An Investigation of Malaysian Secondary School Students' Mental Models of Acid-Base Chemistry

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Abstract

There are many studies in chemistry investigating students' difficulties in understanding chemical bonding, particle nature of matter and others, but relatively few on acid-base chemistry. One approach for reducing students' learning difficulties uses model-based science teaching, which involves models and mental models.

This thesis study investigates students' mental models in acid-base chemistry concepts to give insights into Malaysian secondary students' thinking in acid-base chemistry. In addition, teachers' mental models and the curricular models were also examined in order to explore the degree of alignment between the three models. At Forms 2, 4, and 6 levels of Malaysian schooling eight secondary school students and two teachers were interviewed at each level in an effort to examine their mental models using the Interview-About-Concepts and Interview-About-Instances data gathering methods. In addition, Forms 2, 4 and 6 curricular models (i.e., curriculum documents) were examined to obtain insights into the curricular models.

The area under investigation for this thesis study involves six selected acid-base chemistry concepts and their links to four acid-base models. The six selected acid-base chemistry concepts are Macroscopic Properties, Neutralisation, Acid-Strength, Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding while the four acid-base models are the Phenomenological, Arrhenius, Brønsted-Lowry, and Lewis models.

To determine the nature of students' mental models, attributes of these models were identified and gathered from students' expressed models, that is their responses to probe questions about the selected acid-base concepts and compared with the attributes of each scientific acid-base models. This comparison provided evidence of students' use/non-use of the attributes of the appropriate acid-base models to explain six selected acid-base chemistry concepts. Next, a mental model framework was developed and used to classify students' attributes into Stage 1, Stage 2, and Stage 3 mental models. The Stage 1 mental model was developed based on the Macroscopic Properties acid-base chemistry concept to indicate students' use or non–use of the Phenomenological model. The Stage 2 mental model was developed to determine students' use or non-use of the Arrhenius model to explain the Neutralisation and Acid-Strength concepts. The Stage 3 mental model comprising the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts were investigated to identify students' use or non-use of the Brønsted-Lowry and the Lewis model.

Also, under investigation was a comparison of students' mental models with teachers' mental models and the curricular model. At Form 6 schooling level the students' mental models demonstrated complete dissonance with the teachers' mental models and the curricular models. The causes for this dissonance may be the lack of specificity in the Malaysian curriculum, students' limited cognitive ability in terms of age-approriate concepts, and insufficient teachers' pedagogical knowledge.

From the findings of this thesis study, it is recommended that the Lewis acid-base model, be omitted from the Form 6 Malaysian curriculum because students' were not able to understand Acid-Base Electron Pair Bonding chemistry concept. Also, for other acid-base chemistry concepts, Malaysian teachers are encouraged to use student-centred teaching methods utilizing acid-base models to help improve their students' understanding.

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The journey to complete this thesis started when I received the offer letter from the University of Waikato to pursue my doctoral study. I felt excited and was delighted to pursue my study in another country. It was a dream come true for me to study overseas as I wanted to experience different cultures and people in other parts of the world. Hence, I arrived to this beautiful land known as Aotearoa, New Zealand and was enrolled as a doctoral candidate on the first day of March, 2012. Within the first few weeks I noticed that the Aotearoa people are well-mannered especially in saying thank you almost in every conversation.

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What happens when we understand a sentence? We are aware of understanding it, and still more aware of having failed to do so. Why can't we follow the mental process of comprehension as we can follow the action of tying a shoelace?

Johnson-Laird (1983, p. ix)

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Chapter 1. Introduction

1.1 Background of the Study

Internationally, all countries desire a scientifically literate population in response to the world becoming increasingly dominated by growth in scientific and technological knowledge and the applications of this knowledge in society. There is awareness of the need for people to be able to contribute to knowledge growth in science and to make informed decisions around scientific related issues (Van Eijck & Roth, 2013). Policy-makers recognise that scientific literacy can be acquired through science education and the production of scientifically literate citizens is now a key curriculum goal globally. A scientifically literate citizen is equipped with a critical mind, uses scientific ways to gain understanding of the world (Laugksch, 2000) and uses this knowledge in everyday decision making (Sadler & Zeidler, 2009). Such citizens can contribute to the benefit of society at large (Lederman & Lederman, 2012). Ogunkola (2013) noted that today employers are looking for prospective employees who hold well-developed level of scientific literacy to solve problems and contribute to the economy of the nation.

The next section discusses scientific literacy in more depth and the role science education can play in the development of scientifically literate citizens.

1.2 Scientific Literacy and Science Education

In a review of the literature, Lederman and Lederman (2012) reported a consensus view that scientific literacy means understanding the knowledge of science, the nature of science and scientific inquiry, and the development of scientific capabilities. Knowledge of science refers to the concepts, theories, models, and laws that comprise the body of knowledge known as science, for example, the concepts of Neutralisation, theories like the atomic theory, models like the particle nature of matter and Newton's law of motion. The nature of science refers to the epistemology of science, that is, the scientific ideas formed from the process of scientific inquiry that scientists need to undertake and experience in order to build knowledge. Scientific inquiry then refers to the "methods and activities that lead to the development of scientific knowledge" (Schwartz, Lederman, & Crawford, 2004, p. 612). These methods and activities include questioning skills, devising scientific investigations and forming explanations (Yuenyong & Narjaikaew, 2009). Bybee, McCrae, and Laurie (2009) describe scientific capabilities as the processes that scientists use to develop knowledge (e.g., data collection, observation, forming hypothesis, modelling, and experimenting) and scientific attitudes (e.g., honesty, openness, and understanding of error).

To help achieve the aims of a scientifically literate society, educators need to examine their pedagogies carefully to ensure that the learning experiences offered to their students do facilitate the learning required to be scientifically literate. This study investigates a model-based science teaching (MBST) approach which is recommended as a pedagogy for ensuring scientific understanding among students. The study of models in science and science education may help achieve scientific literacy goals because models can provide students with a means for gaining both scientific knowledge and a framework for conducting inquiry (Gilbert, 2011). This approach is further explained in the next section.

1.3 Models and Their Characteristics

Models in science are representations of scientific theory. They are tools that simplify a phenomenon and behave as a medium for explanation in scientific phenomena (Coll, France, & Taylor, 2005; Halloun, 2011; Koponen, 2007). It is argued that understanding scientific models and their characteristics will enhance students' ability to not only understand scientific concepts but also the nature of science (Portides, 2007) and the role models play as part of scientific inquiry (Lederman & Lederman, 2012). These models help scientists to develop questions in an inquiry and provide an explanation for the inquiry (Committee on Conceptual Framework for the New & National Research, 2012). Examples of models could be an object (e.g., a model plane), an abstract concept (e.g., forces), or a process such as the Haber Process to produce ammonia (Gilbert, Boulter, & Elmer, 2000). These examples are just three models in an array of models and researchers have devised many different ways of classifying models (Section 2.4).

Models have many characteristics, but a key characteristic of all models is that they are only a representation of reality and, therefore, incomplete (Johnson-Laird, 1983). Models are a simplified version of something we want to study, called the *target* and as such are focused on the important aspects of the target. Since not all components of the target are included in the model, it may result in inaccuracy and false information or knowledge (Duit, 1991). Scientists create models because they cannot fully study the target, and models provide a way to know the target even though they do not furnish the complete information embedded in the target (Coll, 2008a; Coll & Treagust, 2003; Gilbert, 2011). As every model is incomplete and requires constant modification (Oh & Oh, 2010), scientists tend to use more than one model to explain a scientific phenomenon, such as the wave and particle models to understand the nature of light (Hubber, 2006).

The characteristic of models presented above are important in understanding the nature of models in science. The characteristics also give insights into the human mind when used to explain phenomenon (Schwarz et al., 2009). To understand the human cognition involved in explaining scientific phenomena, the study of conceptual models and mental models becomes a useful field to explore.

1.4 Conceptual Models and Mental Models

Conceptual models are a representation of a scientific phenomenon that enables scientists to provide a version of currently accurate, scientifically correct, knowledge. These expressed public models contain scientific knowledge which is agreed upon by scientists and in this study they will be termed scientific models (Committee on Conceptual Framework for the New & National Research, 2012).

In contrast, a mental model is considered to be a representation constructed personally in an individual's mind (Gilbert, Boulter, et al., 2000; Gilbert, 2011; Greca & Moreira, 2000; McClary & Talanquer, 2011). It requires interpretation in the light of prior knowledge and internalization. Typically, mental models are incomplete and unstable because they are based on personal experiences which are on-going and can result in changes (Greca & Moreira, 2000). Characteristically mental models change or evolve over time and consequently can provide a record of learning progression. Gilbert (2011) claims that understanding what scientific knowledge students have acquired and how it is acquired, is important in understanding students' mental models in chemistry education and how they evolve over time.

The scientific knowledge represented in the conceptual models of scientists and the construction of mental models by learners is crucial in understanding the learning of chemistry, which is now discussed.

1.5 Learning Chemistry

Learning chemistry is said to be highly challenging, and many educators find chemistry difficult to teach. These challenges occur because understanding chemistry involves three levels of representation (Özmen, 2007). The first, the macroscopic level, corresponds to representations of the observable properties of chemical phenomena while experimenting. The second, or sub-microscopic, level is an abstract version of the macroscopic phenomena explained in terms of atoms, electrons, and molecules, which cannot be seen using optical microscopes. The symbolic level refers to other abstract forms of representation of the macroscopic phenomena that involve number or alphabets such as symbols, formulae and equations (Adbo & Taber, 2009; Cokelez & Dumon, 2005; Coll, 2008a; Johnstone, 1991). Of the three levels of representation, Taber (2009) argues the symbolic level could be considered a basic language in chemistry acting as a bridge between the macroscopic and sub-microscopic levels. Examples of representations at the macroscopic level are the sour taste of acid, the bitter taste of a base, and the slipperiness of bases. At the sub-microscopic level, an illustration of a representation would be the model of an atom which includes particles such as proton, neutron, electrons, (Gilbert & Treagust, 2009). Another representation would be solids portrayed as closely packed particles representing atoms. Some of these representations can be translated into diagrams or graphs such as the 'ball and stick' model to visualize positions in an atom. At the symbolic level, examples of representations include equations such as $HCl + NaOH \rightarrow NaCl + H_2O$.

For many students, chemistry concepts are commonly associated with a particular context, and their conceptual understanding often differs from scientists' views because they cannot shift from the macroscopic to the sub-microscopic level (Hodson, 1992). An example is students' perception of the word 'salt', which they conjure up as table salt; while scientists' view of salt comprises an array of anion and cations in a networked lattice (Lin & Chiu 2007). This 'salt' example indicates one of many instances where much science teaching and learning involves application of understanding at all three levels, particularly more so in chemistry studies (Johnstone, 2006), which may affect students' mental models.

To help students' attain mental models which involve macroscopic, sub-microscopic, and symbolic levels of thinking, as well as acquiring mental models similar to those held by scientists and teachers, new pedagogies need to be found. Achieving these two learning goals concurrently is difficult for students because students tend to hold a number of mental models at any given time, causing confusion (Coll, 2008a; Coll & Treagust, 2003; Jabot & Henry, 2007). This confusion arises because many students' mental models in chemistry are often used to describe macroscopic phenomena at the sub-microscopic level which is hard for students to imagine.(Johnstone, 1991; Mendonça & Justi, 2014).

The context of acid-base chemistry will be now used to illustrate how this issue of multiple models impact on student learning in chemistry. To deeply understand acid-base chemistry scientists look to a number of conceptual models such as the Arrhenius and Brønsted-Lowry models (Erduran & Duschl, 2004), the Phenomenon model (Lin & Chiu, 2007), and the Lewis model (Lin & Chiu, 2007; Shaffer, 2006) which will be discussed in greater detail in Section 2.9. These four acid-base models provide explanations of acid-base chemistry concepts that students need to become familiar with and use comfortably as they learn acid-base concepts. Typically, scientists come to realize that both the applicability and the limitations of different models are important as more than one model is necessary to gain a better understanding of scientific concepts (Coll & Lajium, 2011). However, students have a tendency to become confused when using many models and tend to think of models as a fixed form of knowledge. Coll and Lajium (2011) argued that students limit themselves to only one model as they find one model easier to understand than multiple models. There is evidence that students may use these models inappropriately and form misconceptions (Hawkes, 1992), which means they may not fully understand acid-base chemistry concepts. An understanding of more than one model is necessary because each model has its own strength and limitations. Thus, with more models, students are able to have a better grasp of scientific concepts.

The statement of the research is now discussed.

1.6 Statement of the Research

The researcher was motivated to undertake this research as a result of his five year experience as a chemistry teacher in a public school in Malaysia. The researcher has taught chemistry in East Malaysia (Sarawak) and West Malaysia (Selangor) during his teaching years. He and his colleagues found students experienced difficulty understanding chemistry concepts for certain topics. A number of these difficulties exist around concepts of atoms, ions, molecules, the mole, chemical bonding, and acid-base chemistry concepts to name a few. It seems learning in chemistry becomes even more difficult when both mathematical calculations and chemistry concepts are required to solve problems and answer questions in chemistry. The researcher discussed these issues with other chemistry teachers, and wondered why teachers were unsuccessful in helping students in their understanding of chemistry concepts despite trying many different teaching methods. The researcher thought the problem may be due to his own lack of pedagogical skills, so he requested a colleague to ask his students if they could understand what the researcher taught. The researcher's students told the colleague they could only partially understand what the researcher was teaching, but were too shy to ask questions in case they might be labelled 'dumb' by other students. The researcher spoke with a number of senior school students, enquiring of them the topics that they found difficult in Forms 4 and 5 (16 and 17 years old) and was told the most difficult topics are redox chemistry concepts and electrochemistry, while acid-base chemistry concepts were thought of as not too difficult. However, while students said they found the acid-base chemistry concepts were not difficult, they actually did not fully understand them as evidenced in assessment tasks and classroom interaction. The researcher started thinking: "What acid-base chemistry ideas are in students' minds"? From "where and when are the students obtaining these ideas"? "What prior understanding do the students have"? Based on some preliminary research, the researcher became aware there were not many studies on students' mental models of acid-base chemistry concepts undertaken in Malaysia or elsewhere. Hence, this thesis explores mental models of acid-base chemistry concepts for secondary students because knowledge of these mental models could give teachers insights into how to improve their pedagogical skills and enhance students' learning of acid-base chemistry concepts. The literature about students' mental models is discussed further in the literature review section.

In section 1.7, science education in Malaysia is described.

1.7 Science Education in Malaysia

Science teaching and learning in Malaysia is guided by the National Science Education Philosophy (MoE, 2002) that states:

> In consonance with the National Education Philosophy, science education in Malaysia nurtures a science and technology culture by focusing on the development of individuals who are competitive, dynamic, robust and resilient and able to master scientific knowledge and technological competency. (p. 40)

Based on this philosophy, the aim of science education, is to develop the potential of individuals, producing Malaysian citizens who are competent in scientific skills, possess good moral values and are able to manage nature for the betterment of mankind (Zin & Maimunah, 2003). In addition, the secondary school science curriculum aims to provide students with knowledge and skills in science and technology, and enable them to solve problems and make decisions in everyday life (MoE, 2002). These curriculum aims are aligned with international goals especially in cultivating scientific literacy globally (Holbrook & Rannikmae, 2008).

Despite having comprehensive and progressive science education aims, students are not performing well in Malaysian schools. This performance was reflected in the Trends in International Mathematics and Science Study (TIMSS) in 2007, which showed Malaysia scoring 471 for the Eighth Grade Science Average or 15 year olds students (Daniel, 2013). High scores between 551 and 625 signify that students are able to apply knowledge of science in a scientific inquiry, while scores between 476 and 550 indicate the ability of students to apply knowledge of science in everyday life. A score between 401 and 475 reflects students' ability to apply science knowledge and understanding of practical situations in science. A score of 400 or below signifies students have only elementary knowledge of life and physical sciences. The Malaysian scores of 471 indicated that Malaysian students are not able to apply knowledge of science effectively (Daniel, 2013).

In another study the Programme for International Student Assessment (PISA) 2009, Malaysia was ranked in seventh place in the Asia Pacific region, behind Thailand and Singapore, with a score of 422 (Daniel, 2013). In PISA, poor performers are classified as Level 1 with a score between 262 and 335 while moderate performers are in Levels 2 and 3 scoring 407 and 480 respectively. Strong Level 4 performers scored 553 and top performers at levels 5 and 6 with 626 and 698 respectively. According to Daniel (2013), the score of 422 indicates that Malaysian students are only moderate performers in science.

These two key international benchmarks suggest that Malaysian students may not be performing well compared to students in other countries in the Asia Pacific region. Daniel (2013) warns that learning science in Malaysia needs to move from memorizing facts to pedagogical methods that promote active learning - at present she claims teacher-centred teaching and lecture-based instruction are the norm in Malaysian classroom. In teacher-centred teaching, the teacher dominates the teaching and learning, and students depend on teachers to decide what and when to learn. In lecture-based instruction, learning science involves transmission of facts and rote learning, resulting in poor application of science in daily life (Zakaria & Iksan, 2007). These approaches persist because the focus is on examinations, resulting in students not being able to see how science is applicable in their daily lives (Daniel, 2013). The Malaysian Education System which is the context of this study is now reviewed more closely in the following section.

1.8 Context of the Inquiry (Malaysian Education System)

Science is a compulsory core subject in the Malaysian education system at primary (7 to 12 year olds) and lower secondary school levels (13 to 15 year olds). However, at the upper secondary level (16 -17 year olds), students are given the option of taking Core Science or Chemistry, Physics, and Biology. At the Form 6 or pre-university level (18 and 19 year olds), students learning science, pursue courses which prepare them for university studies (Table 1.1).

Table 1.1: Science education in Malaysian schools

Level	Age	Institution	Science Type
Year 1 - Year 6	7 to 12 years	Primary school	Primary science
Form 1- Form 3	13 to 15 years	Lower secondary school	Core science
Form 4 - Form 5	16 to 17 years	Higher secondary school	Science electives • Biology • Chemistry • Physics • Additional science
Form 6	18 to 19 years	Pre-university secondary school	Science electives • Physics & Chemistry • Chemistry & Biology

Although chemistry is not taught as a separate subject in primary and lower secondary schools, students are exposed to some chemistry knowledge in their Malaysian science programme (Table 1.2).

Table 1.2: Chemistry content in science education in Malaysian (Curriculum and Specifications Guide, MOE, 2005)

Core Science			Additional Science	Chemistry	
Primary	Lower secondary	Upper secondary	Upper secondary	Upper secondary	Pre-university
• Properties of materials • ***Acid and base (physical properties of acids and bases)*** • Solid, liquid and gas	• Matter • Variety of resources on earth • The air around us • ***Water and solution*** • Land and its resources	• Matter and Substance • Carbon compound	• Periodic Table • Chemical bonding • Mole concept • Chemical reactions • Petrochemicals	• Introduction to chemistry • Structure of atom • Formula and chemical equation • Periodic Table of Elements • Chemical bonds • Electrochemistry • ***Acids, bases and salts*** • Carbon compounds • Rate of Reaction • Oxidation and Reduction • Thermochemistry • Manufactured substances in chemistry • Chemicals for consumers	• Matter • Electronic structure of atoms • The Periodic Table • Chemical Bonding • Reaction Kinetics • ***Ionic Equilibria*** • Electrochemistry • Thermochemistry and chemical energetics • Period 3 and Group 2 • Group 13 • Group 14 • Group 15 • Group 16 • Group 17 • An introduction to chemistry of d-block elements • The chemistry of carbon • Hydrocarbons • Carbonyl compounds • Carboxylic acids • Carboxylic acid derivatives • Amines • Amino acids and proteins

Note : Science content containing acid-base concepts are italicized and in bold

Table 1.2 shows that basic ideas about acid-base chemistry concepts are introduced as early as primary school, mostly about physical properties of acids and bases. Specialization in chemistry knowledge occurs in secondary and pre-university programmes to prepare students for pursuing their studies related to science careers such as industrial chemistry, pharmacy, medicine, biotechnology, and so forth. Therefore, Malaysian students learn basic concepts of acids and bases in primary and lower secondary because these concepts are considered crucial for students' future learning of chemistry in Malaysia as indicated in the Curriculum and Specifications Guide MoE (2005):

> As a nation that is progressing towards a developed nation status, Malaysia needs to create a society that is scientifically oriented, progressive, knowledgeable, having a high capacity for change, forward-looking, innovative and a contributor to scientific and technological developments in the future. In line with this, there is a need to produce citizens who are creative, critical, inquisitive, open-minded and competent in science and technology. (p. 1)

1.9 Significance of the Inquiry

Many studies of mental models exist in the literature (see, Adbo & Taber, 2009; Chiou & Anderson, 2010; Gentner & Stevens, 1983; Harrison & Treagust, 1996; Jansoon, Coll, & Somsook, 2009; McClary & Talanquer, 2011). Research suggests that few of these studies to date have been conducted in a non-Western cultural setting (Adbo & Taber, 2009; Cokelez, 2010; Harrison & Treagust, 1996) and little is known in these settings about mental models. So, this study aims to explore students' mental models of acid-base chemistry concepts within the Malaysian educational environment to better understand the nature of students' learning in this setting. In addition, research in this area will consider models that scientists use in understanding acid-base chemistry concepts. It is expected the present study will provide more insight into the students' mental models and their use or non-use of multiple models when utilizing multiple models in acid-base chemistry concepts and into learning progressions in acid base chemistry to help understand Malaysian students' mental models in acid-base chemistry.

There have been studies into students' mental models on a number of different chemistry topics such as chemical bonding (Coll, 2008a), particle nature of matter (Adbo & Taber, 2009; Harrison & Treagust, 1996), and metals (Taber, 2002). Also, studies have been identified from the literature that include research about *individual* scientific models for acid-base chemistry learning; viz, the Arrhenius model (Ouertatani, Dumon, Trabelsi, & Soudani, 2007), the Brønsted–Lowry model (Hawkes, 1992), and the Lewis model (Shaffer, 2006) for acid-base chemistry concepts. However, there are a few studies, for example, (Drechsler & Schmidt, 2005; Tarhan & Sesen, 2012), that examined a combination of acid-base models in the teaching of acid-base chemistry concepts and this gap is significant because some studies suggest that students' tend to use one model in their explanations of scientific phenomena which may hinder learning. This study should provide evidence to verify or nullify these claims.

Thus, for the reasons above, the researcher agrees with Harrison and Treagust (1996) who argue that determining students' mental models can enhance science teaching and learning. Accordingly, this present study investigates students' mental models for six acid-base chemistry concepts selected from the curricular model (Curriculum and Specifications Guide, MoE, 2005). These concepts are fundamental to acids-base chemistry and most require the use of multiple scientific models for deep understanding .

The six acid-base concepts selected for this study are: Macroscopic Properties, Neutralisation, Acid-Strength, Acid-Base Equilibrium, Buffers, and Acid-Base

Electron Pair Bonding. They have been identified through careful examination of the intended learning outcomes related to acid-base chemistry at three different schooling levels of the Malaysian curriculum. Development of these concepts is considered integral to the achievement of the intended learning outcomes at the different levels. For example, the concept of Macroscopic properties is required to achieve the intended learning outcome *identify the properties of acids and bases* at the Form 2 level of the Malaysian curriculum document. Also, at this level students are expected to *explain the meaning of Neutralisation*, *write the Neutralisation equation*, and *explain through examples the uses of Neutralisation* indicating understanding the concept of Neutralisation as an requirement for achievement of the intended learning outcomes. At the Form 4 schooling level, the intended learning outcomes from the curriculum document include: *explain the meaning of Neutralisation*, and *explain the application of Neutralisation*, indicating the concept of Neutralisation needs to be covered. Another learning outcome, relate *strong and weak acid with the degree of dissociation*, implies the concept of Acid-Strength is needed. For Form 6, the learning outcomes, *identify conjugate acids and bases*, *pKa*, and *Ksp* requires the concept of Acid-Base Equilibrium while the learning outcome for *define buffer solution* is linked to the concept of Buffers. The sixth concept, Acid-Base Electron Pair Bonding underpins another Form 6 learning outcome (i.e., *using the Lewis model to explain acids and bases*).

