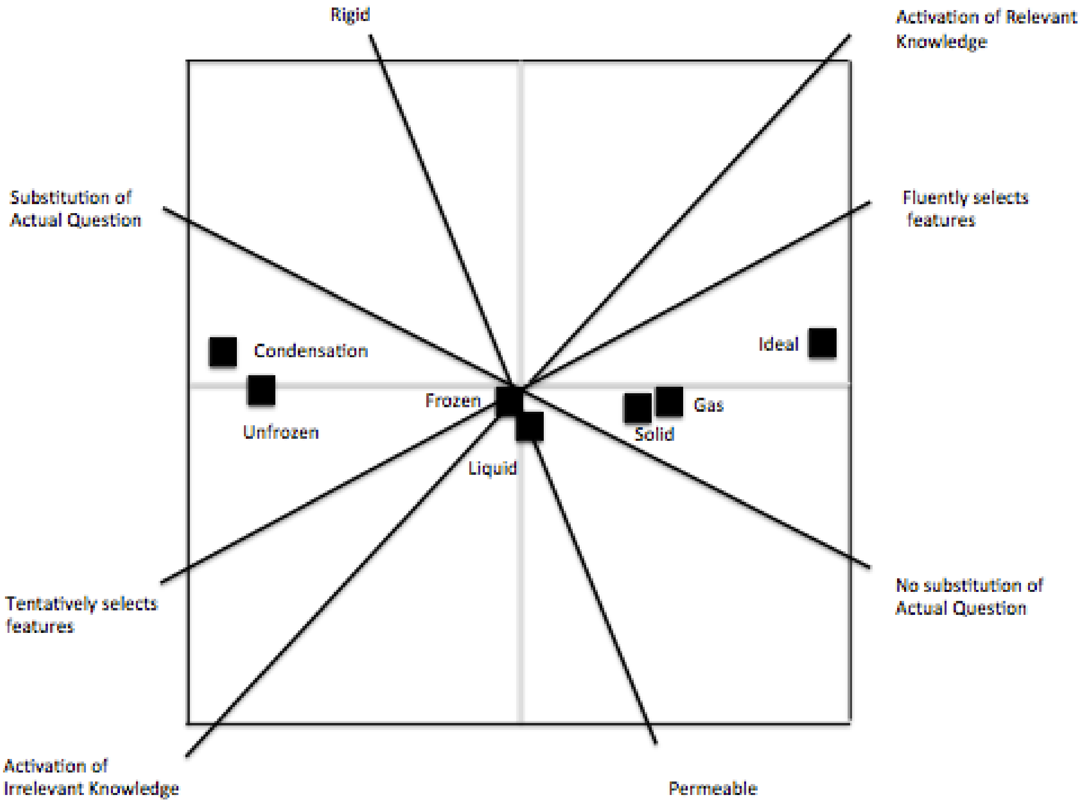


Figure 7.8: PCA of Students Answers in terms of Implicit Knowledge to Questions requiring Drawing (N=68)

(Variation accounted for by Component 1 is 96.7% while Component 2 accounts for 2.0%)

The element of 'Gas' appears closest to the 'Ideal' on the PCA. The 'Solid' element is located nearby and slightly further from the 'Ideal'. All elements on the PCA appear close to component 1. The element 'Frozen' is located almost half-way along the construct 'Activation of Relevant Knowledge---Activation of Irrelevant Knowledge'. 'Liquid' appears along the construct 'Permeable---Rigid' and slightly towards the 'Permeable' pole. The elements that are illustrated furthest from the 'Ideal' are 'Condensation' and 'Unfrozen' and this pair are located approximately half-way between the poles 'Substitution of the Actual Question' and 'Tentatively selects features'.

It appears from the PCA that the construct:

‘No Substitution of Actual Question---Substitution of Actual Question’

depends on the constructs:

‘Fluently selects Features---Tentatively selects Features’, and

‘Permeable---Rigid’.

To move all elements closer to the ‘Ideal’, appears to depend on students answering questions in a way whereby their implicit knowledge elements allow them to fluently select features of a question. This relates to being able to recognise and process the salient explicit features of a question and the implicit components that are unfamiliar in an equal manner. It also requires that there is no subconscious substitution of a more simplistic question for the ‘actual’ question that is asked.

Summary of Implicit Knowledge

In relation to the influence of implicit knowledge elements on students’ explanations through drawings, a pattern appears to emerge. The drawings in response to questions where students were asked to *directly* follow an instruction to draw a <u>solid</u> or a <u>gas</u> are those closest to the ‘Ideal’ element’ (see Figure 7.8). The answers involving the drawing of a gas were the closest to it. Characteristics of implicit knowledge that are applied in the successful drawing of these phases are ‘fluently selects features’ and ‘no substitution of actual question’. The former means that the cognitive framework (construct system) of the student has a sufficient range of convenience to answer the question in an uninhibited way. The latter indicates that the student is answering the actual question as opposed to another question they are subconsciously substituting in its place. The explanation drawings in response to the direct instruction to represent a liquid at the particulate level appear, on average, slightly towards the pole labelled ‘Permeable’ and further from the ‘Ideal’ element than answers for a solid and a gas. Hence, when requested in a direct way to draw a liquid at the particulate level, students tend to be able to generate a hypothesis in relation to the question even if it is not correct. The drawings representing answers where inference must be used to draw water when it is ‘Frozen’ using a macroscopic visual cue of a ‘final product’ of ice are further from the ‘Ideal’ answer than those for a liquid. These drawings appear to be the result of moderate levels of all four implicit knowledge elements.

The responses that are positioned adjacent to one another and furthest from the 'Ideal' are 'Condensation' and 'Unfrozen'. In each case, the student needs to infer from the information in the respective questions, the state of matter they are required to draw. Of the two, drawings in response to a condensation scenario appear slightly further away from the ideal answer. This suggests that it is more difficult to draw accurately where inferences must be made using visual cues where a phase change is involved and when there is no 'final product' displayed on a macroscopic level. In the case of the 'Unfrozen' drawings, a macroscopic visual cue of a 'final product' of water is displayed. The drawn answers to these questions may be characterized by the implicit knowledge characteristics of a) 'Substitution of the Actual Question' and b) 'Tentatively selects features'. These automatic cognitive processes involve:

a) substitution of a (more) simple question unconsciously for the one that is actually being asked;
b) indiscriminate use of cues in the question to draw an answer as the question is outside the range of their cognitive framework (construct system).

Table 7.11 summarizes the way in which implicit knowledge has influenced the capacity to draw at the particulate level. The relative proximity of student responses to the 'Ideal' answer is described by the term 'Rank' in Table 7.11. All drawings require procedural knowledge in order to apply factual knowledge about the behaviour of the states of matter.

Table 7.11 Influence of Implicit Knowledge on Student Drawn Explanations

State of Matter	Rank	Relative Inference Level	Cue Used	Implicit Knowledge Used
Gas	1	Low	Direct instruction	Fluently selects features No substitution of actual question
Solid	2	Low	Direct instruction	Fluently selects features No substitution of actual question
Liquid	3	Low	Direct instruction	Permeable
Solid	4	Moderate	Macroscopic 'final product'	All (moderately)
Liquid	5	Moderate	Macroscopic 'final product'	Substitution of the Actual Question Tentatively selects features
Liquid	6	High	Macroscopic but 'no final product'	Substitution of the Actual Question Tentatively selects features

In order to move all elements closer to the 'Ideal' answer, it would require students answering questions in a way whereby their implicit knowledge elements allow them to fluently select features of a question. This relates to being able to recognise and process the salient explicit features of a question <u>and</u> being more circumspect when choosing familiar components of a question over unfamiliar components. It also requires that there is no subconscious substitution of a more simplistic question for the actual question that is asked.

7.5 Comparison of Phase 3 and Phase 4 Evaluations and Teacher Evaluations

The following presentation of the remaining qualitative results in this work includes tables containing construct poles linking those from phase 3 and phase 4. As a construct is dichotomous it is deemed to have a preferred and a non-preferred pole. These tables display 'preferred' poles that were, on average, favoured by respondents with respect to the pedagogy. A preferred pole was deemed to be favoured if it received an average rating between 1 and 2.9. This idea was applied to how students viewed themselves as scientists and how teachers and students viewed the pedagogy. Ratings of the pedagogy were underpinned by those received for 'modelling' and the 'workbook' elements. Results tables are not intended to represent the preferred poles in a hierarchical manner. For presentation purposes, the poles from respective phases that are deemed related are located opposite one another using italics. This is done to reveal possible consistencies that exist in students thinking.

Regarding 'How I as a Student see myself as a Scientist', repertory grid analysis from phase 2 indicated that students ideally wish to move towards remaining confident, being a modest risk taker, remaining organised and being persistent. At the top of Table 7.12 is the scientist with whom the students most strongly identify. At the bottom, there is an indication of how students view themselves ideally as a scientist.

The metacognitive characteristics that have been identified by students indicate the importance of thinking and learning in relation to how they see their work as scientists. Table 7.13 illustrates how students view the pedagogy from a cognitive perspective over the respective phases.

Table 7.12 Favoured preferred Poles concerning 'How I see Myself as a Scientist' in Phase 3 and Phase 4.

Phase 3	Phase 4
Scientist rated as similar: A. Fleming	Scientist rated as similar: Galileo
Use experiments to prove theories	*See if you could improve the experiment*
Kept trying to solve the problem	*Learned by figuring out*
Tested problems for themselves	Not afraid to take a risk in the lab
Ideal: Kept trying to solve the problem	Ideal: Greater opportunity to learn 'by figuring out'.

Table 7.13 Favoured preferred Poles concerning 'How I as a student see the Pedagogy from a Cognitive Perspective' in Phase 3 and Phase 4.

Phase 3	Phase 4
I understand better if I make or model something	*I get to make models myself so it's easier to remember*
Models look realistic	*Get a realistic 3D view of what a molecule should be like*
Working in groups allows me to see what others are thinking	*I experience other peoples' point of views while solving problems*
I get to make my own notes and drawings	*Put what is important in your own words*
Allows me to think about what I have learned so that I can figure out and remember	*I get to think about what I'm doing or trying*
Allows me to express my own way of understanding	
I actually get to figure things out for myself	
I can see how states of matter behave	
Gives me a visual aid that tells me what a molecule is like	
Ideal: 'I get to make my own notes and drawings' and 'I actually get to figure things out for myself'	Ideal: I get to make models myself so it's easier to remember

From a cognitive perspective, students are able to identify the tools of modelling and visualization as being important regarding conceptual change. These tools can be supplemented by metacognitive strategies employed as an individual or in group-work.

Table 7.14 illustrates how students view the pedagogy from an affective perspective over both phases. Modelling and visualization give students confidence to be active in their understanding of the particulate level. This confidence serves to promote learning strategies such as trying to learn from mistakes and talking about their mental models.

Table 7.14 Favoured preferred Poles concerning 'How I as a Student see the Pedagogy from an Affective Perspective' in Phase 3 and Phase 4.

Phase 3	Phase 4
I feel more confident as I know what atoms can make up a molecule	*Figuring out how to make models gives me confidence*
I use my own information to learn and I know from others the group that it is not wrong	*I get confidence from trying to tackle a new problem I have never seen*
I know I understand and so I feel more confident	*It gives you confidence for normal exams*
I feel I get to help someone who is confused (during group-work)	I get confidence trying to learn from my mistakes
I get the opportunity to say what I think	
Ideal: I get the opportunity to say what I think	Ideal: I get confidence from trying to tackle a new problem I have never seen

Table 7.15 illustrates how teachers view the pedagogy in phase 4. The active involvement in actions related to metacognition such as explaining ideas, thinking, applying information, debating are identified as important for conceptual change and learning. Confidence is also mentioned in terms of communication as a contributing factor to learning.

Table 7.16 identifies possible incentives related to using the pedagogy in phase 4. Teachers identify modelling and visualization tools as helpful in terms of understanding. Active thinking among students contributes to explaining ideas during groupwork which assist in conceptual development. The nature of the workbook in terms of its flow and structure allowed links to be established in an iterative fashion. These characteristics were viewed as helpful involving the promotion of learning.

Table 7.17 identifies potential barriers to the use of the pedagogy in phase 4. While modelling is deemed a useful learning tool generally, care has to be taken when using it initially so that confidence is allowed to build and contribute to learning. The same is true of students offering explanations if it is a new activity for them. It is acknowledged that time is necessary to prepare materials for class activities and that further contact time would be desirable.

Table 7.15 Favoured preferred Poles concerning 'How I as a Teacher see the Pedagogy' in Phase 4.

Teacher 1	**Teacher 2**
Correcting each other and explaining conjectures	*Can communicate with someone their own age and argue their point*
Formulate and apply information	*They get a chance to know if they understand something*
Picking up learning skills	*Active ways of figuring out learning outcomes*
Generate answers and ideas	*Remember better if working stuff out for themselves even if they are wrong*
Students need to construct the material themselves	*They need to be given the opportunity to be thinking*
Giving rationale for the answer	*Debating over challenging questions involving peer learning*
To facilitate the acquisition of learning skills	*Student led*
Make decisions regarding presenting information	*Gives confidence to talk out in a group*
Work could look messy but is their interpretation	Better retention longer-term
	Students questioning with resource to work from
	They get to do their own work
	Molecules are coloured to promote understanding
Ideal: Work could look messy but is their interpretation/ Make decisions regarding presenting information	Ideal: Gives confidence to talk out in a group/ Better retention longer-term

Table 7.16 Features of the Pedagogy deemed to be Incentives by Teacher 1 and Teacher 2 in Phase 4

Teacher 1	Teacher 2
Students loved activities e.g. human modelling.	Mass (of particle) necklaces (during human modelling of the states of matter) worked really well
Weaker students liked models more than human modelling.	Visual aids meant there was understanding e.g. 'Is this a compound?' because it enabled visual paraphrasal by the teacher.
Understanding achieved was more comprehensive	Themes such as mass, symbols, macro-properties to submicroscopic e.g. Iron sulfide experiment promoted integration of knowledge rather than fragmentation. Otherwise the idea of particle mass is completely forgotten and seen as disconnected/unrelated when teaching the atom
It promoted peer-peer discussion whereby the role of the teacher was to cajole and lead/facilitate.	Group work is/was good for understanding
It improved note-taking which was a big advantage. This gave student ownership as its part of their own cognitive structure. This is particularly helpful for juniors as it gives them scaffolding.	Weaker students get more of a structured flow – everything is linked and they get to choose what is important to know [note taking]
Students were much more active versus the traditional approach and engaged and got a lot out of it – ideally teaching should be like this.	Human modelling promoted understanding e.g. by physically vibrating and doing and moving. This allowed the mind and body connection to be promoted.
Students communicated better than otherwise (e.g. using a traditional pedagogical style) and enacted a better use of language.	Repetition (of conceptual themes) was better than seeing something in the book once and not knowing what it means.
Students had confidence in explanations and wording in both student-student and student-teacher interactions.	The repetition allowed for more opportunity for students to identify the themes
	Good sequencing (occurred) to allow for understanding

Table 7.17 Features of the Pedagogy deemed to be Barriers by Teacher 1 and Teacher 2 in Phase 4

Teacher 1	Teacher 2
Some students were nervous modelling initially as they were not used to it – it took a leader within a group to help.	More preparatory time (was needed) to have materials to hand versus textbook (approach)
Concept maps did not suit weak students	Weaker students found the first iteration of modelling hard going but really got into the understanding of it afterwards in (further) other attempts
The very weak students were overwhelmed and lost during human modelling	
Video clips were a challenge for the weak students – stronger wanted to know if they could get them (on YouTube).	
There was some unsuredness regarding if the students felt they were over-reasoning regarding their own words.	
Time constraint as class contact time was only once a week	

7.6 Conclusions

Through the development of cognitive frameworks regarding the analysis of students' answers in phase 3, information regarding the use of implicit knowledge components emerged that supported the posing of a new research question at the beginning of phase 4. This was: "Can I continue to use IBL as a pedagogy to increase student competence in comprehending the area of PNM while developing an analysis tool that has the potential to reveal core implicit knowledge components within students' drawings?" It was considered important within the learning environment that a teacher would facilitate students in the evaluation and modification of their analogies/models. This approach was supported using visualization ideas from Yenawine (2012). Strategies included paraphrasing student's comments, the use of conditional language and 'visual paraphrasing' while students tried to explain phenomena. Literature was surveyed and used to inform the development of the workbook pedagogical instrument in conjunction with qualitative and quantitative analysis of phase 3. A psychological approach that acknowledged the validity of evaluating student explanations through the use of drawing at the submicroscopic level was used in interpreting exam questions. This acknowledged therefore that drawings may allow students' internal representations of particle models to be assessed with a higher validity than written or spoken answers**.** Therefore, it was again decided to invoke PCP theory to develop an evaluation approach to drawings with a specific emphasis on implicit knowledge elements. In this way it was intended to develop an assessment tool so that strategies to improve pedagogy and the capability of students to sense-make might be revealed.