The research aim and research questions are discussed in the next section.

1.10 Research Aim and Research Questions

The aim of the research in this thesis is to explore the nature of students' mental models around selected acid-base chemistry concepts as students learn acid-base chemistry through their secondary education. The study will address the following questions:

1. What are the attributes of students' mental models for selected acid-base chemistry concepts at given Malaysian levels of schooling in relation to their applications of the Phenomenological, Arrhenius, Brønsted-Lowry, and Lewis models?
2. How can students' mental models for the six selected acid-base chemistry concepts be classified based on their attributes and used to identify students' mental models development at different stages of Malaysian schooling?
3. In what ways do the attributes of scientific models, curricular models, and teachers' and students' mental models for selected acid-base chemistry concepts compare at different schooling levels?

In brief, the first research question seeks to identify what understanding students have demonstrated at different schooling levels in the six acid-base chemistry concepts in relation to the four acid-base models. The second research question sought to identify the types of mental models students have formed in their learning of acid-base concepts while the third research question seek to investigate the degree of alignment between the scientific models, students' mental models, their teachers' mental models and the curricular model.

Overall, this study focuses on understanding Malaysian secondary students' use of scientific acid-base models and their own mental models in the learning of selected acid-base chemistry concepts. The findings from this study of models, especially mental models in acid-base chemistry concepts, may provide educators with tools to help students so that their classroom learning is closely aligned to scientists' understandings in this chemistry area. Ultimately, this study may pave the way for planning a better Malaysian acid-base chemistry curriculum which acknowledges and encompasses the key role of models and mental models in effective science education.

The thesis structure is described next.

1.11 Thesis Structure

The thesis has eight chapters. Chapter 1 introduces the thesis and is followed by the literature review in Chapter 2. Chapter 3 discusses research design used whilst Chapters 4, 5, and 6 describe the findings of the data. Chapter 7 discusses the meaning and significance of the findings. Chapter 8 presents the implications of the findings and conclusions.

For this thesis, when referring to the selected acid-base concepts that were a focus in this study uppercase was used for the first letter of words comprising the title of the concept, for example, the Macroscopic Properties concept. In contrast, *italics* were used to indicate attributes and learning outcomes, for example, *product formation* attribute and *describe acid-base titration* learning outcome. Note for the Neutralisation concept, for example, an uppercase N is used when describing the Neutralisation concept and a lowercase n when describing the *neutralisation* attribute. Similarly, an uppercase for N is used for Neutralisation to describe selected learning outcomes such as *describing Neutralisation in daily life.*

The next chapter discusses in detail a critical review of the research literature for models, acid-base models, and mental models.

Chapter 2. Literature Review: Learning and Mental Models in Science

2.1 Introduction and Chapter Overview

This review first examines what is needed for scientific literacy: that is an understanding of science concepts, the nature of science and the nature of scientific inquiry and the development of scientific capabilities. The review then highlights the role of models in science and in the learning of science. Next, theories of learning are discussed, followed by a discussion of the knowledge required to understand selected acid-base chemistry concepts. This chapter continues with common misconceptions found in the literature related to these selected acid-base concepts before moving to the role of mental models and modelling in learning. Finally, the chapter ends with the conceptual framework underpinning this investigation.

2.2 Scientific Literacy as a Curriculum Goal

Science educators have the responsibility to assist students in acquiring scientific knowledge and capabilities in order to be scientifically literate (Partin, Underwood, & Worch, 2013). Internationally, scientific literacy is an important curriculum goal because we live in a scientific and technological society where understanding of scientific knowledge and the nature of science and scientific inquiry can allow members of society to be engaged in science and technology. Members of society then can use this understanding for making informed decisions about science related issues (Lederman & Lederman, 2012). The requirements for scientific literacy are discussed in the next section.

2.3 Requirements for Scientific Literacy

As explained in earlier sections scientific literacy requires understanding of scientific knowledge, the nature of science, and the nature of scientific inquiry. The scientific knowledge component is discussed first in the next section.

2.3.1 Scientific Knowledge

Scientific knowledge is considered to be an understanding of phenomena in the physical world such as the concepts of light and evolution (Bybee et al., 2009). Understanding of this scientific knowledge is constructed with the use of theories and models (Hodson, 2008; Lederman & Lederman, 2012) which are explanations of phenomena.

Theories and models can cause confusion and need to be carefully differentiated. For clarification, a theory is “an integrated set of statements, ideally derived from a general framework or paradigm from which hypotheses can be deduced to explain particular outcomes" (Perri & Bellamy, 2012, p. 309). In contrast, a model in science is a representation linked to a specific phenomenon which according to Gilbert, Boulter and Elmer (2000) is:

> A representation of a phenomenon initially produced for a specific purpose. A phenomenon is any intellectually interesting way of segregating a part of the world as experienced for further study. The specific purpose for which any model is originally produced in science (or in scientific research, to be precise) is as the simplification of the phenomenon to be used in inquiries to develop explanations for it. (p. 11)

In other words, theories are explanations based on evidence, while models are used as a mediating tool to explain theories or hypotheses to another person – they help in making meaning of those theories (Coll & Lajium, 2011). An example of a theory is the kinetic theory of matter which states that all matter is made up of particles while an example of a model is particle nature of matter, a representation of particle behaviour at the sub-microscopic level.

The second component of scientific literacy (i.e., the nature of science) is discussed next.

2.3.2 The Nature of Science

Typically, the phrase *nature of science* (NOS) is concerned with the epistemology of science which is the way of knowing scientific knowledge (Abd El Khalick & Lederman, 2000). In addition, the nature of science "addresses the importance of creativity and imagination in scientific work; how scientists invent explanations for phenomena; the difference between observation and inference; how scientific ideas are subject to change; and how culture and society influence science" (Hanuscin & Lee, 2009, p. 64). Raman (2009) agrees, and adds that scientific knowledge is derived from human senses and "awareness and understanding that one has gained from a facet of our experiences resulting in either intellectual satisfaction, explanatory confidence, and/or a capacity to solve a practical need or problem" (p. 91).

Importantly, Schwartz et al. (2004) maintained that the nature of science also refers to the values and underlying assumptions within scientific knowledge, including the influences and limitations that result from science as a human endeavour. They identified eight features of the NOS that are important to know for scientific literacy. The first feature of the NOS, is that scientific knowledge is *tentative* meaning it may change as a result of new findings. The second is its *empirical basis,* that is, science is based on evidence derived from observations. Another aspect of the NOS is *subjectivity*. In other words, what scientists consider correct is something of a subjective judgement because science relies upon accepted scientific theories and laws. However, Lederman (2007) argued that scientists are bound by their training, exposure, and beliefs which may shape their understanding of science, and, therefore, may not be scientifically correct. A fourth aspect is *creativity*, Creativity in the nature of science is described as using visualizations in creating rational explanations to understand a phenomena such as using a Venn diagram or an atomic model. It is this visualization aspect that forms models (Valanides & Angeli, 2011). The NOS is also characterized by its *sociocultural embeddedness.* This idea recognizes that science is a human endeavour and, as such, considered science to be important to society. The sixth feature of NOS is *observation and inference*. Observation gathers information using sensory means while inferences are the interpretation of that observation. Next feature of NOS are *laws* (i.e., observed phenomena of nature) and *theories* (i.e., explanations for observed phenomena). The final defining feature of the NOS is the *interdependence of features*, where information gathered from phenomena is dependent on other features of NOS.

In summary, Hanuscin and Lee (2009), Schwarz et al. (2004) and Raman (2009) agreed that the nature of science involves the humanistic element. This humanistic element refers to the presence of humans (i.e., scientists) to interpret scientific knowledge because scientific knowledge is not absolute and long-lasting (Allchin, 2014). Hanuscin and Lee (2009) point out the importance of creativity and visualization in the understanding of the scientific knowledge in the form of models which makes science more explicit (Schwarz et al., 2009).

In the third aspect of scientific literacy, the nature of scientific inquiry is discussed.

2.3.3 The Nature of Scientific Inquiry

Scientific inquiry is a set of processes used by scientists in answering a problem involving the combination of process skills such as observing, measuring, hypothesising, designing, testing, analysing, interpreting, and theorising (Lederman & Lederman, 2012). Scientific inquiry is also considered as "a process of comparing and testing competing models" (Schwarz & White, 2005, p. 172). According to Adbo and Taber (2009), these models particularly scientific models may serve as "tools for connecting the domain of theory with the domain of experiment" (Koponen, 2007, p. 765). Also, models may be used as part of an organized approach for acquiring scientific knowledge since they are able to explain an abstract view of a theory as well as the observable view of an experiment. Also, models are used by scientists to describe and predict phenomena (Morgan & Morrison, 1999) and to interpret data obtained through experiments (Cokelez & Dumon, 2005). The use of models to predict and interpret, known as 'modelling', is a form of reasoning that scientists use to explain phenomena.

In summary, models play an important role in all three components of scientific literacy. In scientific knowledge, models are representations of concepts, laws and theories. They serve to enhance understanding of phenomena in the nature of science and for making predictions and interpretation of data in scientific inquiry. Since models form such an integral part of scientific literacy, it is important to examine the form and functions of models in science more closely especially as they apply in science education which is discussed next.

2.4 Role of Models in Science Education

The use of models in science learning is important to consider because students learn and understand many science concepts through the introduction of scientific models. Not only can students learn to use models to explain concepts but they can also gain appreciation of the role of models in science (Mendonça & Justi, 2014).

In science education research, models have been widely explored and researched (Coll, 2006; Duit, 1991; Gentner & Stevens, 1983; Gilbert, Boulter, & Rutherford, 1998; Johnson-Laird, 1983; Norman, 1983; Suckling, Suckling, & Suckling, 1978). In this thesis study, models are broadly considered to be a "representation of a phenomenon initially produced for a specific purpose" (Gilbert, Boulter, et al., 2000, p. 11) and may represent an idea, object, event, process or a system.

The purpose and representations of models are discussed in the next two sections.

2.4.1 Purpose of Models in Science Education

Treagust, Chittleborough, and Mamiala (2002) pointed out that in science education models are essential for the learning of theories and for making predictions. They achieve these goals through two distinct functions. First, models serve as a bridge or connection between the abstraction of theories and the concrete world of experiments (Gilbert, Pietrocola, Zylbersztajn, & Franco, 2000; Koponen, 2007). Second, models act as mediators (Duit & Glynn, 1996) between a target (i.e., an explainable phenomenon that we want to comprehend) and a source (i.e., prior knowledge). In these roles models are important tools in the understanding of scientific knowledge (Coll et al., 2005).

The representation of models is discussed in the next section.

2.4.2 Representations of Models

As representations, models come in a variety of modes and they have been classified in various ways. Gilbert (2011) provides a useful classification system by grouping models in science into six categories based on their form. *Concrete models* are models that could be seen and touched such as an airplane model made of balsam wood. *Pictorial models* are models in the form of pictures such as photographs, drawings, and cartoons while formulae and equations represent *mathematical models,* such as the wave equation (Figure 2.1) for the hydrogen atom.

$$H\Psi = E\Psi,$$

Figure 2.1: Wave equation of hydrogen atom where Ψ is the wave function, H is the operator and E is the wave energy (from Mills, 2000, p. 1173)

A description of phenomenon is called a *verbal model.* Simulation games like cockpit simulators in an aeroplane are considered to be *simulation models,* and words and numbers are *symbolic models.* For instance 45ºC represent a temperature at 45 degrees where C is the unit for Celsius.

Oh and Oh (2010) provide further insights into the role of models as representations of science theory in science education by explaining the meanings, purposes and multiplicity of models in science and their changeable nature (Table 2.1).

Table 2.1: A summary of the nature of models (from Oh & Oh, 2010)

Topic	Summary
Meanings of a model	• A model is a representation of a target (i.e., what we want to comprehend). • A model serves as a bridge or mediator connecting a theory and a phenomenon.
Purpose of model	• A model plays the roles of describing, explaining and predicting natural phenomena and communicating scientific ideas to others. • The functional roles of models are facilitated by models using analogy and allowing mental and external simulations.
Multiplicity of models	• Multiple models can be developed to study the same target because scientists may have different ideas about what the target looks like and how it works and because there are a variety of resources available for constructing models. • Each model has limitations because it represents only a specific aspect of a target, and diverse models may be needed to provide a full-fledged explanation of the target.
Change in science model	• Models are tested empirically and conceptually, and they can change with the process of developing scientific knowledge.

In short, a model is a representation of a target and its function is to describe, explain, and predict a natural phenomenon. A model, however, has limitations, and is subject to changes when new knowledge emerges. The importance of models in chemistry education is now discussed in the context of acid-base chemistry.

2.5 Models in the Context of Acid-Base Chemistry

Models in chemistry education play an important role because "few of the macroscopic observations can be understood without recourse to sub-microscopic representations or model" (Oversby, 2000, p. 227). In other words, to understand macroscopic observation one has to explain at the sub-microscopic (i.e., non-observable) level. Thus, models are able to provide explanations for many phenomena and because of this capability, a wide variety of models are used in chemistry. According to Harrison and Treagust (2000) examples of these models range from concrete scale models (e.g., scale model of sodium chloride) to symbolic models (e.g., kinetic model of matter). In the context of this study, the use and importance of acid-base models in understanding acid-base chemistry are explored and discussed.

Acid-base chemistry is an important area in chemistry education from elementary to university levels (Barcza & Buvári, 2003). The significance of learning acids and bases lies for younger students in their occurrence in many everyday phenomena, which is why the concepts of acid-base chemistry have been historically important. Since the emergence of chemistry as a science, models have emerged to explain acid-base behaviour (Drechsler & Van Driel, 2008). Oversby (2000) summarises the key characteristics of seven historically important models in acid-base chemistry as they relate to acids (Table 2.2).

Table 2.2: Models for acids (from Oversby, 2000)

Model	Year	Definition of Acids
Behavioural Model (later called Phenomenological Model)	1777	Acids are sour
Lavoisier Model	1777-1787	Acids are substances containing oxygen
Priestley Model	1772-1775	Acids are substances that contain hydrogen
Arrhenius Model	1884	Acids are substances that produce hydrogen ions in solution
Brønsted-Lowry Model	1923	Acids are proton donors
Lewis Model	1923	Acids are lone pair electron acceptors
Usanovitch Model	1939	Acids are solvent cations

Over time the acid-base models changed and evolved as scientists strived to provide a working definition of acids that was a better fit for emerging evidence. The existence of a number of models as reported by Oversby (2000) and their continued use demonstrates an important aspect of the NOS; that certain models are more appropriate to explain certain acid phenomenon, but that no single model is able to explain every acid-base phenomena. For this reason, practising scientists use a number of models pragmatically and do not exclude the earlier models but use them along with the newer models (Coll & Lajium, 2011). This practice is called modelling.

Note that the strong inter-relationship between acids and bases is evidence that many people used the term acid-base instead of acids and bases. In this current study, four acid-base models are of particular interest because they are mandated for the teaching of acid-base chemistry in the Malaysian curriculum. The models are the Phenomenological Model, the Arrhenius Model, the Brønsted-Lowry Model, and the Lewis Model.

A number of researchers have investigated the use of these acid-base models in chemistry education (Cros et al., 1986; Nakhleh, 1994). For example, Hawkes (1992) suggested that using the Arrhenius model confuses students because the absence of OH^- ions in a base like ammonia (NH_3) makes it difficult for students to recognise it as a base. Ouertatani et al. (2007) refuted this suggestion and argued in their study of Tunisian Grade 10 students the Arrhenius model was found to be important for the Tunisian students' understanding especially when explaining everyday life examples and the strength of an acid or a base. Shaffer (2006) proposed that one advantage of the Lewis model gives priority to valence electrons in understanding acid-base reactions. However, Sacks (2007) disagreed and argued that the Lewis model may have drawbacks because the Lewis acid behaves differently compared to a Brønsted-Lowry acid (e.g., boron trihidride or BH_3) even though the Lewis base shows similar behaviour to a Brønsted base (e.g., ammonia or NH_3). In a comparison of Brønsted acids and Lewis acids Gupta, Roy Subramanian, and Chattaraj (2007) indicated that a strong Brønsted-Lowry acid is generally a strong Lewis acid but not for all acids. This occurrence suggests that there is no one encompassing all acid-base model.

In this thesis study, the researcher indicates that four acid-base models should be emphasised because each of the acid-base models has its own strengths and weaknesses in terms of explaining acid-base behaviour.

Each of these models is now discussed, highlighting each model's strengths and weaknesses beginning with the Phenomenological model.

2.5.1 Phenomenological Model

A number of names have been given to models that describe the macroscopic properties of acids and bases. For example, Sheppard (2006) employed the name Operational model while Lin and Chiu (2007) used the name Phenomenon model. In this thesis, the researcher adopted the name Phenomenological model as a means of referring to the macroscopic properties of acids and bases to help distinguish different levels of representations i.e., the phenomenological and the sub-microscopic levels (Drechsler & Schmidt, 2005; Drechsler & Van Driel, 2008). These properties are detected by sensory perception, for example, acids are sour and bases are bitter (Oversby, 2000). Other properties include toxicity and corrosiveness, however, not all acids and bases display these characteristics. For example, ethanoic acid, which is the active ingredient in vinegar and used in food flavouring, is not corrosive (France, 2014). Similarly, sodium bicarbonate (a base) is an active ingredient in baking soda used in bread making and is not toxic (Shelton & Kumar, 2010). It is important to note that unlike the other acid-base models, the Phenomenological model is used to describe rather than explain acidic or basic properties – it has no explanatory power for acid-base concepts.

2.5.1.1 Strength and Limitations of the Phenomenological Model

The strength of this model is that it is easy to apply because of its ability to identify acids and bases using observable features. In other words, the Phenomenological model can be used as a qualitative tool for identifying substances as acids or bases. However, the Phenomenological model has no explanatory aspect to account for acid-base reactions. For this reason, the Phenomenological model is mainly used at the primary or early secondary years of schooling because students at these levels are able to identify the macroscopic feature of substances without requiring the knowledge of the sub-microscopic representational level for an extensive explanation. In addition, the Phenomenological model acts as an introductory level learning in acids and bases for students at primary schooling level.

Next, the Arrhenius acid-base model is described.

2.5.2 Arrhenius Model

Arrhenius in 1887 termed his acid-base model the “Theory of electrolytic dissociation”, which stated that an acid, base or salt when dissolved in water dissociates into positive and negative charged ions. Significantly, at that time the positive or negative charged ions were not identified as hydrogen or hydroxide ions (Ihde, 1964). In later years, the Arrhenius model defines an acid as a compound that produces hydrogen and a base as a compound that produces hydroxide ions in water (Atkins, Jones, & Laverman, 2013). Today, it is accepted that the Arrhenius model portrays acids as substances that dissociate to produce hydrogen ions in an aqueous solution, and bases as substances which dissociate to produce hydroxide ions (De Berg, 2003; de Vos & Pilot, 2001; Drechsler & Schmidt, 2005; Drechsler & Van Driel, 2008; Erduran & Duschl, 2004; Ihde, 1964; Ouertatani et al., 2007) as presented in Figure 2.2.

$$HA(aq) \rightarrow H^+(aq) + A^-(aq)$$

$$BOH(aq) \rightarrow B^+(aq) + OH^- (aq)$$

Figure 2.2: The Arrhenius model of acids and bases where an acid HA dissociates to form H^+ ions and an anion A^-. Similarly, a base BOH dissociates to form a cation B and OH^- hydroxide ion (from Erduran & Duschl, 2004, p. 119)

In addition, Arrhenius introduced the Neutralisation concept, as a reaction between an acid and a base producing salt and water, which was represented in the form of an equation (Figure 2.3). This equation illustrates the formation of new substances and the disappearance of the original acid and base - it implies a neutral solution is formed.

$$\text{Acid + base} \rightarrow \text{salt and water}$$

Figure 2.3: The Arrhenius model of acids and bases (from Cokelez, 2010, p. 102; de Vos & Pilot, 2001, p. 495; Saglam, Karaaslan, & Ayas, 2011, p. 1398)

In Figure 2.3 salt is defined as a substance containing oppositely charged ions and is referred to as an ionic compound (e.g., the salt sodium chloride comprises Na^+ and Cl^- ions). When dissolved in water, a salt breaks up into its ions. For example, when hydrochloric acid reacts with sodium hydroxide, the reaction produces sodium chloride and water (Cokelez, 2010). The two new products formed are a direct result of a chemical reaction, that is, “a process in which a substance (or substances) is changed into one or more new substances” (Chang, 2002, p. 82). The interaction causes the hydrogen ions to pair with the hydroxide ions to form water, while the chloride ions pair with sodium ions to form salt and water as presented in the following equation Figure 2.4:

$$H^{+} + Cl^{-} + Na^{+} + OH^{-} \rightarrow Na^{+} + Cl^{-} + HOH$$

Figure 2.4: An example of a Neutralisation chemical reaction

In addition to the formation of salt and water and the presence of hydrogen and hydroxide ions in the neutralisation reaction, the Arrhenius model also introduced the concept of partial and complete dissociation to explain the behaviour of strong and weak acids and bases (Ouertatani et al., 2007). The Arrhenius model identifies strong acids or bases as acids or bases that ionise completely in water. On the other hand, acids or bases are considered weak if they partially ionize in water. In later years, Arrhenius also introduced important concepts such as the acid constant (Ka), the base constant (Kb), the degree of ionization (α), and the negative base-10 logarithm of acid and base called pKa and pKbs (de Vos & Pilot, 2001; Ihde, 1964). Also, "in the Arrhenius model, a solution is neutral if its pH = 7 (at 25°C)" (Cokelez, 2010, p. 103). For this reason, pure water is regarded as neutral because the concentration of H_3O^{+} and OH^{-} is 1.0×10^{-7} M respectively at 25°C (McQuarrie, Rock, & Gallogly, 2011).

The strength and limitations of the Arrhenius model are discussed next.

2.5.2.1 Strength and Limitations of the Arrhenius Model

The strength of the Arrhenius model lies in its ability to identify the strength of an acid or base using the degree of dissociation in an aqueous solution (Demerouti, Kousathana, & Tsaparlis, 2004). Although the Arrhenius model can explain strong and weak acids and bases through the involvement of hydrogen and hydroxide ions (de Vos & Pilot, 2001) the model is confined to substances that can dissolve in aqueous solution (Brown et al., 2010; Chang, 2002; Erduran & Duschl, 2004). For this reason, Drechsler and Schmidt (2005) pointed out that the term base in the Arrhenius model can only be applied to substances containing hydroxide ions (OH^-) and thus, could not explain basic substances without the hydroxide ions. For example, the Arrhenius model may not be able to explain why ammonia (NH_3) is a base, since it turns litmus blue and reacts with acids but does not contain OH^- ions (Calatayud et al., 2007; Kauffman, 1988; Petrucci, 1989). This inability of the Arrhenius model to explain bases like ammonia (NH_3) illustrates the model's limitations. Another limitation of the Arrhenius model is its inability to explain pH value of the resulting solution at the equivalence point or the stoichiometric point of a titration. The model is only applicable to a reaction between a strong acid and a strong base where the pH of the final solution is 7.

In the next section, the Brønsted-Lowry acid-base model is discussed.