Repertory grid analysis of implicit knowledge elements used in drawing answers to questions indicated that the greater the levels of inference that had to be employed to answer a question, the more likely 'substitution of the actual question' would occur. In addition, students were more likely to tentatively select features of a question and use knowledge cues to answer in an indiscriminate way. In instances where the levels of inference across questions were equivalent, students were more likely to employ implicit knowledge elements unsuccessfully in the cases of liquids as opposed to solids and gases.

At the beginning of this phase the following question was posed: 'Can I continue to use IBL as a pedagogy to increase student competence in comprehending the area of PNM while developing an analysis to that has the potential to reveal core implicit knowledge components within students' drawings?' With respect to the summative analysis the intervention group outperformed the control group in all questions (4 out of 6 were statistically significant). According to repertory grid analysis, the pedagogy was scored towards the preferred pole of all constructs according to students and placed very close to the Ideal element by teachers. This type of analysis also indicated a pattern of implicit knowledge that exists within answers to exam questions involving student drawings. It can be reasonably assumed that this phase of the study has successfully answered the above question.

The next chapter is the concluding Chapter 8. It offers an explanation of how the action research was carried out over four phases and will consider all the results obtained through the four phases and particularly in terms of student learning. These results will be discussed in terms of their significance for chemistry education practitioners and researchers.

CHAPTER 8: CONCLUSION

Introduction

The previous chapter outlined the development and analysis of the final phase of this work to answer the questions posed in the earlier chapters. This concerned increasing student conceptual knowledge and the development of an alternative evaluation tool that sought to inform future teaching and learning in chemistry. This chapter summarises the direction this thesis has followed in methodological and implementational terms in order to plan and execute the provision of an answer to the ongoing research question: 'Can an Inquiry-based Learning approach to PNM (Particulate Nature of Matter) that includes modelling and visualization among junior second level school students serve to increase their conceptual understanding?' The nature of the constant evaluation used to monitor progress towards formulating the answer is given. Reasons for evident increases in student knowledge in the PNM context are described. From the evaluations conducted, a model of learning is proposed, with supporting rationale. This responds to the secondary research question: 'Can a Model of learning and conceptual change be developed through an IBL pedagogy incorporating modelling and visualization but informed by PCP (Personal Construct Psychology)?' Finally, the steps required to use this model in another area of learning in chemistry are suggested as are recommendations for the future directions of this work.

8.1 Implementation of the Research Question

The approach used to answer the original research question took the form of a pedagogical intervention instrument which became a PNM workbook based on IBL teaching and learning. Modelling and visualization strategies were also used to define the nature of this instrument. These strategies were often adapted using research literature. The merits of these approaches were provided in Chapter 2.

In order to implement the ongoing development and evaluation of the workbook in a considered way, a Practitioner Action Research methodology based on the Kemmis and McTaggart (1982) research-spiral was used. The rationale for using this form of methodology was provided in Chapter 4. PCP served as an adjunct to this methodology to advance the efficacy of using a diagnostic tool to enhance the evaluation of the work. Thus, repertory grid interviews were conducted from phase 2 onwards. The rationale for repertory grid interviews and an outline of the interview methodology was also provided in Chapter 4. A description of the study profile and an action plan are also outlined in this chapter.

Assessment tools were developed following monitoring and evaluation of the pedagogical instrument through successive cycles of action research. A summative exam was undertaken by all students each year while a diagnostic assessment applied to the intervention group in phases 3 and 4. The rationale for the development of these exams with an emphasis on drawings and conceptual questions was provided in Chapters 5 and 6. Finally, in order to supplement the constant monitoring of student learning in relation to the workbook, a teacher journal was recorded in phases 2 to 4.

An outcome of constant reflection and engagement with the research literature by the author served to illustrate that there was a natural alignment between both chemistry and chemistry education literature, and PCP. These observations are based on the Dichotomy Corollary (see Section 3.4.3). In the case of both chemistry areas and their relation with PCP, there is a shared view that people think in terms of contrast (Fransella, 2016). It is helpful to acknowledge this. PCP provided the researcher with more information about the interaction between the student experience and the learning materials based on modelling, visualization and IBL. A further outcome was that it served to explain the learning that took place. This was because the overlap in the lexicon of PCP and aspects of the chemistry education literature relating to conceptual change became apparent. Hence, an opportunity to develop a coherency of vocabulary in relation to learning that could serve to bridge theory and practice also became apparent. The description of this framework, given in Chapter 3, discusses how an individual learns. This is reflected in practical terms in the first alternative evaluation tool that was developed (in phase 3). It involves the identification of critical differential poles within construct systems of student reasoning and serves to identify learning gaps in PNM knowledge.

A further attempt to bridge theory with practice was developed in relation to implicit knowledge. This featured an analysis of student responses to exam questions involving drawings. Both tools are an expression of the author's attempt to increase the range of convenience used to interpret the reasoning of his students. The ideas generated in this sense-making experience increased the author's awareness of learning from one rooted in intuition to one that was more comprehensive and also converged in a proposed model of conceptual change discussed later in Section 8.3. Therefore, this journey emanating from a desire to change my practice led to a growth in the understanding of both my own practice as a teacher and the understanding of PNM among students. The product has also been met with favour among my colleagues and can potentially facilitate a growth in understanding of their practice. In this way, the process of practitioner action research has allowed me to go towards the realisation of my values about justice, care, dignity, freedom and excellence. The next section illustrates the learning gains achieved by learners and attempts to explain the reasons for this phenomenon which can contribute to a proposed model of learning and conceptual development.

8.2 The Rationale for Student Learning

Intervention students outperformed their counterparts in the control group over the four phases of the study. In many cases, the differences in results were statistically significant.

Invoking the idea of a 'favoured pole' of a construct as described in Section 6.2.8, the following section presents favoured poles according to the category of constructs to which they belong. This approach was first discussed in Section 6.1. These themes include: Choice; Metacognition; Sociality; Aggression and Permeability. For ease of analysis, constructs from students regarding the pedagogy are combined over phase 3 and 4. Teacher constructs from phase 4 are also grouped in this way. A description is given by pedagogical theme to explain the consistently superior exam performance of the intervention group. This is done in a way that acknowledges the defining components of the pedagogy; modelling and visualization and IBL.

It serves to illustrate the significance of the pedagogical characteristics of knowledge building which inform the proposed model of learning that is discussed in Section 8.3. For ease of explanation, preferred poles are given reference numbers. It is worth noting that the categorisation of a preferred pole was made in the context of its corresponding non-preferred pole.

Inquiry-based Learning:

Given that the nature of inquiry learning in this study involved an emphasis on groupwork, the category of preferred poles from student repertory grids that are viewed as most closely related to IBL are those of 'sociality'. There is evidence from the literature that links IBL with conceptual understanding. Preferred poles are used to explain how inquiry based learning in the case of this study led to improved understanding. This is expressed in Table 8.1.

Table 8.1 Student Favoured Poles Relating to Sociality / IBL

1.	I experience other peoples' point of views while solving problems (C)
2.	Working in groups allows me to see what others are thinking (C)
3.	I feel I get to help someone who is confused (during group-work) (A)
4.	I know I understand and so I feel more confident (A)
5.	I use my own information to learn and I know from others the group that it is not wrong (A)
6.	Open to others' opinions (S)
	Legend *(Corresponding to preferred pole source)* S= Construct from 'How I see myself as a Scientist' Grid C= Construct from 'How I see the Pedagogy from a Cognitive Perspective' A = Construct from 'How I see the Pedagogy from an Affective Perspective'

According to the IAP (2006), promotion of learning involving student participation is evident in poles 1 and 2 (Table 8.1). Poles 3 and 5 (Table 8.1) align with the conclusion by Minner et al. (2010) that inquiry-based instructional practices emphasize student active thinking. Pole 6 (Table 8.1) illustrates the intent to engage in science learning that is a positive feature of IBL (IAP, 2006). According to Friesen and Scott (2013), another indicator of successful inquiry implementation which strongly features in this pedagogy is scaffolding. Pole 5 (Table 8.1) emphasises its use in this study. The deeper understanding of knowledge synonymous with inquiry lessons (Furtak, 2006) is visible in poles 4 and 5 (Table

8.1). Finally, Grandy and Duschl (2007) point to the possible development of the skill of thinking critically arising from criticisms from others and arguing the merits of alternative models which are associated with poles 1, 2 and 3 (Table 8.1). To do this successfully, Wolf and Fraser (2008) note that the classroom must be a risk-free environment in which to work. This view echoes the learning environment plans that were exercised in this study.