2.5.3 Brønsted-Lowry Model

In the Brønsted-Lowry model acids and bases are no longer interpreted as chemical species which produce H^+ and OH^- ions, as in the Arrhenius model, but rather species which donate protons and accept protons. In this model proton donors are called acids and proton acceptors are bases (Drechsler & Schmidt, 2005). In addition the Brønsted-Lowry definition allows an ion to be classed as an acid, such as hydrogen carbonate ion (HCO_3^-), or a base like the ethanoate ion (CH_3COO^-) (Atkins et al., 2013). De Vos and Pilot (2001) add that the Brønsted-Lowry model places no importance on salts, but links the ideas of acid and base by promoting the concepts of conjugate acid, conjugate base and conjugate acid-base pairs. A conjugate base is produced when an acid donates a proton to a base, while a conjugate acid is formed when a base accepts a proton from an acid (Kousathana, Demerouti, & Tsaparlis, 2005; McClary & Talanquer, 2011). In the generalised acid-base reaction below (Erduran & Duschl, 2004) an acid HA donates a proton to a base B forming the conjugate acid HB^+ and conjugate base A^- (Figure 2.5).

An acid donates a proton to a base forming a conjugate base

$$\underset{\text{Acid}}{HA\,(aq)} + \underset{\text{base}}{B\,(aq)} \rightleftharpoons \underset{\text{conjugate acid}}{HB^+\,(aq)} + \underset{\text{conjugate base}}{A^-\,(aq)}$$

A base accepts a proton from an acid forming a conjugate acid

Figure 2.5: The Brønsted-Lowry model of acids where HA is an acid, B a base, HB^+ a conjugate acid and A^- a conjugate base (from Erduran & Duschl, 2004, p. 119)

The term acid-base conjugate pair is used to describe the relationship between HA and A^- where A^- is considered to be the conjugate base of the acid HA. Similarly B and HB^+ are called a base-conjugate acid pair since HB^+ is considered to be the conjugate acid of the base B.

Another frequently used equation in the Brønsted-Lowry model is based on formation of a new acid and base, as presented in the figure (Cokelez, 2010; Drechsler & Schmidt, 2005).

$$\text{acid}_1 + \text{base}_2 \rightarrow \text{acid}_2 + \text{base}_1$$

Figure 2.6: Brønsted-Lowry model (from Cokelez, 2010; Drechsler & Schmidt, 2005)

Both forms of the Brønsted-Lowry equation (see Figures 2.5 and 2.6) display the different product forms that the Brønsted-Lowry model caters for. The first equation clearly introduces the acid-conjugate base pairs while the second equation shows an acid reacting with a base to form a new acid and base (Barcza & Buvári, 2003).

The next section describes the strength and limitations of the Brønsted-Lowry model in terms of explaining acid-base behaviours to students.

2.5.3.1 Strength and Limitations of the Brønsted-Lowry Model

One of the strengths of the Brønsted-Lowry model is that the model acknowledges water as a reactant in aqueous solutions of acids and bases through the concepts of conjugate acid and conjugate base (Erduran & Duschl, 2004). Using the Brønsted-Lowry Model, water may now be considered as an acid or a base (see Figure 2.18). Thus, substances without OH^- ions can now be considered as a base since they react with water to produce OH^- ions. An example of this would be ammonia (NH_3) or the ethanoate ion (CH_3COO^-).

NH_3 +	H_2O	$\rightarrow NH_4^+$	+	OH^-
base	acid	conjugate acid		conjugate base

Figure 2.7: The use of the Brønsted-Lowry model to identify water as an acid where ammonia(NH_3) is a base, water (H_2O) an acid, ammonium (NH_4^+) ions a conjugate acid and hydroxide (OH^-) ions a conjugate base (adapted from Drechsler & Schmidt, 2005)

Additionally, this model is able to explain the concepts of Acid-Base Equilibrium and Buffers as described in Sections 2.9.4 and 2.9.5. Another strength of the Brønsted-Lowry model is that an acid-base reaction in this model is independent of an aqueous system. For example, the reaction between ammonium chloride (NH_4Cl) and sodium amide ($NaNH_2$) in liquid ammonia (Ihde, 1964) in Figure 2.8.

NH_4Cl	+	$NaNH_2$	→	$2NH_3$	+	$NaCl$
Ammonium chloride		sodium amide		ammonia		sodium chloride

Figure 2.8: A Brønsted-Lowry acid-base reaction in liquid ammonia (from Ihde, 1964, p. 547)

Another strength of this model is the its ability to explain changes in pH when strong acids and weak bases or vice versa are reacted by illustrating the mechanism involved while the Arrhenius model cannot.

However, one weakness of the Brønsted-Lowry model is its inability to explain the acid properties of substances without the hydrogen atom, such as carbon dioxide (CO_2).

The Lewis acid-base model is described in the next section.

2.5.4 Lewis Model

In the Brønsted-Lowry acid-base model the reaction between an acid and a base is focused on the transfer of protons, but in the Lewis acid-base model the focus shifts to the transfer of an electron pair resulting in bond forming (Atkins et al., 2013). Erduran and Duschl (2004) stated that in 1923 Lewis theorised that an acid can accept a pair of electrons and a base can donate a pair of electrons resulting in a covalent bond between the acid and the base (Barcza & Buvári, 2003; Erduran & Duschl, 2004). Ouertatani et al. (2007) pointed out that the Lewis model emphasis on bases (e.g., NH_3), rather than acids, means the model has the ability to explain reactions involving non-hydrogen acids such as carbon dioxide (CO_2) which previous models cannot. For example, any species which has multiple bonds between S, C or N, and O is a Lewis acid, such as sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) molecules (Global, 2015).

One example of the Lewis model in action involves the reaction between hydrogen and oxide ions (Figure 2.9).

$$H^+ + :O^{2-} \rightarrow O\text{-}H^-$$

Figure 2.9: The Lewis model of acids and bases where H^+ is the hydrogen ion $:O^{2-}$ is the oxide ion and $O\text{-}H^-$ is hydroxide ion (from Erduran & Duschl, 2004, p. 120)

In Figure 2.9, the oxide ($:O^{2-}$) acting as a base donates a pair of electrons to a hydrogen ion which acts as an acid - an electron pair acceptor to form hydroxide ions (OH^-). Another application of the Lewis model involves the formation of complex ions where the electron pair donor (base) forms a covalent bond with electron pair acceptor (acid) (Tarhan & Sesen, 2012). For example, in Figure 2.10 the silver ion (Ag^+) is considered to be an acid, since it is able to receive an electron pair from the ammonia molecule (NH_3), which is a base, with an unbonded electron pair to form the complex ion $Ag(NH_3)_2^+$ [i.e., diamminesilver(1)].

$$2{:}NH_3 + Ag^+ \rightleftharpoons [Ag(NH_3)_2^+] \text{ - complex ions}$$

Figure 2.10: Complex formation between an electron pair donor (a base) and an electron pair acceptor (an acid) where NH_3 is the ammonia ion as the base, Ag^+ the Argentum ion, $Ag(NH_3)^{2+}$ diamminesilver(1) (from Barcza & Buvári, 2003, p. 823)

The strength and limitations of the Lewis model are outlined next.

2.5.4.1 Strength and Limitations of the Lewis Model

Commonly, the Lewis model can be used to identify acids and bases for compounds that do not contain hydrogen atoms (Erduran & Duschl, 2004). A key strength of the Lewis Model is its ability to explain concepts of bond formation through the transfer of electron pairs (Zumdahl & Zumdahl, 2003), because the bond forming shows how a new substance is formed.. In addition, the Lewis acid-base model can be applied to reactions in the solid and gaseous states and does not require the presence of H^+ or OH^- ions to determine whether a species is an acid or a base (Petrucci, 1989). A Lewis acid can be also identified in reactions that involve the oxide of a non-metal in water (Brown et al., 2010), for example, carbon dioxide (CO_2) and sulphur dioxide (SO_2). The Lewis acid-base model involves transfer of a pair of electrons from a base to an acid, which is considered an acid-base reaction.

Another example of the strength of the Lewis model is its applicability to an acid-base reaction in the absence of water as shown in the reaction between ammonia and boron trichloride in Figure 2.11 below.

$$H_3N{:}(g) + BCl_3(g) \rightleftharpoons H_3N{:}BCl_3\,(s) \text{ – a complex}$$

Figure 2.11: Application of the Lewis model without the presence of water and hydrogen atoms where H_3N is ammonia, BCl_3 is boron trichloride, and $H_3N{:}BCl_3$ is borane ammonia complex (from Barcza & Buvári, 2003, p. 823)

Unlike the Arrhenius model, this reaction does not produce salt and water (Chang, 2002), which is a limitation of the Lewis model when explaining salt formation.

To appreciate the role these four acid-base models play in the learning of acid and base chemistry, it is valuable to first examine the theories underpinning learning in general before exploring the learning of more specific acid-base concepts. Key learning theories are discussed in the next section.

2.6 Theories of Learning

In the following sections, the key learning theories that are prevalent in the science education literature are discussed. The theories are: Piaget's theory of cognitive development, Vygotsky's theory of social cognitive development, and finally the complementary Information-Processing theory.

Next, Piaget's Theory of Cognitive Development is discussed.

2.6.1 Piaget's Theory of Cognitive Development or Learning

In the 1960s, Piaget's theory of learning placed emphasis on an individual attempting to construct a cognitive or a mental representation of an object, event, or idea (Bell, 2005). In Piaget's cognitive theory, the terms 'cognitive' and 'mental' are considered to all extents and purposes synonymous and are used interchangeably in the literature, while the term 'schemata' as the plural form of a 'schema' can be considered forms of mental models. Considering the result of learning to be knowledge in the form of a mental representation, Piaget's view of learning maintained that this knowledge is created or constructed through interaction between intelligence (i.e., innate ability of a person) and conditions (i.e., environment). He introduced the concepts of *schemata, assimilation*, and *accommodation* (Piaget, 1953). which together make up the Theory of Cognitive Development (Ewing, Foster, & Whittington, 2011; Hergenhahn, 1988; Maier, 1965). According to Piaget (1953) a *schema* can be defined as a "constituent of a person's schemata" (p. 7) . In other words, a *schema* is the learning that occurs as a result of experience through interaction with the environment and as such forms the basic building block of a person's schemata. In addition, Taylor et al. (2008) assert that individuals schemata is restructured when they learn new information. The new information Piaget says, when integrated into the schemata and modified, can result in a process called *assimilation* (i.e., existing schemata's response to environment stimulus) and the development of a new cognitive structure or schemata (Crain, 2011). To be more precise, assimilation is the process where new linkages between the old schemata and the new schema are being made. However, Galotti (2011) argues that students may sometimes adhere to an existing idea and do not adapt by forming new links. This non adaption can cause some difficulty for students in grasping new ideas so learning does not occur. If the linkages are successful then the result of assimilation that is, the restructured schemata is called *accommodation* (Hergenhahn, 1988), which involves a change in comprehension, (Crain, 2011; Galotti, 2011; Taylor et al., 2008). In other words, when there is an increase in the extent of knowledge, schemata are modified to include old and new information and a new schemata is formed (Galotti, 2011; Piaget, 1953; Wadsworth, 1984).

Piaget also considered cognitive development to be an evolutionary process and introduced the idea of developmental phases linked to the chronological ages of children (Maier, 1965; Piaget, 1953): the Sensorimotor phase (0- 2 years); the Preoperational thought phase (2 to 7 years); the Concrete Operations phase (7 to 11 years); and the Formal Operations phase (11 years to adulthood). In the *Sensorimotor* stage, babies coordinate their actions or motor activities with sensory perception like the action of sucking (Crain, 2011; Piaget, 1953). As Johnson, Slater, and Hocking (2011) explain, during this stage the child develops its own ideas by linking past experiences with objects and people. For example, the child when pulling a cloth to reveal a hidden toy shows that children at this age are starting to solve problems. Piaget believed that at this stage the way childrens' cognitive structure functions is based on their prior experiences and sensory experiences (Galotti, 2011).

In the second *Preoperational,* stage, Piaget viewed children as having the ability to think and represent ideas and objects (Galotti, 2011). Children at this stage only concentrate on one object and see the world through their own eyes. Crain (2011) added that children at this level in Piaget's model of cognitive theory learn to think; however, their thinking is unsystematic.

In the *Concrete Operations* stage children are able to grasp the concept of number, quantity, area, and can classify or arrange objects in order (Galotti, 2011). Children are also able to develop thinking systematically, especially learning from observable phenomena such as acid is sour. During this stage children have the ability to categorize or arrange objects which requires a higher level of thinking (Crain, 2011).

In the *Formal Operations* stage, Piaget described how children or adolescents are able to think more systematically and understand abstract objects logically (Galotti, 2011). At this stage, adolescents and adults develop thinking on an abstract level (Crain, 2011), such as the concept of Buffers in chemistry.

To summarise, Piaget believed that thought develops from simple reflexes to a schemata that allows thinking from the concrete to the abstract and more systematic forms of knowledge. Thus, learning is then seen as a thinking process where individuals try to understand phenomenon through development of mental or cognitive structures which are dependent on age and experience or prior knowledge (Scott, Asoko, & Leach, 2007). Piaget appears to have focused on an individual internal development and the individual construction of knowledge. This construction of knowledge is encompassed in constructivism theory, and, therefore, sometimes Piaget's cognitive theory is sometimes known as a Piaget's constructivism theory (Powell & Kalina, 2009). In later years, other theorists led by Vygotsky gave greater recognition on cultural influence.

The theory of Vygotsky Social Cognitive Development by Vygotsky is discussed next.

2.6.2 Vygotsky Social Cognitive Development Theory

Crain (2011) reported that Vygotsky maintained that cultural experiences influence cognitive development and that this influence was overlooked by Piaget. This omission occurs because Piaget perceived cognitive development as coming from within the child with no external factors contributing to the development. However, Vygotsky believed that after two years of age, intellectual growth is heavily influenced by culture, since culture involves speech and interaction between humans (Crain, 2011). Vygotsky maintained that high levels of thinking, such as those required for mathematics, required some form of instruction between an educator and a learner - a form of social interaction.

The theory of social cognitive development explains that interaction between humans shapes the knowledge that the child is acquiring. For example, a child's interaction with parents and teachers forms the child’s knowledge of phenomena surrounding them (Galotti, 2011). This knowledge that children learn “begins long before they attend school” (Vygotsky, 1978, p. 84). In school, these children learn new knowledge and the difference before and in school creates a gap called zone of proximal development that Vygotsky (1978) defined as:

> …..the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. (p. 86)

Defeyter (2011) reports that this zone provides challenges and it is usually difficult for children to understand certain concepts on their own. Thus, closing the gap requires help from an external source such as an expert or an adult like a teacher (Vygotsky, 1978). In this challenging task, the expert or adult may break the task into smaller more manageable tasks while offering assistance. In order for this learning to occur, the broken down tasks must match with the child's abilities. Defeyter (2011) added that the method is known as scaffolding and when the child starts to acquire the desired knowledge, assistance from the expert is gradually withdrawn. At this point, when the child becomes more capable of handling new information, they are able to internalize this knowledge forming new cognitive structures. The interaction between the expert and the child through language is vital in constructing knowledge during scaffolding (Defeyter, 2011). The construction of knowledge during scaffolding is similar to the constructivism theory and, therefore, sometimes Vygotsky theory is known as Vygotsky's constructivism theory (Hean, Craddock, & O'Halloran, 2009; Powell & Kalina, 2009).

Both Piaget's and Vygotsky's interpretations of constructivism theory identified the key to learning lies in the scaffolding of new concepts based on prior knowledge. If knowledge is constructed carefully, the learners will be able to acquire meaningful learning (i.e., knowledge), and existing concepts or knowledge are altered to more appropriate forms.

The next section on the Information Processing Theory discusses the processes involve in learning.

2.6.3 Information Processing Theory

A third theory with potential for informing science education is the Information Processing Theory. In this theory the terms 'information' and 'knowledge' are regarded as synonymous. This theory was developed by Richard Atkinson and Richard Shiffrin in 1968. In their model information flows in a systematic manner from the sensory memory (SM) to the short-term memory (STM) and on to the long term memory (LTM) (see Figure 2.12).

Firstly, the sensory input flows into the sensory register that senses the visual, touch, and audio stimuli. Next, the information is temporarily sent to and stored in the short-term memory where memory processes occur. The memory processes are categorized into three phases: *coding*, *storage* and *retrieval* (Atkinson & Shiffrin, 1968).

Ceci, Fitneva, Aydin, and Chernyak (2011) describe coding (also known as encoding) as the phase where the memory system of the brain selects and encodes certain important aspects of events and rejects other insignificant aspects for storage in the short term memory (STM). For example, when driving, drivers focus on the road and may not be totally focused on the songs that are playing on the car radio. This selection means not all events may get stored in the STM, only the encoded ones. Depending on the number of times it is recalled, the piece of information in the STM may decay over time resulting in a decrease in memory, that is, the more times it is recalled, the longer its memory life (Figure 2.12).

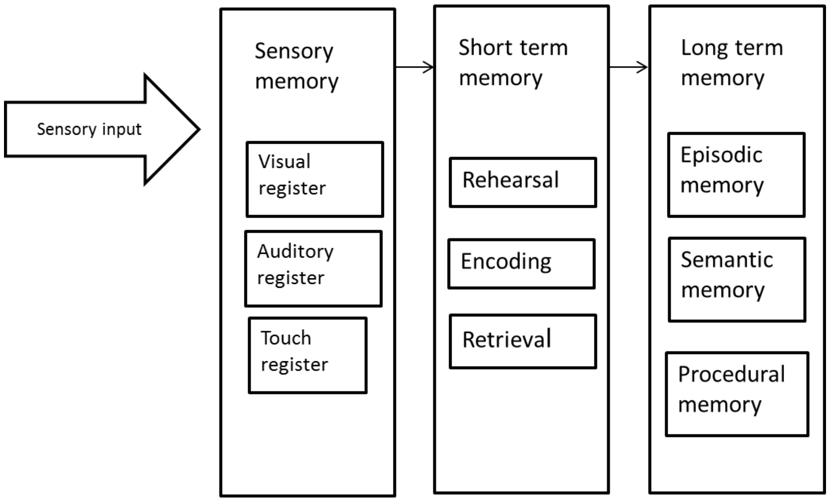

Figure 2.12: The Information Processing Model of the learning process (adapted from Chia & Kee, 2013)

The final step involves retrieval of stored information in the process of remembering. However, there are factors that may influence the retrieval process, such as low motivation or very old memories, which may hinder the retrieval process. When continuous repeating and retrieving occurs, the information is sent to the LTM. According to Chia and Kee (2013), the information stored in LTM can be divided into three different memories: *episodic, semantic,* and *procedural*. The episodic memory holds a number of previous experiences which happened at a specific time, for example, remembering a friend's birthday. In semantic memory, the information stored may contain the understanding of a concept. This memory could give meaning, for example, to symbols and equations. The semantic memory together with the episodic memory will help students to understand concepts being learnt. The third form of memory, called the procedural memory, involves mental collection of processes for certain actions such as driving a car or swimming. In driving, the knowledge of driving is stored in the LTM and when retrieved, the process of driving is automatic without needing to remember steps in driving (Chia & Kee, 2013).

Another Information Processing Model illustrated in Figure 2.13 was proposed by Johnstone (2006) who reviewed other researchers work on difficulties in teaching and learning in science education.

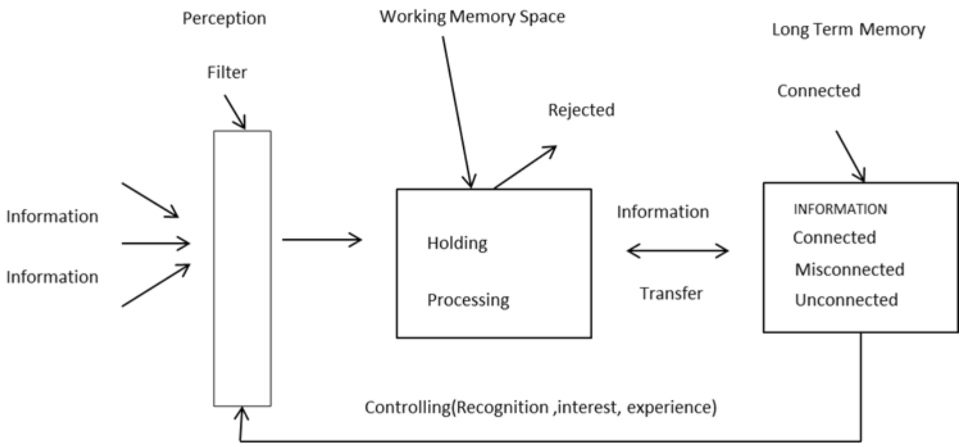

Figure 2.13: Information Processing Model (from Johnstone, 2006, p. 56)

This version of the Information Processing Theory shows that in the process of learning, the information is first received by the learners' sensory perceptions and filtered. The filter acts as a separator between new knowledge and knowledge stored in the long term memory. The filtered knowledge then enters into the Working Memory Space that acts as storage for incoming information for a short period of time and makes sense of the new knowledge before being stored in the Long Term Memory. At this point, Johnstone (2006) explained that the Working Memory Space interacts with knowledge in the Long Term Memory to form new knowledge, and this new knowledge is then stored in the Long Term Memory. However, if the new information cannot be comprehended, the information may enter the Long Term Memory as memorized knowledge (i.e., rote learning) for which sometimes there is often difficulty when recalling. If new information received is extensive, there is little space to process the new knowledge, resulting in an overload or a high cognitive demand and a failure in processing and storage occurs (Johnstone, 2006).

The two Information Processing Models showed similarities in the three components, that is, Sensory, Working Memory Space /Short Term Memory and Long Term Memory. One difference between the two models lies in the short term memory or Working Memory Space. In the Atkinson and Shiffrin model, the knowledge undergoes rehearsal (i.e., repetitions of using same knowledge) and is stored in the Short Term Memory, and later retrieved to answer problems. However, in the Johnstone (2006) model, information is processed to make ‘sense’ of the new knowledge in the Working Memory Space similar to Piaget’s assimilation and accommodation concepts. Another difference between the two models is the information transfer mechanism into the long term memory. For the Atkinson and Shiffrin model, any rehearsed information is stored in the Long Term Memory while in Johnstone’s model information is transferred to Long Term Memory only if the knowledge is logical and sensible. If the knowledge is not logical or sensible, the knowledge is still kept in the Working Memory Space.

For this study, the researcher adopts Johnstone’s Information Processing model because this model is more aligned to chemistry education. Further, the model was able to explain the inability (i.e., cognitive overload or cognitive demand) of the Working Memory Space to cope with large information. This inability then forms difficulties in learning which is discussed next.

2.7 Difficulties in Learning Chemistry

Chemistry is difficult to understand for many reasons (Cros et al., 1986; Demircioğlu, Ayas, & Demircioğlu, 2005; Gabel, 1999; Nakhleh & Krajcik, 1994). First, chemistry is particularly complex to learn because it covers many abstract concepts, for example, chemical bonding, and molecular orbitals (Demircioğlu et al., 2005; Gabel, 1999; Nakhleh & Krajcik, 1994). Second, students often fail to appreciate that chemistry is represented at three levels; macroscopic, sub-microscopic, and symbolic, that thinking in chemistry frequently requires chemistry ideas or concepts to be described at all three levels of representation for a given phenomenon (Chandrasegaran, Treagust, & Mocerino, 2007; Cheng & Gilbert, 2009). Students may find it difficult to explain the phenomena observed on a macroscopic level (the observable world) because they need to seek their explanations in the sub-microscopic or unseen level (Calatayud et al., 2007; Coll & Lajium, 2011; Justi, Gilbert, & Ferreira, 2009). Third, chemistry learning is difficult for students because teachers themselves find certain chemistry topics difficult to understand, and, thus, teach (Özmen, 2007). These difficulties hinder chemistry knowledge building for students, and create problems for them in developing chemistry knowledge. To lessen some of these difficulties, the use of models in explaining a phenomenon may be an answer. However, as noted earlier there is often more than one model needed to explain a phenomenon (Lin & Chiu, 2007) and the way scientists use models is often different to how students use models. Scientists tend to use more than one model when explaining a phenomena. Students on the other hand are more likely to hold a simplistic view of science and learn only from the single 'correct' model that is they tend to use only one model (Shen & Confrey, 2008) and fail to use multiple models. Students need to understand, according to Harrison and Treagust (2000) that no single model can fully represent a phenomenon because a model represents only a fraction of the complete phenomenon to be learned. Certainly in acid-base chemistry, the learning and use of multiple models is necessary to understand acid-base chemistry that is, consistent with the scientific view

(Harrison & Treagust, 2000). However, trying to understand acid-base concepts using multiple models may be quite difficult as the concepts are often introduced at different levels of representation (Nakhleh & Krajcik, 1994). This situation is now discussed.

2.8 Levels of Representation

As stated earlier, one of the difficulties in achieving chemistry knowledge is the inability to move thinking with ease from one level of representation to another (e.g., from macroscopic to sub-microscopic and symbolic). Nakhleh and Krajcik (1994) reported four levels of representation (i.e., *macroscopic*, sub-*microscopic*, *symbolic* and the *algebraic system*). These authors included the algebraic system as a level of representation to indicate the importance of mathematical calculations in acid-base chemistry for identifying quantities such as concentration and pH of acids or bases as presented in Table 2.3. However, in more recent studies, science education researchers have agreed that it is best for the algebraic system to be subsumed into the symbolic system, leaving just three levels of representation (i.e., macro, sub-micro, and symbolic) (Gilbert & Treagust, 2009; Taber, 2009; Tan, Ngoh, Lian, & Treagust, 2009).

To elaborate on the nature of these levels, Gilbert and Treagust (2009) explain that the macroscopic level involves concrete representations, whose features are experienced through the senses, such as mass, density, and concentration. In contrast, thinking at the sub-microscopic level involves representations related to phenomena such as ions, atoms, or molecules that are 'unseen' or abstract. These phenomena are frequently explained using visual modes of representation, such as the ball and stick models. The symbolic level introduces thinking processes that call on quantitative capabilities for example, the number of atoms and ratios.

Table 2.3: Conceptual knowledge of Acids, Bases, and pH categorized by levels of representation (from Nakhleh & Krajcik, 1994, p. 1079)

Macroscopic system
1. Acids taste sour, like lemon or sour milk. Bases sometimes taste bitter, like soap. Bases also feel slippery. Acids have a pH < 7. Bases have a pH >7
2. Acids are found in many foods, such as citrus fruits. Bases are often found in household cleaners, such as oven cleaners
3. Acids and bases affect the color of indicator
4. Acid reacts with bases to form a salt; this is called a Neutralisation reaction. In aqueous solution, water is often formed; this occurs at pH 7
5. A titration is a laboratory procedure in which a known concentration of a substance is added to another substance to determine the unknown concentration. This procedure is often used to calculate an unknown concentration of an acid and a base
Microscopic system
1. Acids donate hydrogen ions (H^+), also called protons, to water molecules to form hydronium ions (H_3O^+). pH is a measure of this H^+ ion concentration
2. Bases are proton acceptors. A typical base is the OH^- ion, also called the hydroxide ion
3. Strong acids dissociate to release all of their hydrogen ions in dilute aqueous solution. Strong bases release all of their hydroxide ions in dilute aqueous solution
4. Weak acids and bases release relatively few hydrogen or hydroxide ions in water solution
5. Neutralisation occurs because the H^+ ions from the acid combine with the OH- ions from the base to form H_2O. The negative ion from the acid and the positive ion from the base remain in solution. If the water is driven off, these negative and positive ions form a salt
Symbolic system
1. Formulas convey information about the number and kinds of atoms that make up a compound
2. Formulas can stand for either a mole of a compound or a molecule of a compound
3. Acid formulas contain a hydrogen atom that can be released as a proton (H^+) ion; examples are HCl, H_2SO_4, HNO_3, and H_3PO_4
4. Base formulas often contain a proton acceptor group, often OH, which can be released in water solution; Examples are NaOH and NH_3
5. A pH graph, which is an S- shaped curve, conveys information about the pH changes that occur when a base and acid neutralise each other
Algebraic system
1. Calculations of concentration using units of molarity or normality
2. Calculations of strength using equilibrium expressions
3. Calculations relating pH and H^+ ion concentration

In Figure 2.14 Johnstone (2006) presented the three representational levels in the form of a triangle. The apexes of the triangle indicated three inter-related representational levels (i.e., macro, sub-micro,and representational) .

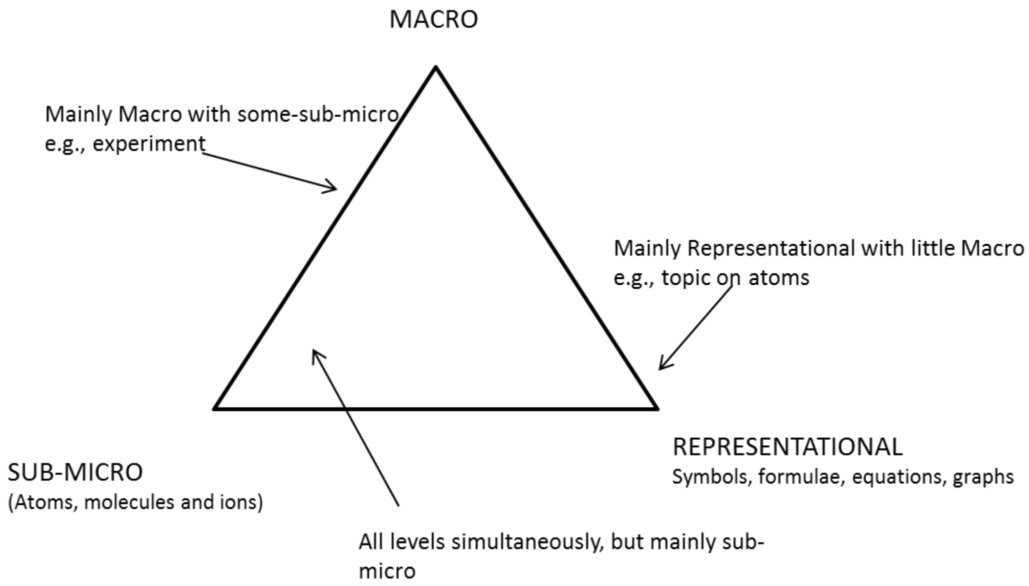

Figure 2.14: The three conceptual levels of chemistry (adapted from Johnstone, 2006)

Johnstone (2006) argues that the significance of this model lie in the corners of the triangle. For example, when a teacher speaks about atoms, a total sub-micro corner is indicated. However, if the teacher performs an experiment using an equation, then the conceptual level lies towards the right side of the triangle based on the higher emphasis being placed on the macro or representational (e,g., symbols, formulae, equations, and graphs). In some instances, aspects of all three representations may be applicable when explaining a concept which is acknowledged as a point within the triangle whose coordinates are determined by the relative .proportion of all three representations. It is those learning instances represented inside the triangle where students commonly have difficulties and may lead to an overload of their Working Memory Space resulting in misconceptions (Johnstone, 2006). These difficulties may also be caused by students' lack of understanding of the particle nature of matter, which is required in the learning of the structure of atoms at the sub-microscopic level (Adbo & Taber, 2009).

For this thesis study, the researcher adopts the Johnstone (2006) view of conceptual levels in chemistry because the interview questions posed to participants do not require them to calculate or use algebra as described in the Nakhleh and Krajcik (1994) literature. Also, the Johnstone (2006) model, included equations as a component of the representational level, essential when learning more complex acid-base chemistry concepts as evidenced by many studies.

The next section describes the literature in acid-base chemistry.

2.9 Acid-Base Knowledge

Acid-base chemistry is an important area to know since it forms the basis in understanding many chemical processes (Bretz & McClary, 2014). The research area in acid-base chemistry education is extensive and many studies have been done to investigate chemistry concepts such as Acid-Base Equilibrium, Neutralisation, and Acid-Strength (Barcza & Buvári, 2003; Drechsler & Schmidt, 2005; Erduran, 2003; Kala, Yaman, & Ayas, 2013; Kousathana et al., 2005; Lin & Chiu, 2007; Nakhleh, 1994; Özmen, DemİrcİoĞlu, & Coll, 2009; Schmidt & Chemie, 1995; Sheppard, 2006; Stoyanovich, Gandhi, & Flynn, 2015; Tarhan & Sesen, 2012). These studies involved students studying at various levels in schools and universities. A few examples of these recent studies are now described that shared similar areas of study with this thesis study.

Sheppard (2006) researched students' studying acid-base titration, Neutralisation concept, pH, acid-base models, and strength of acids and bases. The results showed that students had difficulty in grasping all five areas of acid-base chemistry due to a poor understanding of chemical reactions and particle nature of matter.

Orgill and Sutherland (2008) investigated undergraduate chemistry students' perceptions and misconceptions about buffers. Their findings revealed that students had difficulties understanding buffers and solving problems related to buffers. The study found that students' problems stemmed from their lack of understanding of concepts like conjugate acid/base pairs, the capacity of a buffer being dependent on the concentration of the buffer components rather than the strength of these components, equating buffers to neutralisers, and the inability to identify one of the components of buffer as a weak acid or a weak base.

In a more recent study, Sesen and Tarhan (2011) conducted an intervention study on 45 high school students utilising active-learning instruction in the teaching of acids and bases. The researchers concluded that the experimental group had a smaller number of misconceptions compared with the untreated group. The study also revealed 14 new misconceptions in the control group. The areas investigated in their studies included acid-base theories, metal and non-metal oxides, acid-base equilibrium, buffers, acid-base strength, and neutralisation concepts.

These three recent studies are typical of studies in the literature that show students at many levels of schooling and university study experiencing difficulties understanding concepts like the acid-base models, buffers, acid-base equilibrium, neutralisation, acid-base strength and pH. Studies to date, however, have not investigated students' understanding of the four acid-base models in relation to the six selected acid-base chemistry concepts which this study focuses on. The six selected acid-base chemistry concepts are: Macroscopic Properties, Neutralisation, Acid-Strength, Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding. These six selected acid-base concepts were chosen because their scientific explanations are reliant on the four scientific acid-base models mentioned in Section 2.5. Each of the concepts are now explained in depth showing how various scientific acid-base models can be applied. The next section starts with an outline of the knowledge that comprises the Macroscopic Properties concept, which can be explained by application of the Phenomenological model.

2.9.1 Knowledge of the Macroscopic Properties Concept requiring the Phenomenological Model for Describing

The Phenomenological model is applicable for explaining acid-base behaviour that is concerned with the Macroscopic Properties concept. Petrucci (1989) stated that these properties include, for example, the sensation felt when there is contact with the skin, and an ability to react with metals, limestone, and carbonate compounds. Other chemistry books authors noted that; acids taste sour while bases are slippery and taste bitter, and acids and bases change the colour of plant dyes or indicators (Brown et al., 2010; McQuarrie et al., 2011). Chang (2002) described similar properties but added that aqueous acid and base solutions conduct electricity, and acids react with some metals to produce hydrogen gas and react with carbonates to produce carbon dioxide gas. Nakhleh and Krajcik (1994) added that the reaction of acids with bases to form salt and water in aqueous solution is considered a macroscopic property (see Table 2.4). Lin and Chiu (2007) did point out that not all acids are toxic, corrosive, or strong, only some acids and bases have these characteristics. For this thesis study, the researcher adopted the view that acids and bases have opposite roles, they can be identified using sensory perception, and they change the colour of indicators. The list of macroscopic properties of acids and bases is presented in Table 2.4.

Table 2.4: Properties of acids and bases

Properties of acids	Properties of bases
Acids taste sour	Bases tastes bitter and feel slippery
Acids change blue litmus to red	Bases change red litmus paper to blue
Acids and bases have opposite roles	Acids and bases have opposite roles

Examples of everyday basics substances include soap, floor cleaner, and baking soda solution (Çil, Çelik, Maçın, Demirbaş, & Gökçimen, 2014) while vinegar, lemon juice, and soda drinks are acidic (Demircioğlu et al., 2005; Lin & Chiu, 2007; Özmen et al., 2009).

In addition the concept of pH is linked to the Phenomenological model because the concept is widely used to describe the acidic or basic characteristic of any given substance.

Next, the knowledge comprising the Neutralisation concept that requires the Arrhenius Model for understanding is discussed.

2.9.2 Knowledge of the Neutralisation Concept requiring the Arrhenius Model for Understanding

The reaction between an acid and a base is called a Neutralisation reaction. In.a reaction in aqueous solution between an acid that releases hydrogen ions and a base containing hydroxide ions a salt plus water is formed as illustrated in the Arrhenius model equation (see Section 2.5.3). The salt produced is an ionic compound consisting of oppositely charged ions while the formation of water is the result of a reaction between the hydrogen ions from the acid and hydroxide ions from the base (Atkins et al., 2013). An example of a strong acid and a strong base Neutralisation is the reaction of aqueous hydrochloric acid (HCl) and sodium hydroxide (NaOH).

In these instances of neutralisation a base is considered to have an opposite role to an acid, and is included as one of the characteristics of acids and bases in the Phenomenological model (see Table 2.4). For example, a base such as “lime is used to reduce the acidity of an acidic soil” (Curriculum Development Centre, 2005, p. 46).

In the next section, the knowledge comprising of the Acid-Strength concept that requires the Arrhenius model for understanding is examined.

2.9.3 Knowledge of the Acid-Strength Concept requiring the Arrhenius and the Brønsted-Lowry Model for Understanding

For this study, it is expected that teachers and students will use the Arrhenius model to explain the Acid-Strength concept because the Malaysian Science Curriculum at the Form 4 schooling level introduces the Arrhenius model as a means of explaining Acid-Strength. The curriculum uses the Arrhenius Model to determine strong and weak acids and bases in terms of the degree of dissociation (see Section 6.5) i.e., the proportion of acid that dissociates to produce hydrogen ions, and for a base the proportion that dissociates to produce hydroxide ions (de Vos & Pilot, 2001; Furió-Más, Luisa Calatayud, Guisasola, & Furió-Gómez, 2005; McClary & Talanquer, 2011). A strong acid is defined as a substance that fully dissociates while a weak acid is defined as a substance that partially dissociates (McQuarrie et al., 2011).

In the following section, knowledge comprising the Acid-Base Equilibrium concept that requires the Brønsted-Lowry and Arrhenius models for understanding is reviewed.

2.9.4 Knowledge of the Acid-Base Equilibrium Concept requiring the Brønsted-Lowry Model and the Arrhenius Model for Understanding

Zumdahl and Zumdahl (2003) identified equilibrium as "the state where the concentrations of all reactants and products remain constant with time" (p. 609). In order to understand the Acid-Base Equilibrium concept, where acids and bases are the reactants, students need to understand the idea of conjugate acids and bases, a feature of the Bronsted-Lowry model as illustrated in (Figure 2.15).

$$CH_3COOH\,(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CH_3COO^-\,(aq)$$

Acid	Base	Conjugate acid	Conjugate base

Figure 2.15: Components of the Acid-Base Equilibrium (Demerouti et al., 2004, p. 125)

Figure 2.15 represents the reaction between ethanoic acid and water, producing hydronium ions (i.e., a conjugate acid) and ethanoate ions (i.e., a conjugate base). According to the Brønsted-Lowry model, an acid (e.g., ethanoic acid) loses a proton to become a conjugate base (e.g., ethanoate ions) and a base (e.g., water) receives a proton to become a conjugate acid (e.g., hydronium ions). Thus, in the Brønsted-Lowry model an acid-base reaction is seen as a proton transfer reaction, as illustrated by the reaction between sodium hydroxide and ethanoic acid represented in the equation below (Figure 2.16).

$Na^+ + OH^-$ (aq) + CH_3COOH (aq) → CH_3COO^- + Na^+(aq) + H_2O (aq)

(Base) (acid) (conjugate base) (conjugate acid)

Figure 2.16: Reaction between hydroxide ions (OH^-) with ethanoic (CH_3COOH) acid producing ethanoate ions (CH_3COO^-) and water (H_2O) Zumdahl and Zumdahl, (from Brown et al., 2010, p. 581; Chang, 2002, p. 628; Zumdahl & Zumdahl, 2003, p. 736)

At the equivalence point, in this reaction the major species present are sodium ions (Na^+) and ethanoate ions (CH_3COO^-) and water (H_2O) molecules, because the OH^- ions have completely reacted with the ethanoic acid (CH_3COOH) acid molecules. However, the ethanoate ions (CH_3COO^-) produced in the reaction is a relatively strong conjugate base and reacts with water to produce ethanoic acid (CH_3COOH) acid molecules and OH^- ions (Figure 2.17). This reaction results in the following equilibrium where the equilibrium position is to the right and the concentration of OH^- ions are high.

$$CH_3COO^-(aq) + H_2O(l) \rightleftharpoons CH_3COOH\ (aq) + OH^-$$

Figure 2.17: Reaction between ethanoate ions with water producing ethanoic acid and hydroxide ions where CH_3COO^- ethanoate ions, H_2O water molecule, CH_3COOH aqueous ethanoic acid, OH^- hydroxide ions (from Chang, 2002, p. 664; Zumdahl & Zumdahl, 2003, p. 737)

Simultaneously, as part of the same reaction system, water dissociates to produce hydronium ions and hydroxide ions (Figure 2.18) but the concentration of hydronium and hydroxide ions produced are relatively small.

$$2H_2O(l) \rightleftharpoons H_3O^+\ (aq) + OH^-\ (aq) \text{ or}$$

H_2O(l) + H_2O(l) ⇌ H_3O^+ (aq) + OH^- (aq)

(acid) (base) (conjugate acid) (conjugate base)

Figure 2.18: Autoionization of water (H_2O) dissociates to hydronium ions (H_3O^+) and hydroxide ions (OH^-) (from Demerouti et al., 2004; 2003, pp. 660,662)

Thus, at the equivalence point for the reaction between ethanoic acid and sodium hydroxide, the concentration of hydroxide ions in the resulting solution overall is higher than hydronium ions. Also notable, the autoionization of water is not included in the Malaysian curriculum but its importance lies in the ability of the Bronsted-Lowry model to explain the amphoteric nature of water and the formation of hydroxide ions (OH^-).

So in conclusion at the point where 50.0 mL of sodium hydroxide (NaOH) is added in the sodium hydroxide/ethanoic acid (NaOH/ CH_3COOH) reaction, the ethanoate ions (CH_3COO^-) that form act as a conjugate base reacting with water to produce hydroxide (OH^-) ions (Chang, 2002). The pH of the resulting solution is > 7 because of the higher concentration of the hydroxide ions (OH^-).

Another example, that uses Arrhenius model explanations, involves common ions in an acid-base equilibrium. In one solution a weak acid hydrofluoric acid (HF) dissociates partially in aqueous solution to form hydrogen ions (H^+) and fluoride ions (F^-). In a second solution sodium fluoride (NaF), an ionic salt, completely dissociates to form aqueous Na^+ (aq) and F^- (aq) ions. The fluoride ion (F^-) is termed a common ion since it is found in both solutions Figure 2.19.

$$HF(aq) \rightleftharpoons H^+(aq) + F^-(aq) \text{ ……..(Reaction 1)}$$

$$NaF(s) \rightarrow Na^+(aq) + F^-(aq) \text{.......(Reaction 2)}$$

Figure 2.19: Dissociation of hydrofluoric acid (HF) into hydrogen ions (H^+) and fluoride ions (F^-) and sodium fluoride, (NaF) into sodium ions (Na^+) and fluoride ions (F^-) (from Zumdahl & Zumdahl, 2003, p. 715)

When the sodium fluoride solution is added to the hydrofluoric acid solution, the concentration of F^- ions increases and, according to the Le Chatelier principle (i.e., if a change is directed towards a system, the direction of the equilibrium shifts in a direction that tends to reduce that change), the hydrofluoric acid equilibrium system will shift to the left to maintain equilibrium. This effect is known as the common ion effect (Brown et al., 2010; Chang, 2002; McQuarrie et al., 2011; Petrucci, 1989; Zumdahl & Zumdahl, 2003). This common ion effect is sometimes necessary to explain Acid-Base Equilibrium concept using the Arrhenius model when an added solution has similar ions to the acid-base reaction, indicated by the F^- ions in the example above. In this thesis study, the probing question did not investigate the concept of common ions for Acid-Base Equilibrium but is presented here to indicate the use of the Brønsted-Lowry and the Arrhenius models Acid-Base Equilibrium.

The knowledge comprising the Buffers concept that requires the Brønsted-Lowry and Arrhenius models is explored next.

2.9.5 Knowledge of the Buffers Concept requiring the Brønsted-Lowry and Arrhenius Models for Understanding

A buffered solution is a solution, for example, that contains a weak acid and its conjugate base that can resist a change in pH when an acid or a base is added to it (McQuarrie et al., 2011). The human blood is an example of a buffer solution that maintains blood at the pH of 7.4 (Chang, 2002). The buffer components for blood are carbonic acid and sodium bicarbonate (Ophardt, 1983).

While a buffered solution contains a “weak acid or a weak base with its conjugate"(Orgill & Sutherland, 2008, p. 135) Zumdahl and Zumdahl (2003) had clarified this statement by explaining that “a buffered solution may contain a weak acid and its salt (for example, HF and NaF) or a weak base and its salt (for example, ammonia (NH_3) and ammonium chloride (NH_4Cl)” (p. 717). By using terms 'salt', 'weak acid' or a 'weak base' Zumdahl and Zumdahl (2003) demonstrated the use of the Arrhenius model while Orgill and Sutherland (2008) in mentioning the term 'conjugate' indicated the use of the particulate nature of matter (i.e., protons) in the Brønsted-Lowry model. Thus, it can be seen that, two acid-base models can be used to explicate the components and behaviour of a buffer solution. For instance, a solution consisting of ethanoic acid (CH_3COOH), which is a weak acid, and sodium ethanoate, (CH_3COONa) which can be thought of as the salt of a weak acid or a conjugate base (i.e., the ethanoate ions, CH_3COO^-) is an example of a buffer solution. Another example is ammonia (NH_3) in the presence of ammonium chloride (NH_4Cl), where ammonia is a weak base and ammonium chloride is the salt of a weak base or a conjugate acid, that is, the ammonium (NH_4^+) ions (Zumdahl & Zumdahl, 2003).

In addition, for the reaction between sodium hydroxide (NaOH) and a buffered solution of ethanoic acid (CH_3COOH) and sodium acetate (CH_3COONa), a small pH increase is observed. For example, a buffered solution containing 0.50 mol L^{-1} ethanoic acid (CH_3COOH) and 0.50 mol L^{-1} sodium acetate (CH_3COONa), yields a pH of 4.74. When a strong base (0.010 mol L^{-1}) is added to the buffer solution, the new solution produced a pH of 4.76, an increase of +0.02 (Zumdahl & Zumdahl, 2003). The small pH increase showed that the buffer solution has the capability to resist a major pH change.

In order to further explore aspects of acid-base chemistry, the knowledge of different types of titration curves becomes essential and is discussed next.

2.9.6 Knowledge of Acid-Base Titration in Understanding Acid-Base Reaction

A titration is a technique commonly used in a laboratory that involves the addition of one solution (e.g., a base) of a known concentration to a known volume of another solution (e.g., an acid) of an unknown concentration (McQuarrie et al., 2011). The apparatus used for titration is illustrated in Figure 2.20.

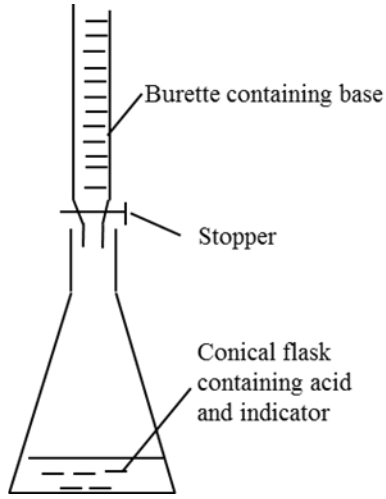

Figure 2.20: The apparatus required for an acid-base titration

For example, the titration technique can be used to determine the concentration of an unknown solution of hydrochloric acid (HCl) using with 0. 10 mol L^{-1} sodium hydroxide (NaOH). A specific volume (e.g., 20.0 mL^{-1}) of the acid is poured into a conical flask and three drops of acid-base indicator such as phenolphthalein is added. Next, the 0.10 mol L^{-1} sodium hydroxide (NaOH) is placed in the burette. The sodium hydroxide (NaOH) solution is slowly added into the hydrochloric acid (HCl) solution until the indicator changes colour. At this point, the reaction between sodium hydroxide (NaOH) and hydrochloric acid (HCl) is complete and said to be the equivalence point on a titration curve, as shown in Figure 2.21. A titration curve is defined as a “plot of the pH as a function of the volume of the added base” (McQuarrie et al., 2011, p. 786).