The corresponding preferred poles involving teacher's constructs regarding 'sociality' are displayed in Table 8.2.

Table 8.2 Teacher Favoured Poles Relating to Sociality / IBL

7.	Debating over challenging questions involving peer learning
8.	Can communicate with someone their own age and argue their point
9.	Gives confidence to talk out in a group
10	Correcting each other and explaining conjectures

The poles illustrated in Table 8.2 reflect the rationale used to explain the relationship between IBL and increased conceptual understanding of participant students. All poles can promote the affective nature of learning. They echo Williamson (2014) who notes that feelings of comradeship enable students to persist with problem solving in chemistry.

<u>Choice:</u>

This section strongly relates to the modelling and visualization tools used in the pedagogy by students to make sense of PNM. The preferred poles from 11 to 14 (inclusive) in Table 8.3 are aligned with the view of Hubber and Tytler (2013) that models are a critical feature of quality learning in science. It is a natural consequence that concept understanding will increase under these conditions.

Table 8.3 Student Favoured Poles Relating to Choice

11.	Gives me a visual aid that tells me what a molecule is like (C)
12.	I can see how states of matter behave (C)
13.	Models look realistic (C)
14.	Get a realistic 3D view of what a molecule should be like (C)
	Legend *(Corresponding to preferred pole source)* S = Construct from 'How I see myself as a Scientist' Grid C = Construct from 'How I see the Pedagogy from a Cognitive Perspective' A = Construct from 'How I see the Pedagogy from an Affective Perspective'

Construction:

Construction refers to the relationship between the generation of an internal and external model. Table 8.4 indicates the importance of this process to their learning. The expression of the alignment between increased conceptual understanding, from a cognitive and affective perspective is, evident from poles 15 to 17 (Table 8.4). Yenawine (2012) cites reasoning as an important behaviour for understanding and motivation. Table 8.5 shows that this characteristic of knowledge building is favoured by teachers even if the current outcome is not correct.

Table 8.4 Student Favoured Poles Relating to Construction

15.	I understand better if I make or model something (C)
16.	I get to make models myself so it's easier to remember (C)
17.	It gives you the confidence to be a scientist (A)
	Legend *(Corresponding to preferred pole source)* S= Construct from 'How I see myself as a Scientist' Grid C= Construct from 'How I see the Pedagogy from a Cognitive Perspective' A = 'How I see the Pedagogy from an Affective Perspective'

Table 8.5 Teacher Favoured Poles Relating to Construction

18.	Remember better if working stuff out for themselves even if they are wrong
19.	Student led

Metacognition:

This is the category that is most emphasised by students in relation to their learning and its association with student conceptual development is illustrated in Table 8.6.

Table 8.6 Student Favoured Poles Relating to Metacognition

20	Working in groups allows me to see what others are thinking (C)
21	I get to make my own notes and drawings (C)
22	Allows me to express my own way of understanding (C)
23	I actually get to figure things out for myself (C)
24	Allows me to think about what I have learned so that I can figure out and remember (C)
25	I understand better if I make or model something (C)
26	It's easier to study for an Inquiry exam (C)
27	Put what is important in your own words (C)
28	I get to think about what I'm doing or trying (C)
29	Figuring out how to make models gives me confidence (A)
30	I get the opportunity to say what I think (A)
31	Kept trying to solve the problem (S)
	Legend *(Corresponding to preferred pole source)* S = Construct from 'How I see myself as a Scientist' Grid C = Construct from 'How I see the Pedagogy from a Cognitive Perspective' A = Construct from 'How I see the Pedagogy from an Affective Perspective'

Pole 25 (Table 8.6) relates to the assertion by Jones (2013) that models of molecules help to form understandings of the submicroscopic level. It is the view of Gobert et al. (2011) that a feature of this approach is that students engage in content-rich conversations conducive to learning. This is also evident in pole 27 (Table 8.6). Anderson (2002) and Grandy and Duschl (2007) contend that becoming conscious of possible deficiencies in thinking is to be able to think critically and therefore argue the merits of alternative models. This approach is reflected in poles 24, 27, 30 and 31 (Table 8.6).

Poles 21, 22 and 27 (Table 8.6) are linked to the advice by Miyake (2008) that teachers should encourage students to write about their knowledge and become "epistemic agents to increase understanding". To underscore the importance of metacognitive activities, Taber (2015) states that engaging in metacognitive sense-making experiences help to encourage a *metacognitive attitud*e.

Metacognition is the category that is most emphasised by teachers in relation to learning. Its relevance to learning from a teachers' perspective is displayed in Table 8.7.

Table 8.7 Teacher Favoured Poles Relating to Metacognition

32.	Picking up learning skills
33.	Students need to construct the material themselves
34.	Make decisions regarding presenting information
35.	Giving rationale for the answer
36.	Work could look messy but is their interpretation
37.	To facilitate the acquisition of learning skills
38.	Formulate and apply information
39.	Correcting each other and explaining conjectures
40.	Molecules are coloured to promote understanding
41.	They get a chance to know if they understand something
42.	Active ways of figuring out learning outcomes
43.	Students questioning with resource to work from
44.	They get to do their own work
45.	Better retention longer-term
46.	They need to be given the opportunity to be thinking
47.	Debating over challenging questions involving peer learning
48.	Can communicate with someone their own age and argue their point
49.	Gives confidence to talk out in a group
50.	Remember better if working stuff out for themselves even if they are wrong

Poles 45 and 50 (Table 8.7) point to the relevance of the pedagogy in terms of accessing knowledge in long-term memory with respect to time. Pole 41 (Table 8.7) is in congruence with the assertion by Driver et al. (1996) that there is a distinction between *believing* something to be the case, and actually *knowing* that it is. The difference is that a learner with a metacognitive attitude will try to carry out a validation of their theory to check if it actually is true.

Permeability:

Table 8.8 indicates the preferred poles of students' constructs that are associated with promoting conceptual change.

Table 8. 8 Student Favoured Poles Relating to Permeability

51.	Question what is being taught (S)
52.	Not afraid to take a risk in the lab(S)
53.	Risk taker (S)
54.	I get confidence trying to learn from my mistakes (A)
55.	I feel more confident as I know what atoms can make up a molecule (A)
	Legend *(Corresponding to preferred pole source)* S = Construct from 'How I see myself as a Scientist' Grid C = Construct from 'How I see the Pedagogy from a Cognitive Perspective' A = Construct from 'How I see the Pedagogy from an Affective Perspective'

The poles illustrated in this table relate to the development of the metacognitive attitude that serves to advance learning. One of the teachers in the study associates this attitude with the capacity to generate answers and ideas.

Aggression:

The preferred poles of students' constructs that are associated with conceptual change and transition are provided in Table 8.9.

Table 8.9 Student Favoured Poles Relating to Aggression

56.	Learned by figuring out(S)
57.	See if you could improve the experiment (S)
58.	Use experiments to prove theories (S)
59.	Tested problems for themselves (S)
60.	I get confidence trying to learn from my mistakes (A)
61.	I get confidence from trying to tackle a new problem I have never seen (A)
62.	I get a chance to be motivated by a challenge (A)
63.	I get to think about what I'm doing or trying (C)
64.	I get to make my own notes and drawings (C)
	Legend *(Corresponding to preferred pole source)* S = Construct from 'How I see myself as a Scientist' Grid C = Construct from 'How I see the Pedagogy from a Cognitive Perspective' A = Construct from 'How I see the Pedagogy from an Affective Perspective'

Mozzer and Justi (2012) note that from the modelling process, scientific attitudes - as important as learning scientific content - can develop. The poles in this table such as 'I get confidence trying to learn from my mistakes' serve to define the qualities a person needs to persist with their learning.

Implicit Knowledge of Students:

Following exams, frameworks of understanding were developed for all exam questions in phase 3. 'Critical Differentiation Poles' were identified to make inferences about gradations of understanding within these frameworks and reveal learning gaps. It was apparent that the main critical differential poles evident were 'Understanding of the Particulate' and 'Range'. It was noted at the time of analysis that there were two implicit knowledge characteristics which were apparent. These features were:

- Attribute Substitution;
- Associative Activation of knowledge.