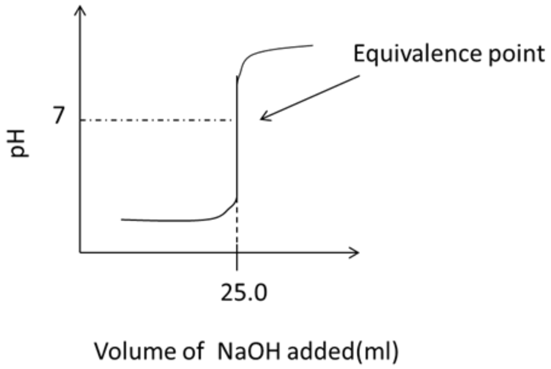

Figure 2.21: Titration curve between strong acid (hydrochloric acid) and strong base (sodium hydroxide) (fromZumdahl & Zumdahl, 2003)

To elaborate, the equivalence point in Figure 2.21 is the point when just enough hydroxide ions (OH^-) are added to react with all the hydrogen ions (H^+) present in the acid.. The resulting solution has a pH of 7, which is a characteristic of a strong acid-strong base reaction (Brown et al., 2010; Zumdahl & Zumdahl, 2003).

In another example between a strong base i.e., sodium hydroxide (NaOH) and a weak acid i.e., ethanoic acid (CH_3COOH), a curve as shown in Figure 2.22 is seen.

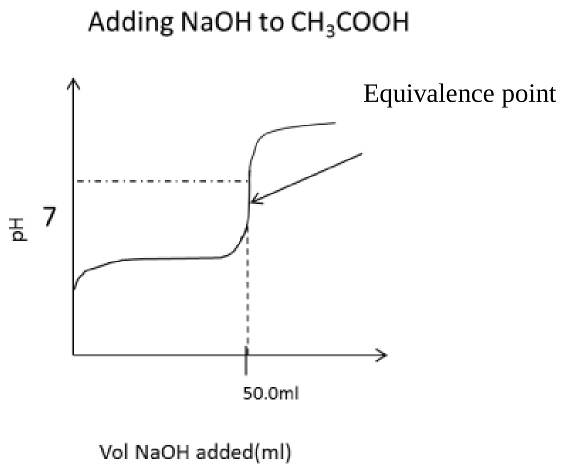

Figure 2.22: Titration curve between weak acid (ethanoic acid) and strong base (sodium hydroxide) (from Brown et al., 2010, p. 583; Chang, 2002; Zumdahl & Zumdahl, 2003)

The illustrated titration curve in Figure 2.22**Error! Reference source not found.** is an example of a titration between 0.10 mol L^{-1} 50.0mL aqueous ethanoic acid

(CH_3COOH) and 0.1 mol L^{-1} aqueous sodium hydroxide (NaOH) where the equivalence point occured when 50.0mL of aqueous 0.1 mol L^{-1} sodium hydroxide (NaOH) is added. At equivalence point, the pH of the resulting solution is more than 7. This equivalence point section of the titration curve is significant because it reveals the required volume for Neutralisation. Also, the pH value of the final solution at equivalence is important when explaining changes in pH required to explain the Neutralisation, Acid-Base Equilibrium, and Buffers concepts.

The next section discusses knowledge comprising the Acid-Base Electron Pair Bonding concept that requires the Lewis model for explanation.

2.9.7 Knowledge of the Acid-Base Electron Pair Bonding Concept requiring the Lewis Model for Understanding

The Lewis Model is a model that focuses on the transference of a pair of electrons, and/or on bond forming. An example of the Lewis model application is presented in Section 2.5.4.1. Similarly, this reaction can be extended to non-aqueous reactions such as the reactions between ammonia (NH_3) and boron trifluoride (BF_3) or boron trihidride (BH_3) , which form complexes (Czerw, Goldman, & Krogh-Jespersen, 1999; Laubengayer & Condike, 1948; Nguyen, Nguyen, Matus, Gopakumar, & Dixon, 2007). These reactions are shown in Figure 2.23.

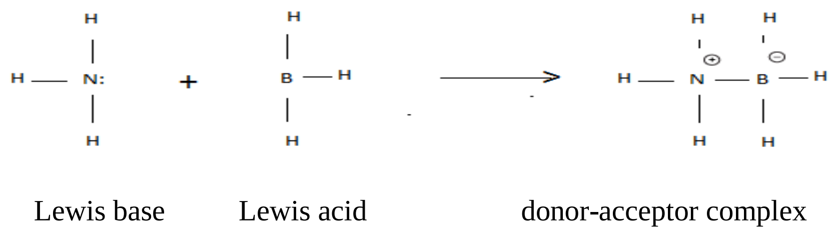

Figure 2.23: A reaction between Lewis acid boron trihidride (BH_3) and Lewis base ammonia (NH_3) to form borane-ammonia complex (BH_3NH_3) is ammonia (Czerw et al., 1999; Guch, 2000-2015)

In Figure 2.23 a boron trihidride (BH_3) molecule reacts with an ammonia (NH_3) molecule by accepting an electron pair on the nitrogen atom to form a borane-ammonia complex. Also, note boron trihidride (BH_3) is not a Brønsted-Lowry acid because it does not donate a proton, but it is a Lewis acid because boron trihidride (BH_3) accepts electron. The B-N bond is called a dative bond where one of the two atoms (i.e., NH_3) involved in a reaction such as the reaction in Figure 2.23 donates both the electrons to the other atom (i.e., BH_3) for bonding (Chang, 2002).

In summary, the six selected acid-base chemistry concepts require the use of the Phenomenological, Arrhenius, Brønsted-Lowry, and the Lewis models for a deep understanding. Learners' failure to acquire and appropriately apply the knowledge embedded in these acid-base models may cause the development of misconceptions, which is discussed next.

2.10 Common Misconceptions in Acid-base Chemistry

The literature says some of the difficulty in studying chemistry may be due to the formation of misconceptions (Demircioğlu et al., 2005; Kousathana et al., 2005; Schmidt, 1997). The term "misconception" is defined as "any concept that differs from the commonly accepted scientific understanding" (Nakhleh, 1992, p. 191). Reasons for misconceptions occurring in acid-base chemistry includes confusion when using chemical terms such as "neutral" in the Neutralisation concept, and "strong" with the strength of an acid (Nakhleh & Krajcik, 1994; Schmidt, 1991; Schmidt, 1997), the use of traditional method of instruction (Sesen & Tarhan, 2011), difficulties in using acid-base models (Calatayud et al., 2007; Kousathana et al., 2005; Schmidt & Volke, 2003), experiences in daily lives (Demircioğlu et al., 2005), and explaining concepts from a macroscopic to a sub-microscopic level of representation (Colburn, 2009; Nakhleh, 1992). These misconceptions create a barrier for students when trying to understand the correct scientific concepts. This barrier works by inhibiting the learners' ability to construct ideas and subsequently influence the process of receiving new knowledge. These misconceptions are known to have certain characteristics that hinder students' ability to construct correct scientific ideas.

One characteristic of misconceptions is that they are challenging to eradicate because they remained in the learners' thinking for a long period (Demircioğlu et al., 2005). To reduce the number of misconceptions that students hold, previous documented misconceptions found in the literature can be used during teaching and learning in the classroom to help students grasp a correct scientific concept (Pinarbasi, 2007). For example, teachers can compare and contrast between the correct scientific conceptions and students'misconceptions in the classroom helping teachers to correct their students' misconceptions.

In the next following sections, common misconceptions found in the literature for Macroscopic Properties, Neutralisation, Acid-Strength, Acid-Base Equilibrium, Buffers, and Acid-base Electron Pair Bonding concepts are presented and discussed. First, students' misconceptions for the Macroscopic Properties concept are explored.

2.10.1 Students' Misconceptions for the Macroscopic Properties Concept

The table below present a number of misconceptions for macroscopic properties of acids and bases identified in the literature (Table 2.5).

Table 2.5: Students' misconceptions of the Macroscopic Properties concept

Sources	Description of misconceptions
Nakhleh & Krajcik (1994)	Bases are not harmful
Demircioğlu, et al. (2005)	Acids burn and melt everything
	Beverages with soda contain weak bases
	Strong acids melt and destroy metals
	All acids have bubbles
	All acids and bases are harmful and poisonous
	The only way to test whether a sample is an acid or a base is to see if it eats something away, for example, metal, plastic, animal, or people
	Bubbles are a sign of chemical reaction or strength of an acid or a base
	While bases turn blue litmus paper red, acids turns red litmus paper blue
	Indicators help with Neutralisation

Table 2.5 shows that the students' misconceptions for macroscopic properties are linked to the sensory perception. For example, the students in the Nakhleh and Krajcik (1994) thought that acids were harmful because acids appeared to be 'strong' because they could burn skin but not bases. Similarly because some acid are known to burn skin and melt metals, students assumed all acids to burn and melt. Also, the students tended to assume that soda drinks are weak bases rather than weak acids because bases are not harmful and can, therefore, be consumed. Other students perceived acids produce bubbles and destroy metals when reacted because of their strong nature (Demircioğlu et al., 2005). These misconceptions showed that students' understanding of macroscopic properties were based on their everyday life experiences that acids are harmful, poisonous and strong, unlike bases.

In Section 2.10.2, students' misconceptions for the Neutralisation concept are examined.

2.10.2 Students' Misconceptions for the Neutralisation Concept

Table 2.6 presents a number of misconceptions for the Neutralisation concept found in the literature.

Table 2.6: Students' misconceptions on the Neutralisation concept

Sources	Description of misconceptions
Demerouti et al. (2004)	A strong acid requires a higher number of strong base moles than a weak one (for neutralisation)
	The acidity is easier to define in the case of strong acid and strong base than for a weak acid and/or base
Nakhleh & Krajcik (1994)	Acids and bases react as an addition and not as bond breaking and salt forming
	Phenophthalein helps in Neutralisation
Schmidt (1991) and Sesen & Tarhan (2011)	Neutralisation will always produce a neutral solution
Pinarbasi (2007)	All salts are neutral
	In a Neutralisation reaction, when one of the reactants (acid or base) is weak, the Neutralisation does not completely take place
Demircioğlu et al. (2005)	In all Neutralisation, acids and bases consume each other completely
	At the end of all Neutralisation reactions, there are neither H^+ nor OH^- ions in the resulting solution
Sesen & Tarhan (2011)	Neutral solutions are formed in all the Neutralisation reactions
	The pH of salts which are products of acid and base Neutralisation reaction is always 7
	The solution formed as a result of Neutralisation does not include H_3O^+ and OH^- ions
	Acids and bases always consume each other
	Neutralisation reactions only occur between strong acids and strong bases

For Neutralisation, Table 2.6 demonstrates that the existence of students' misconceptions lies in the word "neutral", which appears to indicate the understanding that when an acid and a base react the products formed are neutral with a pH 7. Students seem to believe that strong acids and strong bases consume each other and the resulting products would be neutral (Sesen & Tarhan, 2011). Overall students believed neutralisation only occurs for a strong acid and a strong base reaction. Similarly, when explaining a reaction between a strong acid and a strong base students appeared to think that the hydrogen and hydroxide ions completely react to form water rather than producing equal amounts of hydrogen and hydroxide ions (Schmidt, 1991). These misconceptions showed that students seemed to be confused with the term neutral.

Students' misconceptions for the Acid-Strength concept are now identified and discussed.

2.10.3 Students' Misconceptions for the Acid-Strength Concept

Table 2.7 presents a number of misconceptions for the Acid-Strength concept gathered from the literature.

Table 2.7: Students' misconceptions for the Acid-Strength concept

Sources	Description of misconceptions
Ouertatani et al., (2007)	Acid-Strength is related to the concentration of hydrogen ions
	A high (low) pH is associated with strong acid (weak acid)
Pinarbasi (2007)	The pH of an acid solution that is excessively diluted can be over 7
Sesen & Tarhan (2011)	While the number of H increases in a molecule, its acidity increases
	Strong acids are always concentrated
	While the strength of an acid increases, its molar concentration also increases
	While a diluted solution of an acid is weak, its concentrated solution is strong
	The strength of an acid or base is related to its electronegativity or size
	The reason for increasing acid strength throughout a group is decreasing electronegativity of atoms

For the Acid-Strength concept students' misconceptions were linked to pH, molar concentration, and the number of hydrogen atoms in a molecule (Table 2.7). For example, students were inclined to confuse the strength of an acid with the concept of acidity, where "pH is a measure of the acidity of an aqueous solution" (McQuarrie et al., 2011, p. 738) but not a measure of strength of an acid. Other misconceptions included students' thinking that the strength of a solution is equated to the concentration of a solution. For example, a solution of 0.2 mol L^{-1} is "more concentrated" than 0.1 mol L^{-1} but students believed a solution of 0.2 mol L^{-1} is "stronger" than 0.1 mol L^{-1}. In addition students tended to think the presence of a high number of hydrogen atoms in an acid molecule were directly correlated with the strength of an acid. For example, the presence of three hydrogen atoms in H_3PO_4 (a weak acid) led students to consider that H_3PO_4 is a stronger acid than H_2SO_4 acid which has only two H atoms. The misconceptions in Table 2.7 shows that students were not able to comprehend that a strong acid or a strong base can dissociate completely to form H^+ (i.e., for acids) or OH^- (i.e., for bases) ions while a weak acid or a weak base partially dissociates to H^+ (i.e., for acids) or OH^- ions (i.e., for bases) and not dependant on the number of hydrogen atoms.

In the following section, students' misconceptions for Acid-Base Equilibrium concept are reviewed.

2.10.4 Students' Misconceptions for the Acid-Base Equilibrium Concept

Table 2.8 provides a number of misconceptions for the Acid-Base Equilibrium concept gathered from the literature.

Table 2.8: Students' misconceptions for the Acid-Base Equilibrium concept

Sources	Description of misconceptions
Demerouti et al. (2004)	Students ignored the self-ionisation of water
	Students write down reactions between weak acids and bases as a single arrow (irreversible)
Griffiths (1994)	Students believed a salt contains neither hydrogen nor a hydroxyl group
Sesen & Tarhan (2011)	If weak acid salt is added to a weak acid solution, the pH decreases
	If a strong base is added to a weak acid solution, there are only OH^- ions in the solution
	Acidity constant does not change with temperature

The students' misconceptions presented in Table 2.8 for the Acid-Base Equilibrium concept indicate that students think a strong acid reaction results in higher hydrogen ions when the reaction is completed. Similarly, when a strong base reacts with a weak acid, a high concentration of hydroxide ions exists at the end of the reaction. This thinking existed because students appeared to believe a strong solution will prevail and consume a weaker solution (Lin & Chiu, 2007). Another misconception was students tended not considering the self-ionization of water which shows that water can act as an acid or a base (see Section 2.9.4, Figure 2.18) to produce hydronium ions (H_3O^+) and hydroxide (OH^-) ions in an aqueous solution.

Students' misconceptions for the Buffers concept as identified from the literature are now discussed.

2.10.5 Students' Misconceptions for the Buffers Concept

Table 2.9 below presents a number of misconceptions for the Buffer concepts found in the literature.

Table 2.9: Students' misconceptions for the Buffers concept

Sources	Description of misconceptions
Demerouti et. al (2004) Sesen & Tarhan (2011)	HCl and NaCl forms a buffer solution
Sesen & Tarhan (2011)	A buffer is only formed by a weak acid and its salt
Orgill & Sutherland (2008)	A buffer is formed by an acid and its salt, not its conjugate base
	Buffers are neutral solutions
	Buffers can be formed by using any acid or base solutions and their salts
	Buffers are formed from any two chemicals that are mixed
	pH of a weak acid solution is equal to its pK_a
	Buffers maintain a pH 7
	Buffer consist of any acid and any base and not a weak base or a weak acid

From Table 2.9, it appears that many students regarded a buffer solution as a reaction between any acid and its salt, not a weak acid or a weak base with its salt. Also a buffer solution is expected to always show a pH 7 because students assumed a buffer solution acts to neutralise an acid and, therefore, is always neutral (Orgill & Sutherland, 2008). Other misconceptions include the strength of a buffer or buffering capacity depending on the nature of components of a buffer rather the scientifically correct idea that a buffer's capacity depends on the concentration of the components of the buffer. For example, a buffer solution of 5.00 mol L^{-1} is able to resist a pH change more than a 0.0050 mol L^{-1} solution. This difference in capacity is because a solution of 5.00 mol L^{-1} "contains a large amount of buffering components and so can absorb a relatively large amount of protons or hydroxide ions and show little pH change" (Zumdahl & Zumdahl, 2003, p. 726).

Students' misconception for the Acid-Base Electron Pair Bonding concept is described next.

2.10.6 Students' Misconception for the Acid-Base Electron Pair Bonding Concept

Two misconceptions are illustrated for the Lewis model Table 2.10.

Table 2.10: Students' misconception for the Acid-Base Electron Pair Bonding

Sources	Description of misconceptions
Calatayud et al. (2007)	Ammonia (NH_3) is an acid because of the presence of hydrogen
Zoller (1990)	$O=P(OH)_3$ is a base and PH_3 an acid

Table 2.10 presents the students' misconception that ammonia (NH_3) is understood to be an acid because of the presence of hydrogen atom, which is associated erroneously with the Arrhenius model which states an acid dissociates in water producing hydrogen ions. Students fail to realise that ammonia (NH_3) is a base using the Lewis model explanation that a base donates a pair of electrons in an acid-base reaction. For example, ammonia (NH_3) and Phosphorus trihidride (PH_3) molecules both have a non-bonding pair of electrons that is used for bonding to a hydrogen atom and, therefore, are considered bases (Calatayud et al., 2007; Zoller, 1990). Similarly, O= $P(OH)_3$ is not a base because of the presence of

the OH group, but an acid because there is no pair of electrons available for bonding. All five electrons of phosphorus atom are involved in bonding - three with OH groups and two with the oxygen atoms (Zoller, 1990).

These misconceptions provide evidence of students difficulties in understanding scientific concepts (Coll, Ali, Bonato, & Rohindra, 2006). These misconceptions may stem from students' interactions with their physical environment and from communication between peers, friends and relatives (Oversby, 2000). Commonly, misconceptions arise from knowledge constructed in students' minds which is different to scientific models. The differences occur because students have difficulty making links to the scientific concepts such that their reasoning is not aligned with scientific reasoning.

In the next section, students' reasoning to explain acid-base chemistry concepts is discussed.

2.11 Students' Reasoning Underpinning their Explanation in Acid-Base Chemistry Concepts

Studies in how students reason when explaining chemistry concepts have occurred for topics like chemical reactions and the structure of matter (Andersson, 1986a; Merritt & Krajcik, 2013). A chemical reaction, according to Chang (2002) is the formation of a new product or products formed from an interaction process of the original substances. In acid-base chemistry this interaction involves the reaction between an acid and a base. One type of reasoning, known as causal reasoning stated by Andersson (1986a) is a relationship between an agent and an object. For example, a warm hot plate (i.e., an agent) slightly increases the temperature of a pan of water (i.e., object). When the hot plate becomes warmer the temperature of the pan of water increases further. In other words, there is a high correlation between an agent and an object. In addition, Andersson (1986b, 1990) classified students' thinking into five groups, gathered from a number of other investigations of pupils' understanding of matter and its transformation involving students from the age 12 to 16 year olds. In the first study the probe question was, "A car weighs 1000kg. It is filled up with 50kg of petrol. The car is driven until the petrol tank is empty. The car then weighs 1000kg again". Approximately how much do you think the exhaust gases given off during the drive weigh? In the second study, the question was about the combustion of alcohol and wood (cf. Andersson, 1990, p. 56). The answers were classified into five groups labelled: 'Disappearance', 'Displacement', 'Modification', 'Transmutation', and 'Chemical Interaction'. Examples of the classification are presented in Table 2.11. The 'disappearance', 'transmutation', and 'chemical interaction' classification were examples referring to the first study while the 'displacement' and 'modification' examples represented the second study.

Table 2.11: Examples of the chemical reaction classification (from Andersson, 1990, pp. 56-57)

Classification	Examples of students' responses
Disappearance	*"The petrol is used up in the car and disappears."*
Displacement	When students were asked to explain the combustion of alcohol and wood, student replied "*There isn't any water in alcohol. I don't see what the water vapour is doing here."*
Modification	*"As alcohol burns, the alcohol turns into alcohol vapour."*
Transmutation	*"Less than 50kg. It's less than 50kg part of the petrol has been changed into heat and kinetic energy."*
Chemical interaction	In combustion, "*The petrol combines with oxygen. Then the exhaust gases weighs more."*

In the 'disappearance' view, some students believed that petrol undergoes a reaction and disappeared. These students did not relate their explanations to a chemical reaction occurring between petrol and oxygen to release energy for a car to move. For 'displacement' reasoning students tended to think the resulting product should only be alcohol and wood. This reasoning did not take into consideration that in the combustion process of alcohol and wood, water is produced. Other students with the 'modification' view described that when alcohol burns it retained its identity as alcohol but changed (i.e., modified) some parts of its properties. For the 'transmutation' view, the reactants undergo transformations that are scientifically unacceptable. In this type of reasoning, students thought that petrol was used up (i.e., transmuted or transformed) to form kinetic energy resulting the car to weigh less. The 'chemical interaction' view, is an acceptable scientific reasoning because combustion is a chemical reaction process that occurred when petrol combines with oxygen to form carbon dioxide and water. One common characteristic of the 'disappearance', 'displacement', 'modification', and 'transmutation' forms of reasoning was the idea that a "new substance appears, and an old one disappears, as a result of a separate change in the original substance, or possibly changes, each one separate, in several original substances" (Andersson, 1990, p. 55). The 'chemical interaction' view is an explanation of chemical reaction that is scientifically accepted while the 'disappearance', 'displacement', 'modification', and 'transmutation' forms of reasoning are not.

Another causal explanation of a chemical reaction based on change in matter was proposed by Hatzinikita, Koulaidis and Haznikitas (2005). In the 2005 study, fifth grade students (11 years old) were asked questions about "mixing salt with water; mixing hydrated copper sulphate with water; mixing an effervescent aspirin tablet with water; mixing blue alcohol with water; passing water vapour through dehydrated copper sulphate; and adding soda to a test tube containing hydrochloric acid" (Hatzinikita et al., 2005, p. 472). Their explanations were classified as 'agentive/ non-agentive', 'macroscopic/sub-microscopic' world and 'naturalistic/non-naturalistic'. Examples of students' responses are presented in Table 2.12.

Table 2.12: Examples of the chemical reaction classification (from Hatzinikita et al., 2005, pp. 474-478)

Classification	Examples of students' responses
Agentive/non-agentive	*"The soda melted because the acid makes the bodies melt, that's why the acid melted soda."*
Macroscopic/microscopic	"*the water became salty because the tiny, invisible pieces that salt became, were diffused throughout the water and gave it their taste."*
Naturalistic/non-naturalistic	*"The soda melted because acid is liquid and dissolves the solids."*

In Table 2.12, Hazinitika (2005) noted that students' 'agentive' reasoning used an agent to explain why acid melted soda. For example, students relate the action of an acid on the human body (i.e., the agent) as melting and transfer this understanding of melting to the reaction between an acid and soda. In the example for the 'macroscopic/sub-microscopic' view in Table 2.12, students tended to interchange between sub-microscopic and macroscopic view. Initially, they explained that water is salty, (i.e., macroscopic view), but later used words such as "invisible" indicating the particulate view (i.e., sub-microscopic). For the 'naturalistic/non-naturalistic' explanation, students tended to hold the idea liquids dissolve solids and concluded that an acid (i.e., commonly liquid in nature) dissolves the solid soda because students thought soda to be solids (Hatzinikita et al., 2005).