Repertory grid analysis of implicit knowledge elements used in drawing answers to questions among the intervention group in phase 4 indicated that the greater the levels of inference necessary to answer a question, the more likely 'Substitution of the Actual Question' would occur. In addition, students were more likely to tentatively select features of a question and use knowledge cues to answer in an indiscriminate way. In instances where the levels of inference across questions were equivalent, students were more likely to employ implicit knowledge elements unsuccessfully in the cases of liquids as opposed to solids and gases.

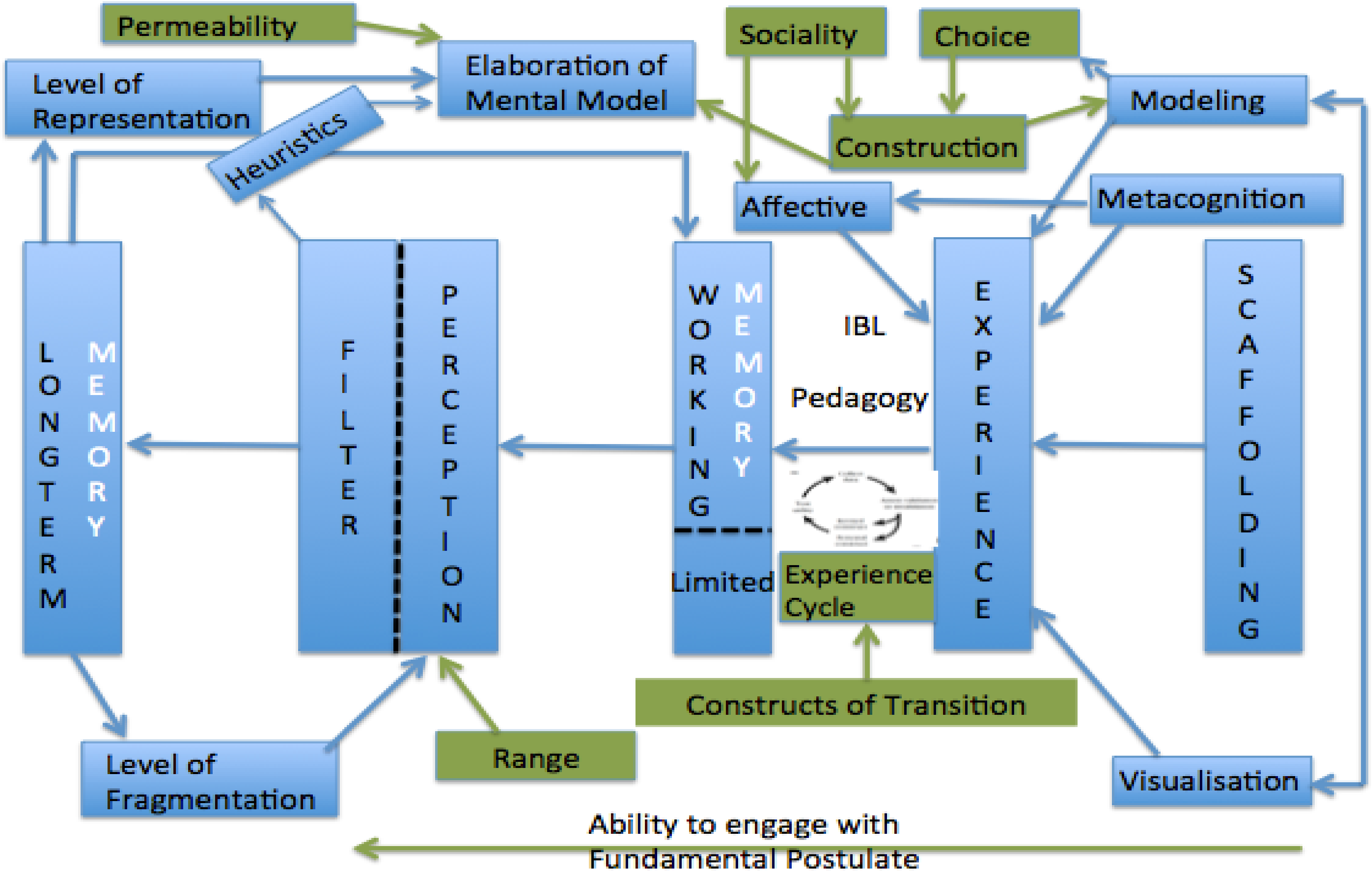
8.3 A proposed Model of Conceptual Change and Learning

The previous section described the importance of the relationship between consistent conceptual gains and the primary features of a pedagogical intervention over four phases in the context of PNM. There is an overlap in the range of these characteristics that are identified by students and by teachers. This expresses a validity towards these aspects of pedagogy from a teaching and learning perspective. Together, these traits form a synergistic relationship to assist in learning and conceptual change. This relationship can be expressed in the form of a proposed learning model that was first discussed in Section 3.5. This proposed model of learning is illustrated in Figure 8.1. It includes cognitive structures and processes that are critical to learning. These processes are framed within a PCP architecture. Ideas from the area of PCP are coloured in green for presentation purposes. The entry point to the diagram is on the right-hand side where knowledge is less sophisticated. The aspiration is to move students in the direction that enables one to fully engage with Kelly's fundamental postulate which has the same epistemological status as a scientist seeking to understand and explain natural phenomena. In order to increase understanding in this way, cognitive tools such as modelling and visualization feature in conjunction with teaching. Teaching may be further influenced by the considered application of scaffolding to promote the efficient use of such tools and to sequence activities appropriately. These components serve to formulate the experience of the learner.

One such way in which they can do this is through 'construction', which is the building of more elaborate internal representations (tentative mental models) through the student experience. In Kellyian terms, as mentioned earlier, learning constitutes the experience. This is represented using the 'Experience cycle' where hypotheses are generated, tested, validated and potentially revised. Metacognition is deemed as taking place within this cycle. This process can be undertaken individually or in groups and may be promoted by observing the actions and behaviour of the teacher as a facilitator. This role permits students to further scaffold their learning using communal ideas in the social interactional space with others.

The 'Experience Cycle' also holds the affective domain of learning. The nature of this domain is based on elements of learning already discussed in this section and it in turn influences the dominant nature of the constructs of transition such as 'aggression' that are used by students. It is more likely that this particular construct of transition will be employed by students who have developed a metacognitive attitude during their learning experience.

Figure 8.1 A Proposed Model of Learning and Conceptual Change



This construct is also related to the level of 'permeability' a student employs to facilitate the generation of new constructs. Hence, a more sophisticated understanding encompassing a broader range of concepts can be achieved, in which sufficient levels of choice have been provided to allow students make decisions involving their learning.

Working memory is used to make sense of new information encountered under conditions of limited capacity. This serves to generate a perception which in turn influences the filtration that determines what gains access to long term memory. The efficacy of filtration depends on the range of convenience of the learner's cognitive system (construct system) which determines how sensitive their perception may be. Long term memory may have information that is isolated or flawed but coherently integrated and that determines fragmentation levels. There is a two-way correspondence between working memory and long term memory. Therefore, both determine the elaboration of a mental model which may be expressed. Cognitive biases, through heuristics, may serve to influence the mental model. The 'Level of Representation' reflects the 'chemistry triplet' which needs to be understood in order to produce a coherent mental model that can convey one or more of those levels. Given that the features of this model can serve to promote learning, it can be viewed in an alternative way. That is to say, it can provide a framework of what successful learning looks like if the features of it are taken in their entirety.

8.3.1 Proposed Model of Conceptual Change versus the Information Processing Model

The model of learning suggested in Figure 8.1 is an expansion of that proposed by Johnstone (1991). This was already represented in Figure 3.2 in Chapter 3. While the original model recognises the importance of working memory and long-term memory in relation to experience, learning is not viewed as constituting an experience cycle. The advantage of interpreting learning in this way is illustrated in Figure 8.2 (the detailed discussion of this cycle is in Section 8.3.3) and planning for teaching using permeable constructs can be linked to it. The affective nature of learning appears to be hinged on 'interest' in Johnstone's model but is contextualised in the newer model. In this case, it is deemed part of the experience cycle and is contingent on the level of metacognition and social interaction offered in the learning experience. In addition, the proposed model of learning in this work highlights Kellyian corollaries that serve to *complement* the original model and therefore potentially allow a more efficient conversation to take place on the factors that promote and hinder learning. The automatic processes resulting from the subconscious (heuristics) are also recognised as affecting the learning that takes place. These are absent from Johnstone's model. Finally, fragmentation which helps to explain the nature of moving from the unknown to the known amid competing conceptions is acknowledged in the expanded model of conceptual change. This feature also has implications for teacher planning as emphasised in Figure 8.2.

In summary, the outputs from the data analysed in this work are represented within this newer proposed model of learning. While it is specific to this present study, nevertheless the model can potentially offer a greater opportunity to consider the teaching and learning that takes place in the science classroom in a more holistic way.

8.3.2 The Context of PCP following the Study

Kelly recognises students as 'active constructive agents' who contribute something to the learning process. This argument has the implication that students are involved in building explanations or making predictions and is echoed by Confrey (2006) and Sawyer (2006). Indeed, Gooding, (2010) claims in this way learners perform the actions of 'cognitive agents'. The author would deem it necessary to extend this claim to that of viewing them as potential 'metacognitive agents'. Students throughout the study demonstrated that they are aware of the necessity to develop metacognitive skills and develop their thoughts by expressing their opinions and listening to those of others. They also proved that they were sufficiently responsible to go one step further and engage in these activities. This phenomenon also indicates the responsible social role that they adopt in their learning.

However, the extent to which students can play this role depends directly on the role that a teacher can perform as a facilitator of learning. Kelly's corollaries can assist both the teacher and the learner by implicitly assuming students are active cognitive agents. These agents need an appropriate breath of choice of learning opportunities in order to engage with models so that mental models at different levels of representation might be constructed. Consequent levels of transitional constructs such as hostility or aggression will influence the capacity of students to engage in active construing.

PCP in the final analysis offered a greater depth to which one could discuss conceptual change. Additionally, the author would agree with Fransella et al. (2003), Warren (1998) and Salmon (1988) that the repertory grid technique is a tool that allows a teacher to 'walk in another's shoes ' so as to see the world from their point of view. This promotes teaching skills that are aligned with the teacher as a facilitator (as discussed previously in Section 3.5) so that students are allowed to externalise their experiences and participate fully within a learning community.

8.3.3 The Application of the Proposed Model of Conceptual Change in other areas of chemistry

This section describes the potential use of the proposed model of learning that has been developed in this work to areas of chemistry education other than PNM.

The proposed model of conceptual change has been developed using a pedagogical approach of IBL to the context of PNM set in the researcher's teaching and learning environment. Therefore, it is set in one context only. However, given that modelling and visualization tools are ubiquitous in chemistry education, and likely to become more so, then it is reasonable to assume they will always be relevant. An ever-present challenge that pervades all areas of chemistry is the three levels of representation used to discuss it. PCP is a theory that acknowledges the constructivist view that knowledge is tentative. Simply put, it is a theory of sense-making for students which is applicable to any area of chemistry in relation to students.

In order to use it in another area of chemistry, it is worth drawing from Pope and DeNicolo (2016), who emphasise the importance of teachers questioning their teaching. In order to do this in a considered way, Pope and DeNicolo (2001a) pointed to the permeability of our constructs as granting us the freedom to respond to new events. This echoes the stance of Kelly (1955/1991) who argued that psychologists need to use more 'permeable' constructs in their own (construct) systems so that they could better subsume the construct system of their clients. Similarly, Pope and DeNicolo (2016) contend that teachers could reflect if they are using a range of permeable constructs which allows them carry out optimum assessment of their students' learning. In order to do this, it is useful to remember, (as discussed in Section 3.4.3) that Kelly noted that learning is the experience. This places the emphasis on the 'Experience cycle' part of the model (Figure 8.1) regarding the application of a range of permeable constructs. A revised version of the Experience model illustrated in Section 3.4.3 is displayed in Figure 8.2. It shows, at its centre, an IBL learning environment but this could arguably be exchanged for a different context.

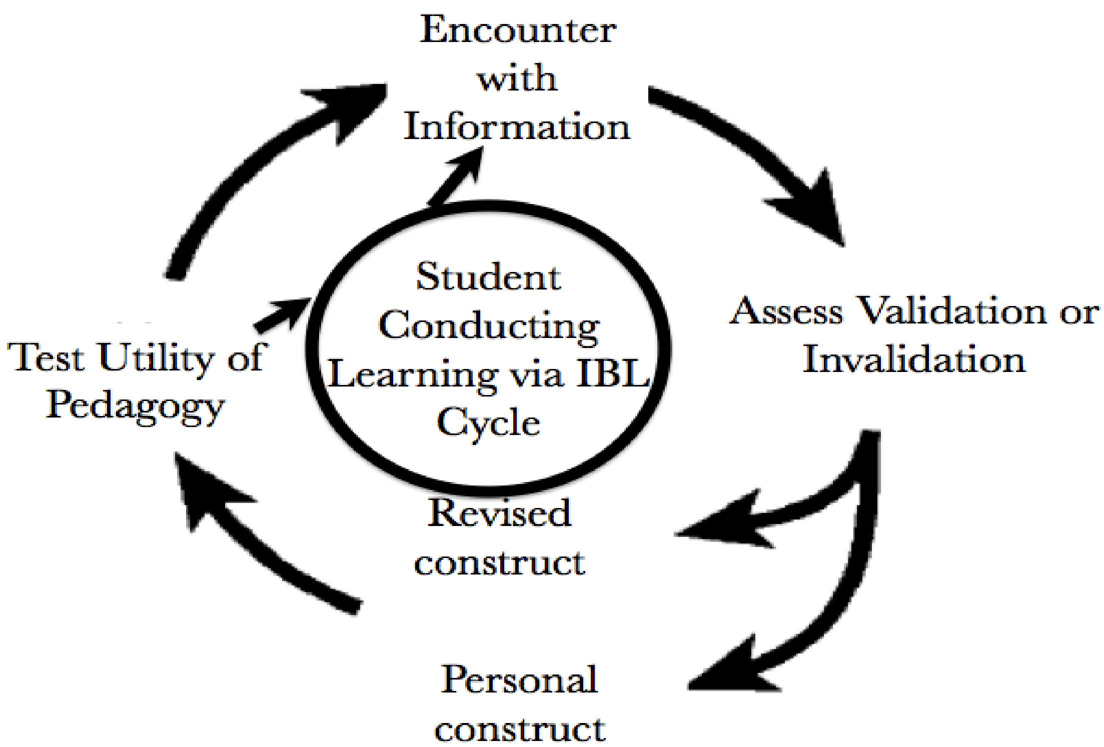


Figure 8.2 Revised Version of the Experience Cycle to assist in the application of the Proposed model of Learning

The entry point is via the pedagogy and first links with the 'Encounter with Information' stage. Now, some constructs that may be useful for a teacher to use at each stage of the 'Experience Cycle' are suggested.

Encounter with Information Stage:

- 'Did I allow students to link prior knowledge to new knowledge---- Did not allow students to link prior knowledge to new knowledge';
- 'Did I relate this concept to other areas within the chemistry curriculum---Did not relate this topic to other areas of the chemistry curriculum';
- 'Did I allow students to discover real-world applications of this topic beforehand---Did not allow students to discover real-world applications of this topic', and
- 'The encounter was active --- The encounter with the topic was inactive'.

Validation/Invalidation Stage:

- 'Did students get an opportunity to form a hypothesis in relation to this topic---Students did not get an opportunity to form a hypothesis in this topic';
- 'Are students going beyond surface features to understand/validate --- Are students focusing on surface features for understanding/validating';
- 'Did I consider an appropriate level of scaffolding in relation to learning before validation---Neglected to consider an appropriate level of scaffolding in relation to learning before validation' ;
- 'Students carrying out validation in groups---Students are carrying out validation in isolation'.

Revised Constructs Stage

- 'I listened to what my students are saying to determine if they need to consider hypothesis revision---- I did not listen to what my students are saying to see if they need to consider revision';
- 'I developed a teaching plan of the topic that may lead students to consider a revision of their hypothesis--- I did not consider a teaching plan that may lead students to consider a revision of their hypothesis';
- 'Debate is permitted before hypothesis revision---No debate is permitted prior to construct revision';

- ‘The need to consider the revision of hypothesis is promoted in this learning environment--- The need to consider the revision of hypothesis is not promoted’.

Test Utility Stage

- ‘I encourage students to use models to test their ideas---I do not encourage students to use models to test their ideas’;
- ‘I permit time to allow students to test their ideas through debate or presentation---I do not permit time to allow students test their ideas through debate or presentation’;
- ‘Technology is provided to allow students to test their ideas---Technology is not provided to allow students to test their ideas’;
- ‘Students are encouraged to test the utility of their hypotheses----Students are not encouraged to test the utility of their hypotheses’.