The examples provided in Table 2.11 and Table 2.12 indicated that there may be two types of causal reasoning. For example, Andersson (1986a) tended to view causal reasoning from the aspect of a relationship between agent and object, while Hazinikita et al. (2005) described causal reasoning from three different perpectives (i.e., 'agentive', 'macroscopic/sub-microscopic', or 'naturalistic') cause of change. For this thesis study, Andersson (1986a, 1986b, 1990) explanations of matter were used because the explanations have direct application in the context of acid-base concepts investigated.

To understand students' reasoning and possible causes of their reasoning, an investigation into students' explanations of their thinking patterns may provide insights into ways of their thinking. Such explanations are expressions of their thinking called *expressed models.* Interpretations of these expressed models are considered a means of determining students' mental representations (i.e., mental models). The nature of mental models is now discussed.

2.12 Mental Models

There are a number of definitions for mental models. Norman (1983) describes mental models as an individual mental construct, while Johnson-Laird (1983) says mental models serve as cognitive structures conceptualized by people, for the purpose of knowledge construction. Vosniadou describes mental models as "a special kind of mental representation, an analog representation, which individuals generate during cognitive functioning" (Vosniadou, 1994, p.48). Gilbert (2004) describes a mental model as an individual mental representation, constructed in an individual's own mind, either alone, or in a group with other individuals. In short, mental models can be considered as mental constructs or mental representations of how an individual perceives the way the world works. For the most parts, the authors agreed that a mental model is a mental representation constructed in the individual's mind.

Franco and Colinvaux (2000) described four characteristics of mental models. First, they are *generative* in nature, which means mental models allow humans to be predictive. Second, they involve *tacit knowledge* meaning the owner of the mental model may describe certain aspects of their mental model pertaining to learned experiences and not be fully cognisant of their complete knowledge which comprises both learned and personal experiences. Third, mental models are *synthetic* in nature, in that they consist of a simpler version of the target system (i.e. what it is we are trying to understand). As a simplified version of the target any representation is never a complete replication of what it represents (Franco & Colinvaux, 2000). Finally, mental models are *constrained* by the everyday experiences of people, limiting the range of mental models. Hence, the full range of any person's mental model would not go beyond the ideas that people have in general and as such sets a limitation to the comprehensiveness of personal mental models. For example, Vosniadou (1994) pointed out that children may believe that people live in all corners of the world and, thus, form the general belief that the earth is flat while in a scientific model Earth is spherical.

These four characteristics of mental models provide a framework for understanding how students learn by making links to prior knowledge to explain their observations which requires a re-construction in their minds (Greca & Moreira, 2001). This construction of knowledge encompasses many areas of study including acid-base chemistry to make sense of students' thinking. Two studies on students' mental models in acid-base chemistry are discussed to understand students' thinking in this area.

2.13 Mental Models in Acid-Base Chemistry

Two recent studies of students' mental models in acid-base chemistry were found in the literature. In the first Lin and Chiu (2007) study, three different mental models were revealed for Grade 9 (15 year olds) students in Taiwan: the Phenomenon acid-base model utilizing macroscopic properties, for example, toxicity to determine acidity or basicity of a solution; the Character Symbol model, using the quantity of H or OH in a chemical formula to determine the acidity and basicity; and the Inference Model which demonstrates the Taiwanese students' partially correct scientific explanations. In addition, a sub-model of the Inference model, called the Pithy Formula model was identified. In the Pithy Formula model, Taiwanese students were inclined to describe an algorithm to explain acidity and basicity. For example, adding strong acids to weak bases produces an acidic solution because the acid is strong. These three main mental models were revealed when the researchers investigated Taiwanese students' understanding of neutralisation and dilute weak acids and bases concepts.

In the other study by McClary and Talanquer (2011) involving American college chemistry students, four students' mental models were identified when an investigation was carried out into their understanding of acids and bases concepts. The four mental models were termed mental models A, B, C, and D. Students with Mental Model A held the view that certain atoms or functional groups determined an acid while students owning a Mental Model B explained acid strength by the number of hydrogen atoms present in the acid molecule. Owners of Mental Model C explained acids as substances that donate a proton, while students with Mental Model D determined acid strength by the number of lone pair electrons that an acid possessed. In contrast, this thesis study places the focus on students' mental models for six selected acid-base chemistry concepts which are: Macroscopic Properties, Neutralisation, Acid-Strength, Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding and how they relate to four acid-base models (i.e., the Phenomenological, Arrhenius, Brønsted-Lowry, and Lewis models).

The study of students' and teachers' mental models is important because it provides inside into their science knowledge and may inform pedagogical practices and curriculum design both in Malaysia and internationally, which is discussed next.

2.13.1 Mental Models for Teaching Science

Harrison and Treagust (1996) stressed that students' mental models can enhance science teaching if teachers consider what mental models students bring into the classroom (i.e., their prior knowledge). Taber (2008) claims that students' mental models can be assessed through relevant mediators. These mediators are people who are engaged in making meaning. For instance, a curriculum developer acts as a mediator by interpreting scientific models; the teacher acts as a mediator by interpreting curricular models; and students act as mediators by interpreting a teaching model. Taber (2008) argues that for these interpretations to occur, scientific, curriculum, teaching, and students' models need to be expressed in the form of a representation, termed an expressed model. These expressed models can be located at various sources, for example, a scientific model is represented in the scientific literature; a curricular model appears in a curriculum document; a teaching model is represented in the form of planning notes and teaching resources and answers; and the students' model is expressed in the form of assignments, written work, and test answers (Taber, 2008).

Taber (2008) adds that when a curriculum developer interprets the expressed model of a scientific model from the literature, they internalize the information and present the acquired knowledge as a curricular model based on their personal understanding. In other words, interpretation and internalization are processes that contribute to construction of mental models. In the next step, the expressed model of the curricular model (i.e., the curriculum statement) is interpreted and internalized by teachers in the form of a teaching model. The final step requires students to comprehend the expressed model of the teaching model (i.e., the teachers' pedagogy) and present their understanding of the knowledge as a student's model in their response to questions. Thus, it can be said that the information embedded in the curricular model is based on the curriculum developer's mental model; the knowledge in a teaching model is based on the teacher's mental model; and the knowledge encountered in the student's model is derived from the student's mental models. In short, these models can be viewed as layers of interpretation (Hume & Coll, 2010) of the original scientific model.

Two intermediary models exist between the scientific models and the student's model, that is, curricular and teaching models (Figure 2.24). For some students, this flow of knowledge may act either as a hindrance or a bridge in acquiring the appropriate target scientific knowledge.

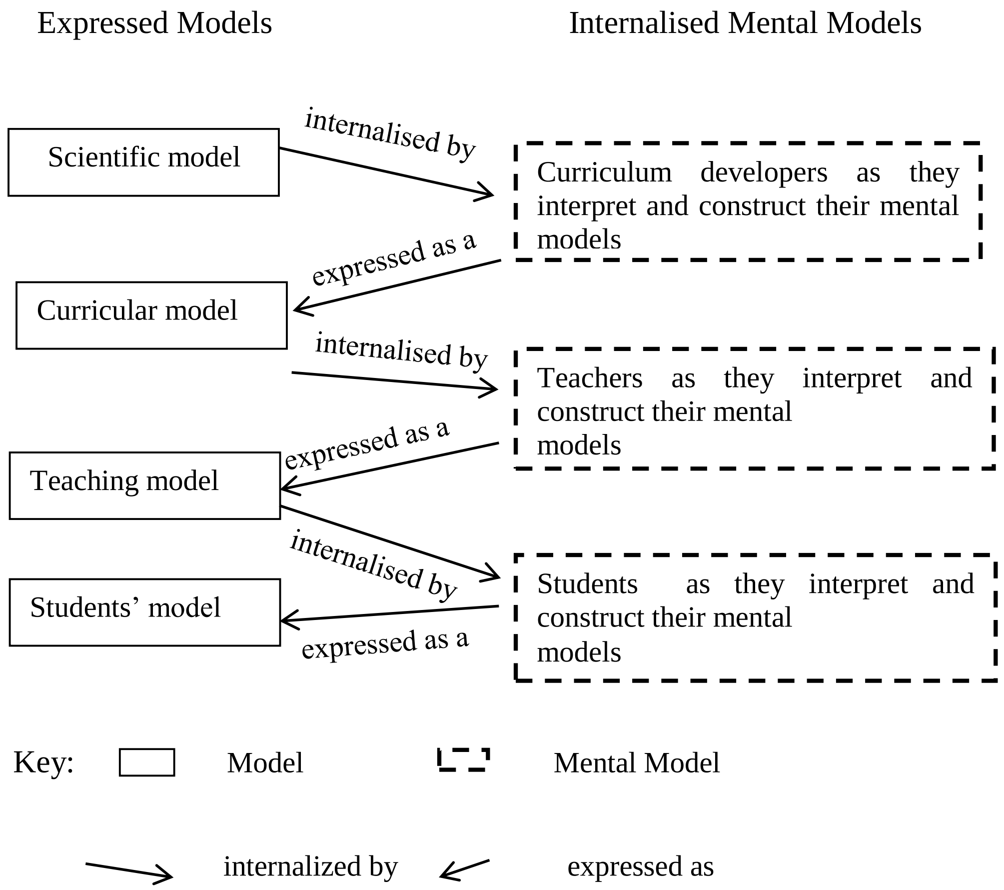

Figure 2.24: Mediation between scientific knowledge through curriculum design, teaching and learning (adapted from Taber, 2008)

The idea of knowledge transformation and the relationship between models and mental models as presented in Figure 2.24 could form part of a conceptual framework to interpret students' mental models, determine their understanding of chemistry concepts and how they acquired that understanding. For this thesis study, acid-base models are used to help students' to make connections with selected acid-base concepts to describe or understand. For example, the use of the Arrhenius model to explain Neutralisation and Acid-Strength concepts. This process of linking the acid-base concepts with the acid-base models is known as modelling, which is discussed next.

2.14 Models and Modelling

Models and modelling are widely used to engage students in developing scientific understandings (Chittleborough & Treagust, 2007). In science education modelling is a process involving a *target*, which is something we want to comprehend; a *source (analog)*, something we have acquired from our daily or prior experiences; and the *model*, which connects the source to the target (Duit, 1991). In other words, modelling involves identifying a relationship between target, and its source (Coll & Lajium, 2011).

Finding the relationship in modelling involves the linking of attributes of the analog via a model to key attributes of the target that students need to focus on. Attributes are considered as parts of a structure (Duit & Glynn, 1996) important when describing a phenomena or concept. This process avoids the learner being distracted by unimportant detail or attributes of the analog (Coll, 2006; Duit & Glynn, 1996). This linkaging is illustrated in Figure 2.25.

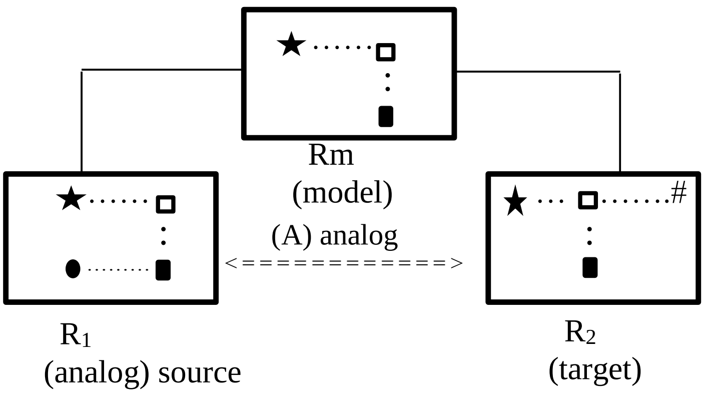

Figure 2.25: The meaning of analogy (from Duit, 1991, p. 148)

Figure 2.25, shows the relevant attributes are ★□▮, linked to the key attributes in the target via the model. The attribute ● is considered a distraction. The # symbol in the target represents new knowledge gained through learning. Thus, a model helps to restructure students' prior knowledge into a new form which is closer to a scientists' model.

Another form of modelling for science education was developed by Justi and Gilbert (2002). Their cyclic model of modelling is a process that involves multiple levels of thinking and action involving mental models (Figure 2.26) at the centre of the modelling framework. This modelling shows that an initial mental model goes through a refinement process that includes actions such as discarding, modifying, selecting, designing, and conducting of experiments to form a new mental model (Figure 2.26).

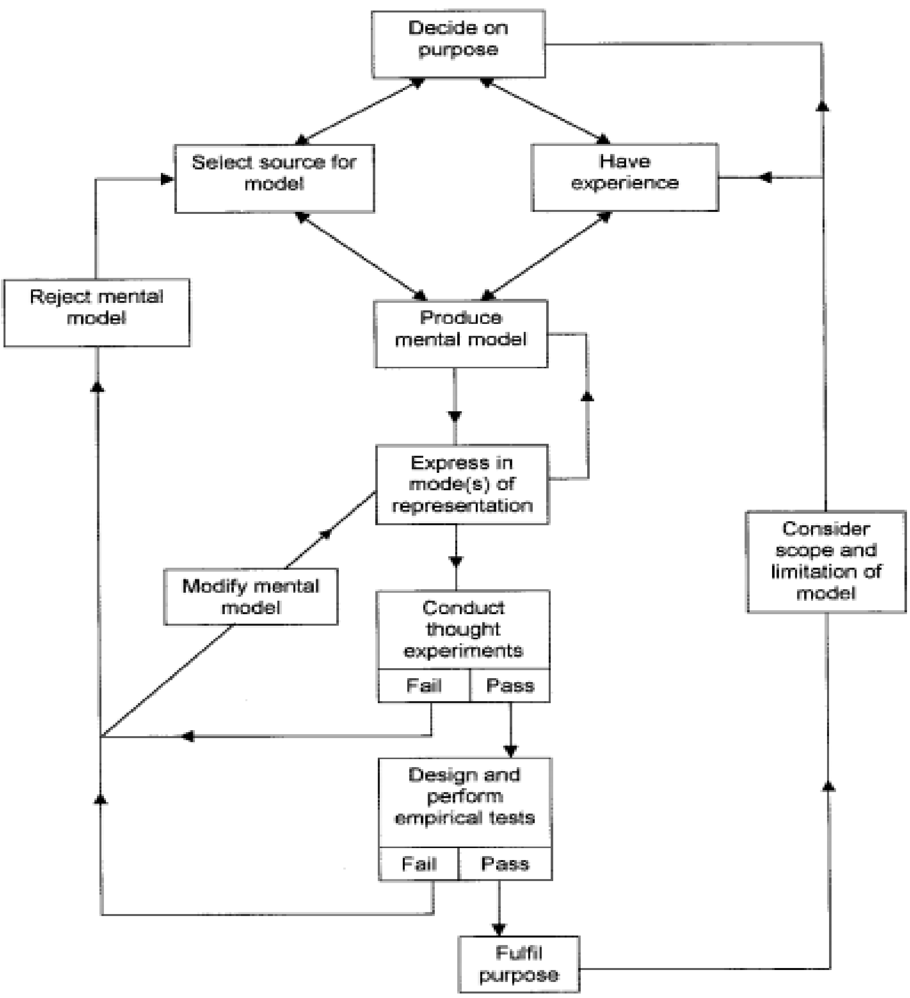

Figure 2.26: A model of modelling (from Justi & Gilbert, 2002, p. 371)

Lesh and Lehrer (2003) described a simpler modelling process comprising describing, explaining, predicting, and testing but there is no explicit mention of a mental model(s) being formed (Figure 2.27). In this 2003 model of modelling, a system was developed for a specific purpose similar called ‘end in view’. This modelling model predicts and tests goals and purposes, forming certain characteristics, themes or patterns which together forms the representational media or the model, used to describe or explain a system being is modelled.

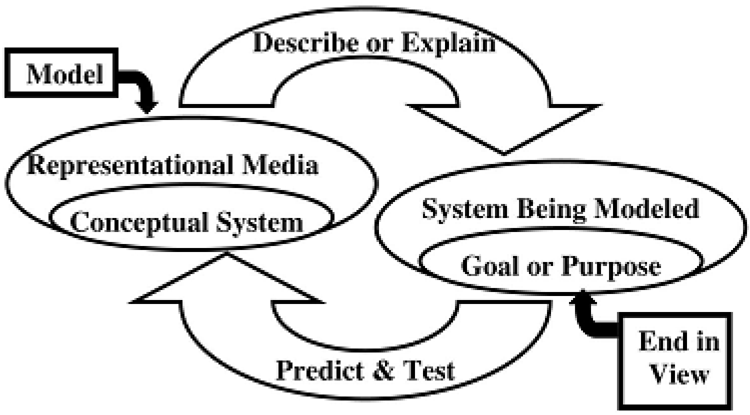

Figure 2.27: A modelling cycle (from Lesh & Lehrer, 2003, p. 112)

For this study, the concepts of modelling as depicted by Justi and Gilbert (2002) and Duit (1991) models in Figure 2.27 and Figure 2.26 appear most useful as frameworks for examining the modelling behaviours and mental models of students as they learn selected acid-base concepts.

To elaborate, utilizing the Duit (1991) model the acid-base models act as connectors or links between the prior knowledge (i.e., analog) and the six selected acid-base chemistry concepts (i.e., target). However, each of these acid-base models is not sufficient to explain all target knowledge. For this reason, multiple acid-base models are used to explain different targets. For example, at the particulate level, the Brønsted-Lowry model could not explain the acid-base reaction consisting of acidic oxides such as sulphur dioxide (SO_2) as there are no hydrogen atoms, and the Arrhenius model could not explain why water can be an acid or a base. Thus, the processes of identifying the attributes of analog and target undergoes constant changes and modification and results in students' mental models as proposed by Justi and Gilbert (2002). This cyclic process continues when other acid-base models are introduced. By utilizing all three acid-base models, students should be more capable of grasping a deeper understanding of acid-base chemistry. The nature of students' understanding can be identified by their use of models in explanations and their act of modelling, which requires skilful reasoning and can contribute to students' inability to transfer from one model to another model (Chittleborough & Treagust, 2007).

In spite of the confusion that may occur during modelling, it is important for students to have good modelling ability to acquire relevant scientific knowledge as the use of multiple models is necessary to acquire a complete understanding of a target.

Next, the conceptual framework for this study is presented.

2.15 Conceptual Framework

According to Shields and Tajalli (2006) a conceptual framework is a "map that gives coherence" (p. 313) to support a research study. Additionally, a conceptual framework acts as a link to the literature and help researchers to understand what is being investigated.

The main objective of the conceptual framework for this study is to provide a mean for assessing students' mental models. This assessment role is approached in two ways.

The first approach in identifying students' mental models starts with the selected acid-base chemistry concepts. Understanding selected acid-base chemistry concepts requires the use of the Phenomenological, Arrhenius, Brønsted-Lowry and Lewis models to explicate the six selected concepts termed target systems as shown in Figure 2.28.

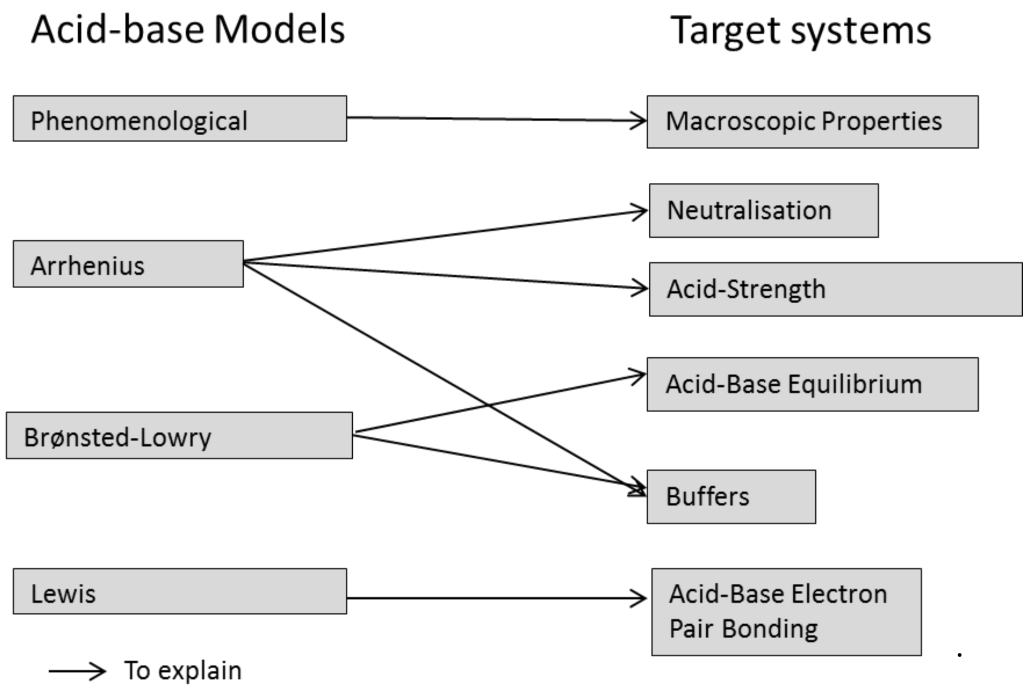

Figure 2.28: The explanatory relationship between acid-base models and the target system (i.e., six selected acid-base concepts)

The second approach is derived from the mediation process that models in science education (i.e., scientific, curricular, teaching, and student's model) go through as they are successively interpreted by participants. This process is depicted as a series of alternating expressed and mental models which can be viewed as layers of interpretation starting with the scientific model. Figure 2.29 below is a flowchart of how this investigation is executed.

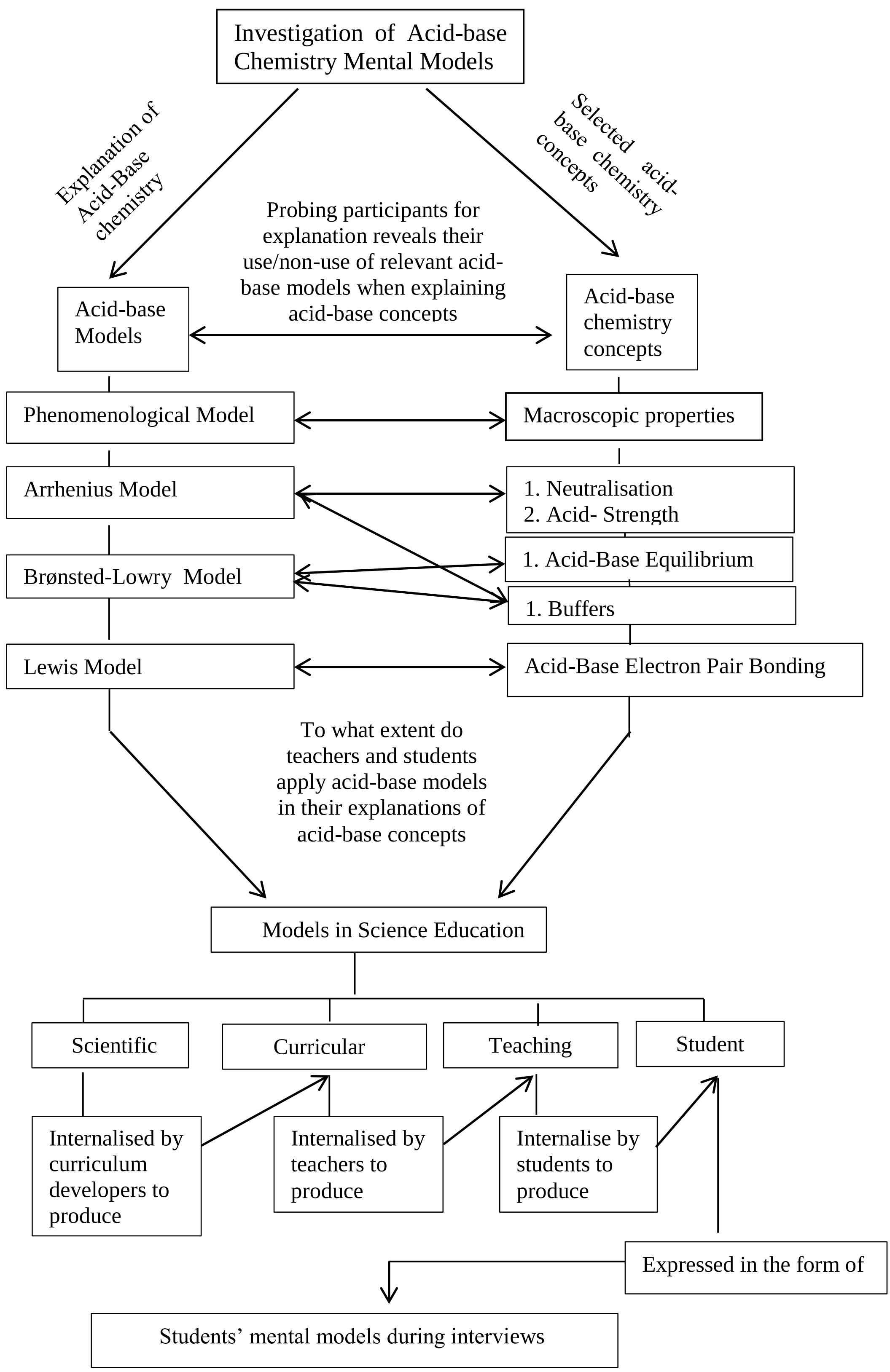

Figure 2.29: Conceptual framework for the study in a Malaysian context

Figure 2.29 shows diagrammatic linkages in the investigation of students' mental models beginning with the linkages between the six selected acid-base concepts and their relations to the four acid-base models. Next the linkages are connected to models in science which develops into layers of interpretation and forms the students' mental models. These linkages provided guidelines in conducting this thesis study.