The permeable constructs offered in this section are suggestions as to how a teacher would begin to consider the proposed model of conceptual change in a chemistry topic in their class. Other considerations that would be useful are: working memory capacity; the range of experiences afforded to students in their encounter with this topic; the capacity for knowledge fragmentation; the areas of the topic likely to be prone to the use of implicit knowledge; the number of levels of representations employed during the teaching and learning of the topic. The extent to which a teacher could embrace the proposed model of learning would depend on constraints of time and the field conditions of a teacher’s work environment. However, it is hoped that the model has the capacity to be portable within the field of chemistry and serve as a useful benchmark against which successful teaching and learning can be gauged.

The acknowledgement of permeable constructs is helpful to a teacher in relation to the focus it places on their potential role as a facilitator. This approach enhances the level of student-centredness of various parts of any given lesson in a meaningful way. It is aligned with practitioner action research as it calls for constant reflection which can serve to increase the range of teaching and learning ideas that a teacher can use with their students on a given topic. Finally, by acknowledging both the experience of the teacher and the student as cycles that may be bridged, teachers may establish a framework to use in order to assist students achieve their optimum level of conceptual change. Thus, a way forward that is aligned with Cochran-Smyth & Lytle (1999) may be achieved. They acknowledge that while research with respect to teaching is complex and uncertain and may pose more problems than it solves, the nature of inquiry both stems from and generates questions. This tool could assist teachers in navigating this cyclical challenge.

8.4 Study Limitations

In any study, it is important that the study limitations are outlined so that the research output is framed within the context of the study. The suggestion of the Hawthorne Effect (Cook, 1967), where participants realise that they are part of a research study and therefore change their behaviour, while ever present, is minimised in this research, due to the cyclical basis of the study, the range of students involved and also the number of teachers involved. Therefore, the improvement in results regarding the PNM by students in the intervention group (due to the pedagogical instrument taught using IBL) would appear to be unrelated to the Hawthorne effect. It is more likely that the results output is due to the cyclical nature of the practitioner action research that was undertaken.

The nature of the analysis which featured critical differential poles and repertory grids is constrained by the author carrying out an act of 'secondary construal' of his students. This is because he was attempting to 'construe their construing'. However, in both cases, PCP helped to provide a structure to this form of construal. It was of assistance regarding the generation of a hierarchical gradation of student explanations. Kelly's theory also proves to be advantageous in terms of student interviews using repertory grid technique. This is because it allowed for the possibility of eliciting 'student' constructs as opposed to 'supplied' constructs. Consequently, the approach employed serves to add validity to the study as grids make better sense of the elements they contain regarding student ratings. However, the repertory grid analysis itself involved the portion of the intervention cohort that was taught by the researcher and not other students in the intervention group (who were taught by other teachers). This was due to the time constraints affecting the conduct of the interviews. The reliability of the repertory grid approach was acknowledged in Section 4.5.3. In terms of the reliability pertaining to quantitative analysis, the aspiration was that results would show an improvement and this happened in most cases of exam questions even if it was not always statistically significant. Hence, while student results among the intervention cohort (consisting of different groups of students) were similar in successive years, it was not expected that they would be repeated. As the sample was one of convenience, it is not asserted that the research results are generalisable. They related to girls only and to a limited number of classes and students. Participants did not constitute a genuine cross-section sample of the entire Irish first year student population. Therefore, as Taber (2007) writes, it does not tell us about another time, another classroom, another class or another learner.

8.5 Conclusion:

This chapter has described how the research question was implemented regarding intended conceptual improvement in the area of PNM using IBL with modelling and visualization tools. Over time, the emphasis changed from a focus on the development of materials to promote learning to include the consideration of how students learn and reason. This led to a secondary research question regarding modelling, learning and conceptual change using PCP as a framework of reference. A rationale based on a PCP diagnostic tool was provided to explain the outcome of the final two phases of the study in terms of the exam performance of the intervention group relative to the control group. This exercise revealed that certain features of learning are important to students and teachers regarding the attainment of an authentic understanding in the area of PNM. These characteristics were framed within the theory of PCP and how students learn. Thus, it was possible to produce a model of learning and conceptual development that acknowledged the dynamic relationship between these features and served to express how PNM could be successfully understood (Figure 8.1).

A possible approach to employ this model of learning in a teaching and learning context other than PNM was outlined involving the consideration of the experience cycle in relation to permeable constructs. Future directions of this work should continue to emphasise the importance of acknowledging the validation of student responses in the classroom or in an exam situation. The component of the model of learning employs heuristics could be further explored to help inform teaching and learning. While its implications for drawings were considered in this study, it would be useful to develop a framework that could examine written responses to questions. In this regard, it would also be useful to conduct interviews with students, specifically about the rationale they understood that they employed while answering the question. It may also be advantageous to consider Figure 8.2 in relation to teacher professional development. By involving teachers (based on their experience) in the broadening of the range of permeable constructs at each stage of the cycle, a useful resource could be developed for use in the classroom. Finally, repertory grids involving 'modelling and visualization' could be explored to focus the critical aspects of student experiences when employing these tools for learning. In order to do so, students could be interviewed on grid elements that represent these learning components.

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APPENDIX A

Syllabus Learning Outcomes related to Phase 1

The following learning outcomes from the Chemistry section of the syllabus help to form the basis of the content of the workcards and are given in their order of appearance within them:

OC1	Name three states of matter and describe their distinguishing characteristics
OC3	Describe, and distinguish between, an element, a compound and a mixture; recall that all known elements are listed in the Periodic table and that, in a chemical reaction, elements may lose their individual properties
OC4	Examine a variety of substances and classify these as elements or compounds (using the Periodic table as a reference)
OC5	List the physical properties (state and colour only) of two examples of metallic and two examples of non-metallic elements
OC13	Compare mixtures and compounds made from the same constituents
OC43	State what a molecule is; recall that covalent bonds involve the sharing of pairs of electrons and describe the bonding in H_2, O_2, H_2O, CH_4 as examples of covalent bonding
OC41	Relate the formation of compounds to the combination of atoms
OC15	Investigate the solubility of a variety of substances in water and the effect of temperature on solubility
OC16	Explain the difference between a dilute, a concentrated and a saturated solution
OC2	Separate mixtures using a variety of techniques: filtration, evaporation, distillation and paper chromatography
OC12	Compare the properties of the simple compounds H_2O, CO_2, MgO and FeS to those of their constituent elements
OC17	Grow crystals using alum or copper sulfate
OC32	Carry out a simple distillation, and obtain a sample of water from seawater
OC45	Appreciate that rusting is a chemical process that changes iron into a new substance

The following Physics learning outcomes are also related to the workcards

OP4	Appreciate the concept of force; recall that the Newton is the unit of force; describe forces and their effects
OP21	Give examples of energy conversion from everyday experience
OP28	Carry out experiments that involve changes of state from solid to liquid and liquid to solid and liquid to gas and gas to liquid

APPENDIX B

Learning Outcomes (Phase 1)

Workcard No.	Learning Outcome(s) Contained within Workcard	Emphasis on Key-Skill
1	• The effect of energy on particles of substances** • Invisible Gases can be made of visible particles (OC1)*	• Predict • Interpret • Explain • Metacognition • Consider alternatives
2	• **What the states of Matter are (OC1)** • To identify the characteristics of matter viz the shapes that states of matter take up, the volume they may occupy and the nature of the movement of their particles (OC1)*	• Model • Interpret • Consider Alternatives • Predict • Explain • Metacognition
3	• To calculate volume	• Interpret
4	• To identify the characteristics of matter viz the shapes that states of matter take up, the volume they may occupy and the nature of the movement of their particles (OC1)* • To distinguish between the compressibility of the states of matter (OC1)* • To understand that mass is conserved when matter changes state e.g. from a solid to a liquid to a gas** • To model iron (solid), water (liquid) and oxygen (gas) at the particulate level using symbols**	• Categorise • Explain • Model
5	• To visualise the diffusion process of a gas in a gas **	• Explain
6	• To recall the names of the changes of state of matter** • To understand the relationship between attractive forces between particles in the 3 states of matter (OC1)* • To generate changes of state of matter using human models** • To identify changes of state using models of particles** • To model at the particulate level (using symbols) what is inside a bubble of a pure substance** • To visualise that the number of particles of a substance are the same while it changes state** • Relate temperature to changes of state** • To model water at the particulate level using symbols**	• Interpret • Model • Metacognition
7	• To model bromine in solid, liquid gas states at the particulate level using symbols** • Visually relate the particles of a substance (which contain symbols) to a picture of how you normally see the substance in everyday life**	• Predict • Model • Explain
8	• Examine a variety of substances and classify those appropriate as elements (OC4)* • **List the physical properties (state and colour) of two metallic and two non-metallic elements (OC5)** • To understand elements contain one type of atom (OC3)* • To understand elements are pure substances (OC3) * • To decide if a representation is an element using the Periodic	• Model

	Table as a reference (OC3) * • To visualise an atom** • To visualise a molecule (OC43) * • To model elements made of atoms and elements made of molecules using appropriate symbols (OC3)*	
9	• To identify the component elements of compounds by name (OC3)* • To understand that compounds are pure substances (OC3)* • To identify the atoms in a molecule of a compound (OC41)* • To visualise the synthesis of the compound iron sulphide (OC3)* • To understand that the properties of a compound are different to its component elements (OC13)* • **Compare mixtures and compounds made from the same constituents (OC13)**	• Compare • Metacognition
10	• To understand the difference between a compound and mixture (OC3)*	• Compare • Metacognition
11	• To understand that the properties of a compound are different to its component elements (OC13)* • To model elements and compounds (in a given phase) using atoms and molecules and appropriate symbols (OC41) * & (OC43) * • **Relate the formation of compounds to the combination of atoms (OC41)**	• Model • Compare • Metacognition
12	• To understand there is an attraction between opposite charges ** • To visualise the interaction between water molecules and sodium and chloride ions as salt dissolves ** • To model salt dissolving** • To identify factors that affect the ability of a substance to dissolve (OC15)* • To understand the difference between dissolving and disappearing** • To identify solutes and solvents** • To understand the mass of a solution is the sum of the mass of solute and solvent** • To understand that the mass of a solution is conserved over time** • **Investigate the solubility of a variety of substances in water and the effect of temperature on solubility (OC15)** • **Explain the difference between a dilute, a concentrated and a saturated solution (OC16)**	• Model • Interpret • Explain
13	• **To Grow crystals of copper sulphate (OC17)**	• Metacognition
14	• **To separate mixtures using a variety of techniques: filtration, evaporation, distillation and paper chromatography (OC2)** • To model the chromatography process (OC2)*	• Predict • Explain
15	• To identify and understand the differences between physical and chemical changes (OC45)*	• Explain • Metacognition
Legend	**Bold** = direct correspondence with Junior Certificate Syllabus with syllabus code in brackets * = deemed a necessary component of a syllabus outcome ** = deemed to serve as scaffolding knowledge	

APPENDIX C

Learning Outcomes (Phase 4)

<table>
<tr><th>WORKBOOK CHAPTER NO.</th><th>LEARNING OUTCOME(S) CONTAINED WITHIN WORKBOOK</th><th>EMPHASIS ON KEY-SKILL</th></tr>
<tr><td>1</td><td>• The effect of Energy on particles of substances**
• Invisible gases can be made of visible particles (OC1)*
• Draw models of the production <u>of the gas</u> (ammonium chloride) (OC1)*</td><td></td></tr>
<tr><td>2</td><td>• Name three states of matter and know their characteristics (OC1)
• To identify the characteristics of matter <u>viz. the</u> shapes that states of matter take up, the volume they may occupy and the nature of the movement of their particles (OC1)*
• To visualise that the number of particles of a substance are the same while it changes state**
• To visualise that particle mass, shape and size is conserved during changes of states of matter**
• To categorise the relative strengths of attractive forces between particles of the three states of matter</td><td>• Interpret
• Model</td></tr>
<tr><td>3</td><td>• To calculate volume</td><td></td></tr>
<tr><td>4</td><td>• To identify the characteristics of matter <u>viz. the</u> shapes that states of matter take up, the volume they may occupy and the nature of the movement of their particles (OC1)*
• To distinguish between the compressibility of the states of matter (OC1)*
• To understand that mass is conserved when matter changes state e.g. from a solid to a liquid to a gas**
• To model iron (solid), water (liquid) and oxygen (gas) at the particulate level using symbols**
• To model mercury in solid, liquid and gas states at the particulate level using symbols**
• Name three states of matter and know their characteristics (OC1)
• Relate temperature to changes of state**
• Visualise the size of atoms**</td><td></td></tr>
<tr><td>5</td><td>• To visualise the diffusion process of a gas in a gas **
• To visualise and understand the movement of gas particles (OC1)*
• To visualise and understand the movement of liquid particles (OC1)*
• To visualise and understand the movement of solid particles (OC1)*
• To visualise the diffusion of a liquid in a liquid **
• To categorise particulate movement regarding scale and direction**</td><td>• Interpret</td></tr>
<tr><td>6</td><td>• To recall the names of the changes of state of matter**
• To understand the relationship between attractive forces between particles in the 3 states of matter (OC1)*
• To generate changes of state of matter using particle models**
• To identify changes of state using models of particles**
• To model at the particulate level (using symbols) what is inside a bubble of a pure substance**</td><td></td></tr>
</table>

	• To visualise that particle mass, shape and size is conserved during changes of states of matter** • To visualise that the number of particles of a substance are the same while it changes state** • Relate temperature to changes of state** • To model water at the particulate level using symbols**	
7	• To identify the characteristics of matter viz. the shapes that states of matter take up, the volume they may occupy and the nature of the movement of their particles (OC1)* • Understand the relationship between the symbolic and the particulate** • To model bromine in solid, liquid gas states at the particulate level using symbols** • To distinguish between the coefficient and the subscript in a chemical formula** • Visually relate the particles of a substance (which contain symbols) to a picture of how you normally see the substance in everyday life**	
8(8)	• Examine a variety of substances and classify as elements (OC4)* • **List the physical properties (state and colour) of two metallic and two non-metallic elements (OC5)** • *To understand the meaning of the word 'type' by categorisation*** • To understand elements contain one type of atom (OC3)* • To understand that elements are pure substances (OC3) * • To decide if a representation is an element (using the Periodic table as a reference) (OC3) * • To visualise an atom** • To visualise a molecule** • *To integrate the concepts of atom/molecule with the categories of element and compound using visualization* • *To visualise a diatomic molecule* • To model the constituent atoms or molecules of an element using symbols (OC3)* • To understand that the properties of a compound are different to its component elements (OC13)* • To model elements made of atoms and elements made of molecules (diatomic) on the particulate level using symbols and macroscopic photographs (OC3)*	• Interpret
9 N	• To identify if a symbol is that of an element (OC4)* • To identify the component elements of compounds by name (OC3)* • To identify the atoms in a molecule of a compound (OC41)* • To visualise a mixture (OC13)* • To visualise the synthesis of the compound iron sulphide (OC3)* • To understand that the properties of a compound are different to those of its component elements (OC13)* • To visualise a molecule** • **Compare mixtures and compounds made from the same constituents (OC13)** • Understand that mass is conserved when 2 elements combine to make a compound** • To classify if something is an element or compound based on its formula e.g. N_2; CO_2 (OC4) * • *To integrate the symbolic level with the particulate level using a chemical equation*** • *To visualise the term 'chemically combined' at a particulate level***	• Considering alternatives • Interpret • Explain

10	• To distinguish between the coefficient and the subscript in a chemical formula** • To understand that compounds are pure substances (OC3)* • *To integrate the symbolic level with the particulate level using a chemical equation***	• Interpret
11	• To understand the difference between an element, a compound and mixture using the particulate level (OC3)*	• Interpret
12	• To relate the symbol or formula of an element or compound to its particulate representation. (OC3)* • To distinguish between the coefficient and the subscript in a chemical formula**	
Appendix [N]	• To model elements and compounds (in a given phase) using atoms and molecules and appropriate symbols (OC41) * • **Relate the formation of compounds to the combination of atoms (OC41)** • Determine from the formula if a chemical is an element or a compound (OC41)* • To identify the characteristics of matter viz. the shapes that states of matter take up, the volume they may occupy and the nature of the movement of their particles (OC1)* • **Examine a variety of substances and classify them as elements or compounds (using the Periodic table as a reference) (OC4)** • To identify the atoms in a molecule of a compound (OC41)* • To classify if something is an element or compound based on formula e.g. N_2; CO_2 (OC4) * • To understand elements contain one type of atom (OC3)*	
Legend	**Bold = direct correspondence with Junior Certificate Syllabus with syllabus code in brackets** *** = deemed a necessary component of a syllabus outcome** **** = deemed to serve as scaffolding knowledge** **N = New chapter** ***Italics* =new learning outcome**	