This thesis study seeks to investigate whether students have acquired the knowledge embedded in the acid-base models to explicate the target systems. For example, the Phenomenological Model is able to explain acid and base macroscopic properties; the Arrhenius Model to explicate Neutralisation and Acid-Strength concepts along with aspects of Buffers concept and so on as indicated in Figure 2.28. Another important function of these four acid-base models is their ability to explain acid-base concepts at a macroscopic and at the sub-microscopic levels. The Phenomenological model can be used to explain acids and bases properties at the macroscopic level, while the Arrhenius model is used to explain at the general particulate level. The Brønsted-Lowry and Lewis models are used to explain acid-base chemistry concepts at the subatomic particulate level. The Arrhenius, Brønsted-Lowry and Lewis models may also be utilized at a symbolic level in chemical equations, chemical formulas and the titration curve (S shape curve).

This study takes the view that the presence of acid-base models linked to the selected acid-base chemistry concepts in students' responses to questions about acid and base behaviour may reveal students' mental models, and,therefore, the nature of their acid-base understanding.

To assess Malaysian students' mental models at three levels of schooling (i.e., Forms 2, 4, and 6), investigation of their use of acid-base models in explaining aspects of the selected acid-base chemistry concepts interviews was undertaken through semi-structured interviews to answer three research questions:

1. What are the attributes of students' mental models for selected acid-base chemistry concepts at given Malaysian levels of schooling in relation to their applications of the Phenomenological, Arrhenius, Brønsted-Lowry and Lewis models?
2. How can students' mental models for the six selected acid-base chemistry concepts be classified based on their attributes and used to identify students' mental models development at different stages of Malaysian schooling?
3. In what ways do the attributes of scientific models, curricular models, and teachers' and students' mental models for selected acid-base chemistry concepts compare at different schooling levels?

To answer Research Question One, the attributes (i.e., words/concepts/explanations used to show for understanding acid-base knowledge and chemistry concepts) of student's mental models in the areas above under investigation were identified. Research Question Two sought an understanding on the process of classifying mental models to identify the nature of mental models at different stages of schooling. Finally, comparing students' mental models with the curriculum developers and teachers' mental models (i.e., curricular and teaching mental models) will address Research Question Three.

2.16 Summary

Achieving scientific literacy curriculum goals is an important pedagogical task and understanding acid-base chemistry concepts is a challenging endeavour. The constructivism theory of Piaget and Vygotsky, combined with the Information Processing Theory provides the researcher with appropriate learning theories to underpin this study. From the review, a number of possible reasons why learning chemistry is a difficult process has emerged. One of these difficulties is caused by students' inability to shift between the three levels of representations which are the macroscopic, sub-microscopic and representational levels (Johnstone, 2006; Nakhleh & Krajcik, 1994). This inability hinders students' learning of acid-base chemistry because shifting between the three levels is necessary when using appropriate acid-base models to describe or explain the six selected acid-base concepts. For example, explaining the Neutralisation concept using the Arrhenius model in the context of titration requires thinking at the macroscopic, sub-microscopic, and representational levels. When students find difficulty learning chemistry, their reasoning underpinning their explanation may not be scientifically accepted and misconceptions can form. An overview of students' existing misconceptions about the selected acid-base concepts was gathered from the literature and presented. Finally, students' use of the acid-base models in explaining the six selected acid-base concepts together with the inclusion of the layers of interpretation provided the conceptual framework for this thesis study. The conceptual framework provided direction for identifying students' mental models.

The need for the theoretical basis underpinning the research and the research methodology for this investigation into students' mental models is discussed in the next chapter.

Chapter 3. Methodology

3.1 Overview

Chapter three describes the methodology underpinning this research. As with any research, a theoretical basis is important to support the inquiry because it creates a framework around which the research takes form. This framework provides a connection between data collection methods, research questions, data analysis and interpretation (Denscombe, 2010). The first section in this chapter identifies the theoretical perspective or paradigm guiding this inquiry followed by a detailed discussion of the research methods and data collection. Next, the development of the interview protocol along with the procedure used for the interviews is described. The chapter concludes with trustworthiness and ethical considerations. Next, a brief explanation of the relationship between research, methodology and research design is discussed.

3.1.1 Research, Methodology and Research Design

According to Mertens (2010) *research* is:

> one of many different ways of knowing or understanding. It is different from other ways of knowing, such as insight, divine inspiration, and acceptance of authoritative dictates, in that it is a process of systematic inquiry that is designed to collect, analyse, interpret, and use data. (p. 2)

Methodology is an overall strategy for resolving the complete set of choices or options available to the inquirer (Guba & Lincoln, 1989). In other words *methodology* is the approach that the researcher takes to answer questions while the term *research designs* means "plans and procedures for research that span the decisions from broad assumptions to detailed methods of data collection and analysis" (Creswell, 2009, p. 3). These three terms (i.e., *research*, *methodology*, and *research design*) are phrases important in any study, closely related but distinct terms.

Next, the term paradigm is explained.

3.1.2 Paradigm

The term "paradigm" originally was used by Thomas Kuhn to refer to the theoretical framework of a study which is a "a set of philosophical assumptions about the nature of the world (i.e., ontology) and how we can understand it (i.e., epistemology), assumptions that tend to be shared by researchers working in a specific field or tradition (Maxwell, 2008, p. 224). Paradigm is also known as a "basic set of beliefs that guides action" (Guba, 1990, p. 17). These basic beliefs are considered to be general perceptions about the nature of the world and how certain researchers perceive it (Creswell, 2009).

Cohen, Manion, and Morrison (2011) identified two types of paradigms predominantly used in education research known as *positivism* and the *interpretive* paradigms. A key feature in the *positivism* paradigm is the focus on behaviour, which are responses either to external environment stimuli (e.g., another person), or internal stimuli (e.g., hunger, need to achieve). In addition, the normative paradigm synthesizes general theories from observations that are generated by a group of people rather than an individual, looking for patterns across large numbers of participants. In contrast, Cohen et al. (2011) point out that the *interpretive* paradigm focuses on the individuals and seeks to comprehend individual experiences. Thus, in the *interpretive paradigm* theories are created from the individuals' actions. In other words, theories are developed after research is done as opposed to the positivist paradigm where research is based on existing theories. In addition, the interpretive researcher seeks to understand the time and place where an action occurs.

The beliefs describing paradigms are based on three fundamental philosophical assumptions; ontological, epistemological, and methodological. The nature of reality is referred to as ontology and there are two perspectives in ontology -the realists and relativists (Neuman, 2011). Neuman (2011) described the realists as assuming that the world exists and is waiting to be discovered, while the relativist adopt the idea that world is viewed through the lens of an interpreter subject to his or her understanding and experiences. Epistemology is considered as “ways of researching and enquiring into the nature of reality and the nature of things” (Cohen et al., 2011, p. 3) an area that pertains to knowledge creation (Neuman, 2011) and the finding of answers to questions. A realist views epistemology as accepting or rejecting knowledge based on empirical evidences from observations using laws and theories to verify knowledge. Neuman (2011) argues that relativists believe observations do not provide knowledge because interpretations of the observations are subjected to the interpreter’s experience and understanding. Finally, methodology, introduced in Section 3.1.1 is the term used to describe how to go about finding what one believes can be known (Guba, 1990). For example, a positivist researcher seeks to investigate reality from the objective and to control factors in either qualitative (e.g., observational) or quantitative (e.g., statistical analysis) approaches to pursue reality (Guba & Lincoln, 1994; Lincoln, Lynham, & Guba, 2011). In contrast, an interpretive researcher seeks to pursue the reality from the perspectives of participants and using a methodology that allows participants to express their understanding (Lincoln et al., 2011; Schwandt, 1994). The relationship between ontology, epistemology, methodology, and what it means is illustrated in Figure 3.1.

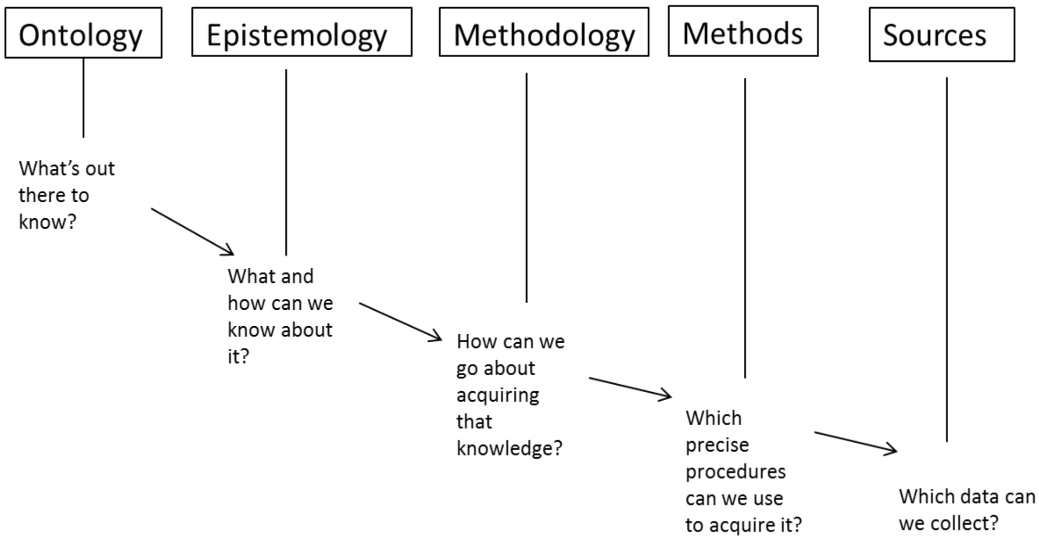

Figure 3.1: The interrelationship between the building blocks of research (from Grix, 2010, p. 68)

The next section discusses the first paradigm which is positivism.

3.1.3 Positivism

According to Neuman (2011) positivism was founded by the Frenchman, Auguste Comte in the eighteenth century, who described events happening in a worldview (i.e., general perceptions of people) derived from observations in a natural setting leading to the discovery of theories and laws (Denzin & Lincoln, 2011). In the positivist paradigm these theories and laws function to regulate the world and are continuously tested empirically to validate observations gathered from the events in worldview (Creswell, 2009). In other words, the observations can be validated using scientific methods based on experiments and laws (Cohen et al., 2011; Mertens, 2010; Neuman, 2011).

Thus, positivists adopt a methodology that includes testing hypotheses using quantitative data from experiments and analysing them through empirical measures which are carefully manipulated to prevent unnecessary influence on the result (Guba & Lincoln, 1994). The quantitative data undergoes statistical tests and procedures to check validity and reliability (Denscombe, 2010). Thus statistical tests and procedures may be used to formulate laws and theories in order to understand behaviour (Cohen et al., 2011).

The positivists assume a realist ontology, where they perceive reality exists and will be exposed in due time (Mertens, 2010). Reality, for positivists, has certain traits and is governed by the laws of nature. Denscombe (2010) points out that these traits form patterns and positivists believe these patterns are not invented but discovered by researchers.

From the epistemological perspective, positivists believe that facts deduced from observations are different from ideas and theories because facts are derived using sensory organs (e.g., sight, smell, hearing, and touch) but theories and ideas may exist as an abstract (Lincoln et al., 2011; Neuman, 2011). Also, positivists are considered to be objectivists because they embrace a dualist approach where the researcher and the research are independent of each other (Guba & Lincoln, 1994).

In the following text, the interpretive paradigm is described.

3.1.4 Interpretive Paradigm

Interpretivism is a paradigm in social research including education research, which is concerned with "making meaning" (2010, p. 16) and seek to understand the complicated world of lived experience from the perspective of people who lived in it and how they develop their comprehension of the world (Perri & Bellamy, 2012; Schwandt, 1994). According to Denzin and Lincoln (2008), research in science education or science traditionally uses quantitative methods including mathematical models, statistical tables, and graphs from which researchers are able to generalize the research findings. They added, however, it is now common for interpretivists inquiries in science education to use qualitative methods which are gaining acknowledgement.

In this study, the researcher adopted the interpretive paradigm, as its theoretical framework since this inquiry involves understanding and interpreting students' and teachers' mental models of selected acid-base chemistry concepts. Thus, the researcher undertook to comprehend what these concepts represent and how the process of meaning making is developed. The researcher sought to probe concepts (such as the Neutralisation concept) using interviews, which involves individual interpretations/perspectives and personal involvement of the researcher as a tool to gather data. As a result, the researcher sought to understand the individual, and the world around the individuals similar to how constructivists work, that is, through experiences gathered from individuals and theory building (Cohen et al., 2011). The next three paragraphs elaborate of the nature of the interpretivist paradigm to illustrate how well aligned this paradigm is to this study.

The interpretivists adopt a relativist ontology which claims "there is no possibility of achieving an account independently of the ways that we observe, recognise, classify, code, and analyse our observations. In other words the truth is relative to any framework within which we collect and analyse data" (Perri & Bellamy, 2012, p. 55). Additionally, the constructivists believe that reality is socially made and produces many mental constructions which may be in conflict with one another (Lincoln et al., 2011; Mertens, 2010). For example, the concepts of disability and feminism may have different meanings to different people.

Interpretivists believe in a subjectivist epistemology where the researchers and participants interact and influence each other (Lincoln et al., 2011; Schwandt, 1994), for instance, interaction between interviewers and interviewees during interviews (Mertens, 2010).

Methodology in interpretivism uses a dialectic approach which involves a logical argument when comparing and contrasting, eventually forming new knowledge (Guba, 1990). Interpretivists believe the construction of knowledge occurs through interaction between researchers and respondents commonly using qualitative methods such as observations, and document analysis (Mertens, 2010).

However, one of the disadvantages of interpretivism is subjectivity where the researcher and the participants are one body or entity (Scott & Usher, 2011). In interpretivism, researchers interpretate actions to make meaning, through " shared and constructed nature of social reality" (Scott & Usher, 2011, p. 29) to form an entity. This one body or entity between the researcher and the participants in any investigation may influence the findings because there is no separation between subjects and objects (Denscombe, 2010).

This thesis study, considered a cross sectional study, is discussed in the next section.

3.1.5 A Cross Sectional Approach

According to Coll (1999) many investigations into student's conceptions in science education occur at a certain period in time. A cross sectional inquiry is where the investigation involves participants of different age groups such as ages 14, 16, and 18. A longitudinal study in contrast involves participants over a period of time. For example, following students from Form 1 to Form 6 (i.e., ages 14 through to 18). In comparison a longitudinal study is often undertaken over many years and frequently involves low numbers of students. A cross sectional study usually involves students of different ages or age ranges at a fixed point in time and can involve large number of students. Coll (1999) says cross age inquiries have some advantages over longitudinal inquiries, as they are conducted in a given period of time, but notes that they it cannot be used to provide information about an individual student's development. However, evidence from cross age studies of students' conceptual understanding in science over a number of school years may provide useful insights into curriculum planning (Driver, Leach, Scott, & Wood-Robinson, 1994).

This study has taken a cross sectional approach, by investigating students of different ages at three levels, (i.e., Forms 2, 4, and 6) respectively and the data collection was conducted over a period of five months. This choice of approach was made because the study seeks to inform science curriculum planning in Malaysia and time for data gathering was limited for a longitudinal study, which may take years of data collection (i.e., from Form 2 to Form 6). The focus of this cross sectional study is on students' mental models in acid-base chemistry concepts at Forms 2, 4 and 6, and the following three research questions were explored using the data sources as presented in Table 3.1.

Table 3.1: Research questions and sources of data

Research Question	Sources of Data
1. What are the attributes of students' mental models for selected acid-base chemistry concepts at given Malaysian levels of schooling in relation to their applications of the Phenomenological, Arrhenius, Brønsted-Lowry, and Lewis models?	Semi structured interviews
2. How can students' mental models for the six selected acid-base chemistry concepts be classified based on their attributes and used to identify students' mental models development at different stages of Malaysian schooling?	Semi structured interviews
3. In what ways do the attributes of scientific models, curricular models, and teachers' and students' mental models for selected acid-base chemistry concepts compare at different schooling levels?	Semi structured interviews Document analysis e.g., Malaysian Curriculum Specifications Guide

The first research question explored students' mental model attributes for six selected acid-base chemistry concepts. The second research question examined students' use and non-use of acid-base model attributes to classify students' stages of mental model development while the third investigated students' mental models and their degree of alignment with the teachers' mental models and the curricular model.

The next section describes the Malaysian context of the study.

3.1.6 The Malaysian Context

Science in Malaysia is taught in primary schools from Standard One to Standard Six (7 - 12 years old) and secondary schools from Form One to Form Three (13 - 15 years old). At Form 4, science is categorized into pure science and science.

Pure science students take biology, chemistry and physics, while other students study science.. At primary and lower secondary levels, science as a subject is compulsory for all; however, at the upper secondary levels, students are streamed into science or arts classes based on the Form 3 public examination results. If their science and mathematics results are excellent (i.e., obtaining an A or a B in the Lower Secondary Examination), students are offered a position in a pure science class, otherwise they undertake normal sciences. Form 4 students in pure science classes are required to undertake chemistry, physics, and biology along with other languages and mathematical subjects (Table 1.1).

The sample for the study is now discussed.

3.1.7 Sample for the Study

The participants comprising teachers and students consisted of 24 students and six teachers in four different schools in Malaysia (Table 3.2). The Lower secondary (Form 2) and Upper secondary (Form 4) students interviewed were from two of the secondary schools near to where the researcher lives while the Form 6 students interviewed were from the two secondary schools offering Sixth Form studies. The content for this science programme is mandated by the Malaysian Curriculum Specifications Guides which is an outcome based curriculum. Further information about this curriculum is given in Tables 6.1, 6.3, and 6.5. For this thesis study, students were randomly selected from a number of students who volunteered to participate in the thesis study. All selected students had previous experience of learning aspects of acid-base chemistry at their respective levels of schooling, which is significant when considering their mental models because a student may use this knowledge in explaining relevant acid-base chemistry concepts at their current level of schooling (Table 3.2).

Table 3.2: Sample in the cross-age study

Schooling level	Student level	Age	Students' prior knowledge	Students sample	Teacher sample
Lower secondary	Form 2	14	Primary	8	2
Upper secondary	Form 4	16	Lower secondary	8	2
Pre-university secondary school	Form 6	17	Upper secondary	8	2

Forms 3, 5, and Upper 6 (pre-university) levels were not participants in this study because permission could not be granted to interview them as they were required to focus on external public examinations at these levels.

In section 3.1.8, the data collection methods are discussed.

3.1.8 Data Collection Methods

Data collection took place over a period of five months at four schools in Selangor, Malaysia. The data sources were interview transcripts, and documents such as curriculum documents presented in Table 3.3.

Table 3.3: Methods of data analysis

Information being sought	Method	Source
Students' mental model	Interview	Student interview transcripts from different schooling levels
Teachers' mental model	Interview	Teachers interview transcripts
Curricular model	Content analysis	Malaysian curriculum specifications guide and Syllabus and Specimen Papers

To investigate students' and teachers' mental models, interviews with teachers and students were performed and their transcripts analysed, while the curricular model was identified by examining the Malaysian Curriculum Specifications Guide for Forms 2 and 4 and the Syllabus and Specimen papers for Form 6.

The next section discusses the qualitative data collection method.

3.2 Qualitative Data Collection Method

Mertens (2010) reports that qualitative research utilizes the researcher as a tool to collect data rather than, for example, using questionnaires in a quantitative research project. The data collection methods in qualitative research are typically observations and interviews. Observation allows the researcher to be in direct contact with participants in the investigated setting and to execute an in-depth analysis. However, for this study no classroom observation data could be gathered as the teaching and learning of relevant acid-base chemistry concepts were done prior to the researcher's data collection period. Form 2 students studied the acids and bases topic in the month of April while the Form 4 and Form 6 students in May.

In the following text, the nature of interviews in science education is briefly described.

3.2.1 Interviews in Science Education

An interview in qualitative research is an inter-action between an interviewer and an interviewee to build knowledge. It frequently involves an interchange of perspectives through discussion on a related matter (Kvale, 2007). The interview technique can be used to ascertain participants' spontaneous comments, thus, allowing the researcher deeper insights into the phenomenon being investigated (Patton, 2002). Posner and Gertzog (1982) termed such interview techniques, which investigate participants' cognitive structures and conceptual change as 'clinical interviews'. Such techniques are highly pertinent to this study which investigates students' mental models in chemistry.

The interview techniques used in this thesis study are now described.

3.2.2 Interview Techniques

Interview techniques in an interpretive inquiry require "good questions that should, at a minimum, be open-ended, neutral, singular and clear" (Patton, 2002, p. 353). Open-ended questions permit the respondents "to select from among that person's full repertoire of possible responses" (Patton, 2002, p. 354). The qualitative interviewer needs to ask unambiguous questions and tries to avoid rare terminologies, which the interviewee may not know to avoid confusion and enhance clarity. A good way to improve clarity is to pose singular questions in order for the interviewee not to be confused about which question to answer and for the interviewer to have less difficulty interpreting the interview data (Coll, 1999).

The above interview approach allows analysis in areas of particular interest, permits the interviewee to speak freely, and the interviewer to check the interviewees' remarks continuously to reveal important information. To obtain relevant data, the interview must take place in a relaxed atmosphere. Responses from the interviewer should not criticise nor commend, and interviews must proceed at an appropriate pace to ensure the participants do not feel disturbed or that their opinions are not valued (Coll, 1999; Posner & Gertzog, 1982; White & Gunstone, 1992).

Although investigations into participants' mental models may use various techniques and strategies, most studies have used interviewing as the basic method of data collection. Interviews offer researchers data that cannot be directly observed, allowing the researcher access to the interviewees' perspective on a particular phenomenon. Semi-structured interviews are favoured when exploring participants' perspective of concepts because the researcher is given more "flexibility" (Cohen et al., 2011, p. 414) to probe for a deeper understanding when required to, while simultaneously acting as a guide or an outline of topics to be covered in the interview and suggested questions (Kvale, 2007). In addition, students were also encouraged to use words, equations and drawings to help explain their ideas.

In this thesis study the researcher used the Interviews About Instances (IAI) and Interviews About Concepts (IAC) methods to probe participants understanding of knowledge and concepts, which are described in the next section.

3.2.3 Interviews About Instances and Interviews About Concepts

In order to elicit participants' understanding of concepts, various approaches can be used in science education. One approach mentioned by White and Gunstone (1992) includes the Interview-About-Instances method (IAI), which is essentially a conversation that the researcher has with one participant about specific instances to do with the phenomenon under study. The focus in the conversation is provided by initial questions about situations, scenarios or phrases to determine the participants' ability to recognize the presence of a scientific concept or the participant's interpretation of a natural phenomenon or social occurrence. The Interview-About-Concepts (IAC) method is used to expose further information that a person has about a specific concept. IAI and IAC can both allow a deep probe of participants' understanding of a particular concept present in specific instances, and the ability of the participant to explain their understanding which reveals the nature and depth of participants' understanding. An example of the application of the IAC technique could occur in an investigation of participants' understanding of velocity and acceleration concepts, where participants are asked to explain what velocity and acceleration means and if there is any relationship between them. For instance, students might be asked to define the two terms and discuss, using examples, how velocity and acceleration are different. This distinction could be described using a distance versus time graph and/or velocity versus time graph. In a distance versus time graph the slope indicates the velocity of an object and in a velocity versus time graph the slope indicates acceleration. The purpose of the IAC is to extract as much information about a concept as possible from participants..

For the purpose of this inquiry, both the IAI and IAC methods were used with the IAI method being used first. For example, students were asked ‘What do you understand by Acid-base Equilibrium?’ After receiving initial responses from participants, they were then given Question Cards that consisted of statements related to an acid-base concept under study with an accompanying question(s). These cards were shown to the participants and discussed (i.e., the IAC method). The advantages of using such interviews in mental models studies are that they are a flexible tool for gathering data, which can be captured via audiotaping or field notes. For this study, interviews were conducted individually and audiotaped, and participants were encouraged to discuss and write as much as they could based on the scenarios on the Question Cards. The writing stategy allowed the interviewees to begin expressing their mental models, which gave the researcher prompts to probe further. The participants were then probed on their responses and all interviews were transcribed verbatim.

Next, the development of the interview protocol is discussed.

3.3 Development of Interview Protocol

In this thesis study, the IAI and IAC approaches were used to investigate the mental models of participants based on attributes (i.e., criterial attributes) or important key terms and phrases found in the national curriculum for the selected acid-base concepts that characterised the anticipated learning of the students. For students the protocol varied slightly depending on the schooling level of the student being interviewed with deeper and more challenging questions for Form 6 students. For the teachers, informal and unstructured interviews were used to help understand how their teaching was aligned with the curriculum document. The interview questions were established with input from two experienced Malaysian school chemistry educators and a university chemistry lecturer. The two teachers verified that the questions asked were appropriate for what was being learned in school while the chemistry lecturer verified a set of responses to the questions that were similar to how scientists understand them.

For this research, the semi-structured interview took place in three distinct phases: the briefing phase at the beginning, the main phase, and the debriefing phase at the end (Kvale, 2007). In the briefing phase the researcher explained the purpose and the procedure of the interview. Students were then asked which science topics they like to learn, whereas teachers were asked which science or chemistry topics that they liked to teach. Students and teachers were also asked for their permission to use the tape recorder for research purposes. In the main phase participants were asked questions about the six selected acid-base chemistry concepts, and acid-base models such as the Brønsted-Lowry and Lewis models. During the debriefing phase students and teachers were again informed about their consent for tape recorded materials to be used in research. The debriefing continued after the tape recorder was turned off to maintain a good relationship with participants. The interview guide is presented in Appendix E. Later, the interviews were transcribed in full. The sources of the interview questions about the selected acid-base concepts are presented in Table 3.4. Note: Some probing questions have been devised and used by other researchers while other questions were designed specifically for this study.

Table 3.4: Sources for the developed Question Cards

Form	Question Card	Acid-base chemistry concepts	Sources
2	1	Macroscopic Properties	Boz (2009)
	2	Macroscopic Properties	Developed by researcher
	3	Neutralisation	Adapted from Ouertatani, Dumon, Trabelsi, and Soudani (2007)
	4	Neutralisation	Ng, Muhammad, Munasib, and Lee (2012)
4	1	Macroscopic Properties	Boz (2009)
	2	Macroscopic, Arrhenius	Developed by researcher
	3	Neutralisation	Adapted from Ouertatani et al.(2007) Ng et al., (2012)
	4	Neutralisation	Adapted from Boz (2009)
	5	Neutralisation	Developed by researcher
	6	Neutralisation	Ng et al., (2012)
	7a	Acid Strength	Adapted from Boz (2009)
	7b	Acid Strength	Coll (2008b)
	7c	Acid Strength	Adapted from Boz (2009) Carlton (1997)
6	1	Macroscopic Properties	Boz (2009)
	2	Macroscopic, Arrhenius, Brønsted-Lowry, Lewis	Developed by researcher, CH_3COO^- from Demerouti , Kousathana, and Tsaparlis (2004)
	3	Neutralisation	Adapted from Ouertatani et al. (2007)
	4	Neutralisation	Adapted from Boz (2009) and Ng et al., (2012)
	5	Neutralisation	Ng et al., (2012) Demerouti et al., (2004)
	6	Arrhenius, Brønsted-Lowry, Lewis	Adapted from Demerouti et al., (2004), Zumdahl and Zumdahl (2003, p. 698)
	7a	Arrhenius	Adapted from Zumdahl and Zumdahl (2003)
	7b	Brønsted-Lowry	Adapted from Zumdahl and Zumdahl (2003)
	7c	Lewis	Adapted from Zumdahl and Zumdahl (2003)
	8a	Acid-Strength	Adapted from Boz (2009)
	8b	Acid-Strength	Adapted from(Demerouti et. al., (2004)
	8c	Acid-Strength	Adapted from Boz (2009) and Carlton (1997)
	9a	Acid-Base Equilibrium	Sesen and Tarhan (2011)
	9b	Acid-Base Equilibrium	Sesen and Tarhan (2011)
	10	Acid-Base Equilibrium	Adapted from Boz (2009) and Hinton and Nakhleh (1999)
	11a	Buffers	Sesen and Tarhan (2011)
	11b	Buffers	Sesen and Tarhan (2011)
	11c	Buffers	Sesen and Tarhan (2011)

The next section discusses the focus of the interview.

3.3.1 Focus of the Interview

The interview used four acid-base models, that is, the Phenomenological, Arrhenius, Brønsted-Lowry and Lewis models as a framework for the interrogation and probing of participants' mental models for the six selected acid-base chemistry concepts under investigation.

In the interview the Macroscopic Properties, Neutralisation, Acid-Strength, Acid-Base Equilibrium and Acid-Base Electron Pair Bonding concepts are referred to as the target systems (i.e., what it is we are trying to understand) while the models are the Phenomenological, Arrhenius, Brønsted-Lowry and Lewis acid-base models (see Figure 2.28, previous).

The rationale for the relationships indicated in Figure 2.28 rested on the anticipation, for example, that the Phenomenological model would be used by students and teachers to explain the Macroscopic Properties concept of acids and bases such as acids are sour. Similarly, it would be expected that: Form 4 students and their teachers used the Arrhenius model to explain the concept of Neutralisation; Form 4 and 6 students and teachers demonstrate use of the Arrhenius model for explaining the Acid-Strength concept; and at Form 6 schooling level students and teachers use the Brønsted-Lowry model to explain the Acid-Base Equilibrium and the use of the Brønsted-Lowry and Arrhenius models to explain the Buffers concepts while the Lewis Model would be applied to the Acid-Base Electron Pair Bonding concept.

The following section introduces the notion of criterial attributes as key characteristics of expressed models.

3.3.2 Criterial Attributes

Criterial attributes in this study are important key terms and phrases found in the national curriculum for the selected acid-base concepts that were the focus of the study and can be used to determine the nature of students' and teachers' mental models in a mental model study. These criterial attributes once identified from students' and teachers' responses in interviews and examination of curricular documents were used to categorise types of mental models and provided a means of mapping students' mental model development over time and understanding teachers' mental models in acid-base chemistry.

Table 3.5: Key terms and phrases for six selected acid-base chemistry concepts from the national curriculum

Schooling levels	Macroscopic Properties	Neutralisation	Acid-Strength	Acid-Base Equilibrium	Buffers	Acid-base Electron Pair Bonding
Form 2	acid base taste litmus paper reaction with metals	salt water pH				
Form 4	acid base taste litmus paper reaction with metals	salt water H^+ ions OH^- ions titration monoprotic diprotic pH end point	degree of dissociation pH value			
Form 6	acid base taste litmus paper reaction with metals	salt water H^+ ions OH^- ions titration monoprotic diprotic pH end point	degree of dissociation pH	pH K_a common ion effect conjugate base conjugate acid K_b	pH K_a common ion effect conjugate base conjugate acid K_b	

Note: No description of key attributes were found in the Acid-Base Electron Pair Bonding concept

Table 3.5 shows the criterial attributes obtained from the expressed curricular models for each of the target systems i.e., the Malaysian Specifications Curriculum Guide for Forms 2 and 4 and the Syllabus and Specimen Papers for Form 6.

The next section discusses how data analysis was carried out.

3.3.3 Data Analysis of Students' and Teachers' Responses to Probe Questions

For analysis students' and teachers' transcripts were converted into a table format and initial coding was performed by examining their responses for indications of their understanding of the selected acid-base chemistry concepts. For the purpose of analysing, the researcher used the La Pelle (2004) method of qualitative data analysis. In this method La Pelle used the Microsoft Word Table as a software tool in order to analyse qualitative data gathered from interviews with students and teachers. In the first phase, the gathered participants' responses were formatted into a layout presented as an example in Table 3.7. The second phase involved the development of the codebook Table 3.6. A codebook is a Microsoft Excel table format that contained three levels of themes, and their respective numbers created by the researcher.

Table 3.6: Analysis codebook

Level 1	Level 2	Level 3	Themes
2.000			General opinion about tastes
	2.050		Acid tastes sour
		2.055	Acid tastes sour and acidic

Table 3.6 shows for example, in level 1, the code 2.000 is assigned for 'general opinion about tastes'. In level 2 'acid tastes sour' is assigned the code 2.050 while 'acid tastes sour and acidic' is assigned the code 2.055.

In the third phase, the participants' responses were assigned with number codes obtained from the codebook. The process of assigning the numbers is called the coding process.

Table 3.7: Data table for transcribed interviews with assigned numerical

Participant Name	Theme Code	Researcher Question/Participant Response	Sequence #
Researcher	1.000	Q1. What comes to your mind when you think about acids and bases?	1
SF2a	2.050	Perform their characteristic in water, acid/alkaline are not in pH 7, acid tastes sour, alkaline taste bitter, acid is corrosive	2
SF2b	3.050	Acid is a solution. If the acid is in high pH value it can make the hand break. Acid in pH value is less than 7. If we test on litmus paper, it will change colour from blue to red. For example, lime water , oranges, and pineapple is acid	3

Table 3.7 shows that the phrase "acid tastes sour" was uttered by student SF2a and assigned the code 2.050 because the response "acid tastes sour" was identical with the theme 'acid tastes sour' in the codebook . This process is repeated for all 30 responses from interviews. In addition, the # (i.e., sequence) shown in the last column of Table 3.7 shows the order of utterances as the interview progressed according to questions and responses. The coding sequences provide a systematic way to identify each participant's response for reference purposes.

Ideally, coding and recoding are necessary to ensure consistency and coverage of codes and data (Cohen et al., 2011). This step enabled retrieval and categorization to be consistent. Emergent themes were continuously compared for similarities and differences, which led to the construction of grounded theory and themes that emerged naturally from the data (Marshall & Rossman, 2011). In addition, the researcher constantly checked the data to ensure it fitted the conceptual framework provided by the anticipated learning of the curricular documents.

For Research Question 1 and 2 students' responses in the interviews unveiled students' mental models, but for Research Question 3 curricular documents and and teachers interview responses revealed two further models (i.e., curricular models and teachers' mental models). The Malaysian Curriculum Specification Guide for Forms 2 and 4 and the Syllabus and Specimen Papers for Form 6 (the expressed curricular models) were closely examined while teachers' interview statements revealed the teachers' mental models (Table 3.8). The Syllabus and Specimen Papers contained within them the learning outcomes and one sample of the exam paper.

Table 3.8: Models and its sources

Models	Source (expressed models)
Students' mental model	Students' interviews
Teachers' mental model	Teachers' interviews
Curricular model	Curriculum and Specifications Guide

In section 3.4, measures taken to maintain trustworthiness are now explained.

3.4 Measures Taken to Maintain Trustworthiness

In an interpretivist inquiry, the researcher needs to use data collection methods in a natural setting and so use methods such as interviews and document analysis to ensure what Guba and Lincoln (1989) called trustworthiness. Trustworthiness refers to the quality or robustness of the research procedures of the interpretive researcher when addressing issues such as the credibility, dependability, confirmability, and transferability of the findings. The following sections explain how these issues were addressed in this study beginning with credibility.

The credibility of the study is now briefly described.

3.4.1 Credibility

Guba and Lincoln (1989) described credibility as the level of confidence that can be placed on the researchers' interpretations of the data gathered. They added that credibility is enhanced by a number of factors, including *prolonged engagement*, *persistent observation*, *peer debriefing*, *member checks*, and *progressive subjectivity*. The purpose of *prolonged engagement* is to establish trust with participants to overcome the effects of misinterpretation. Guba and Lincoln (1989) stated that p*ersistent observation* allows the researcher to identify features in the inquiry that are most related to the issue being investigated. *Peer debriefing* involves interaction with friends who have no connections to the study, to help the researcher explore other perspectives that are not within the researcher's mind. *Member checks*, that is, the continuous process of negotiation with stakeholders, provides participants with the opportunity to offer additional information from that previuosly gathered. For example, providing participants with a summary of an interview, or allowing participants to confirm individual data. Finally, *progressive subjectivity* is the degree of alignment between the researcher's understanding of a subject area of study before and after the investigation, so as not to be overly influenced by his/her prior knowledge (Guba & Lincoln, 1989). To assure high levels of credibility the researcher in this study employed methods of data collection that reflects the situation being studied. In other words, the researcher interviewed participants in their natural setting, that is, in a school setting. The students were introduced to the researcher and were informed that the researcher was a secondary school teacher. Thus, participants knew that the researcher was a teacher and were, therefore, comfortable with the interviews. In addition, the researcher asked two teachers to review and provide feedback on the interview questions, considered as *peer debriefing*. Their comments and feedback were used to build the final version of the interview questions.

The strategies used to enhance dependability are now described.

3.4.2 Dependability

Dependability is regarded as a match between recorded data and the actual occurrence in the natural setting (Cohen et al., 2011). In a positivist inquiry, the same methods of data collection (e.g., using the same questionnaire) are necessary in ensuring research can be executed elsewhere. However, for a naturalistic inquiry, the same methods of data collection are not necessary because as Guba and Lincoln (1989) pointed out methodological changes are important aspect of naturalistic study, and do not influence dependability. On the other hand, for conventional inquiries, alterations in research design are “thought to expose inquiries to unreliability” (Guba & Lincoln, 1989, p. 242). However, in naturalistic inquiries, these changes are seen as an integral part of the inquiry process to increase the robustness of the inquiry. What is critical, is that changes and shifts in constructions be clearly identified and should be “tracked” and “trackable” (Guba & Lincoln, 1989, p. 242). In other words, data should be able to be tracked to their sources.

To ensure stability of data, the researcher sometimes had to employ changes in the inquiry process. For example, if students’ responses were superficial the researcher did further probing to ask participants to explain particular words if meaning is not clear. Depending on the responses, the researcher needed to track the changes from the initial interview questions and further interview questions were posed to ensure a good understanding of what is responded.

The next section discusses the confirmability and transferability.

3.4.3 Confirmability and Transferability

Like its positivist equivalent, objectivity, confirmability seeks to ensure that the results of an inquiry have not been subject to undue influence by the researcher. The usual means of ensuring objectivity in conventional enquiries is via strict adherence to method, that is, “follow the process correctly and you will have findings that are divorced from the values, motives, biases, or political persuasions of the inquirer” (Guba & Lincoln, 1989, p. 243). However, in constructivist inquiries the confirmability of an inquiry rests on the data themselves. In other words, the researcher must not interfere with the data gathered to ensure objectivity. In this study, the participants were given the transcribed interview for their validation. Using participants’ feedback the transcribed interviews were revised and later used in data analysis. This step ensured the researcher did not interfere with the data.

Transferability is the constructivist equivalent to external validity or generalizability (Guba & Lincoln, 1989). Typically in an interpretivist study a target population is identified and a selection of participants made via a random sampling procedure, or some efficient variation such as stratified random sampling. To ensure transferability, participants’ responses in the form of verbatim excerpts from students and teachers’ interviews and an examination of the document analysis together provided thick description (i.e., rich data in the form of detailed and specific attributes). Such rich data allows readers to transfer similar characteristics of this thesis study to other settings (Cohen et al., 2011); they are necessary to “facilitate transferability judgements on the part of others who may wish to apply the study to their own situations" (Guba & Lincoln, 1989, p. 242).

The next section discusses how triangulation occurred for this thesis study.

3.4.4 Triangulation

Triangulation is the term used to refer to information that is collected in a number of different ways, for example, from different sources, or using different methods of data collection such as interviews, document analysis, and observations. Using triangulation of data a study can achieve greater consistency in the findings (Mertens, 2010).

Triangulation offers the details and complexities of human behaviour from more than one perspective and consequently increases the trustworthiness of the study. Cohen and researchers (2011) added that there are four common triangulations used. *Source triangulation* sometimes referred to *combined levels of triangulation* that involves multi layered levels of analysis (i.e., the individual level, the interactive level (groups), and the level of collectivities such as "organisational, cultural and societal" (Cohen et al., 2011, p. 196). Another form of triangulation is termed *methodological triangulation* that uses qualitative and quantitative data collection methods (Creswell, 2011). *Time triangulation* takes into considerations a cross sectional, such as this study, or longitudinal approach. Therefore, comparison of the findings could be attempted within different time frame. Next, is the *space triangulation* that addresses the limitations of studies conducted in one school.

For this thesis study, the sources of data or *source triangulation* included students, teachers, and curriculum documents. The *methodological triangulation* is adhered when interviews and examination of documents were conducted. *Time triangulation* is dealt with by interviewing participants at three schooling levels while the researcher conducted interviews in four schools to address the *space triangulation*.

Next, the validation of data through peer review is discussed.

3.4.5 Validation of Data Peer Review

To ensure the credibility of the data coded using the La Pelle method of analysis, a previous doctoral student, who had used the same data analysis method in his study, validated the coding in the theme codebook and the coding table displayed in Table 3.6 and Table 3.7. Revisions were made to the codebook after receiving feedback from this doctoral student and some refinements were made.

In section 3.5, ethical considerations are outlined.

3.5 Ethical Consideration

For this thesis study, the adopted interpretivist approach posed some threats (Guba & Lincoln, 1989; Lincoln, 1990) such as possible harm (e.g., issues of confidentiality) to the participants. One of the approaches used to address this issue was the Informed Consent Letter, which ensured participants were informed on the nature of the study and their confidentiality would be protected (Cohen et al., 2011). Ethical approval by the relevant authorities is described further, including the introductory letters and the Informed Consent letters which are found in Appendix A through D.

In order to conduct educational research in Malaysia, the researcher needed approvals from two authorities - the Education Planning and Research Division (EPRD), which is located in the Malaysian Ministry of Education, and the

Economic Planning Unit (EPU), a division of the Prime Minister's Department (Appendix A) at the Malaysian Ministry of Education (Appendix B), and the district Education Department (Appendix C). To interview participants, the researcher had to seek permission from four school principals in the form of a letter (Appendix D1 and D2). After gaining the principals' permissions to conduct the study and interview teachers (Appendix D3), the teachers were given the Informed Consent Letter for Teacher by the Principal (Appendix D4), the Informed Consent Letter for Teacher (Appendix D5), Research Consent Form for Teachers (Appendix D6) and the Consent Form Copy (Appendix D9). In these letters, the researcher explained the use of data and how confidentiality was to be ensured. In order to gain access to students, the researcher approached the class teachers who then introduced the researcher to the students in order for students to become familiar with the researcher. Next, the students were given the Informed Consent Letter for Student Participants (Appendix D7), the Research Information Form (Appendix D8) and the Consent Form Copy (Appendix D9). After introductions, similar to the teachers, the students were informed of the purpose of the interview, the use of data and confidentiality aspects. The use of the Informed Consent Letter and Consent Form was principally concerned with addressing participants feeling forced to participate, and ensuring confidentiality of the participants' identity and the opinions they expressed. These issues were addressed by briefly explaining what the research purpose was and seeking participants' permission before conducting the interviews. The confidentiality of the participants remains secure because participants were identified using code numbers. The researcher then obtained the participants' permission to use the data for the research. In addition, all ethics considerations involve in this thesis study were approved by the University of Waikato Human Research Ethics Committee (Appendix D10).

3.6 Summary

In this chapter a detailed outline of the methodology and methods used in this research was provided. This thesis study adopted the interpretive paradigm and is considered a cross-sectional research study. To investigate students' and teachers' mental models, semi-structured interviews utilizing the Interviews About Instances and Interviews About Concepts data gathering methods were used to gain access to participants' thinking.

A number of measures were also undertaken to ensure the trustworthiness of the study, that is, the consideration of the credibility, transferability, dependability, and confirmability of the research findings. In addition, participants were given Consent Letters and Information Forms to ensure no possible harm was caused to the participants.

The next chapter delves into the attributes of students' and teachers' mental models as revealed in their responses to questions related to the selected acid-base concepts.

Chapter 4. Results: Attributes for Students' Mental Models

4.1 Chapter Overview

This chapter provides an overview of findings for the first research question, that is, the attributes or characteristics of students' mental models for selected acid-base chemistry concepts. The chapter starts with background information about students who participated in the study, followed by an analysis of their responses to questions that probed their understanding of the selected acid-base chemistry concepts. The analysis pinpointed key themes in their responses that were subsequently identified as the attributes of students' mental models. Finally, the attributes that students displayed when answering each of the questions were analysed to determine the degree of alignment with the attributes of relevant scientific models.

4.2 Introduction

In the first phase of the study, 24 students from different levels of education in Malaysian schools (Table 4.1) and six science teachers were interviewed using Interview-About-Concepts (IAC) and Interview-About-Instances (IAI) questionnaires to probe their understandings of selected acid-base chemistry concepts. In this chapter, the attributes revealed in the students' responses were identified and gathered to describe their understanding for each selected acid-base chemistry concept and determine their mental models. The students came from lower and secondary school (Form 2 and Form 4) and post-secondary (Form 6) levels of schooling as presented in Table 4.1.

Table 4.1: Participants involved in this research

Education level	# of Teachers	# of Students	Codes
Lower secondary (Form 2)	2	8	SF2a,SF2b,SF2c,SF2d,SF2e, SF2f,SF2g, SF2h, TF2a, TF2b,
Upper secondary (Form 4)	2	8	SF4a,SF4b,SF4c,SF4d,SF4e, SF4f,SF4g, SF4h, TF4a, TF4b,
Pre-university (Form 6)	2	8	SF6a,SF6b,SF6c,SF6d, SF6e,SF6f,SF6g,SF6h, TF6a,TF6b

Note: Where T = teachers, and S = student, F indicates the Form, and the last letter indicates the participants. For example, SF6b = Second student in Form 6

Students in this research had been exposed to the acid-base chemistry concepts selected for this study in teaching and learning programmes at their schools before the interviews were conducted. So it was assumed that they could demonstrate their understanding of the concepts during interviews. Form 2 students had learned acid-base topics in April, in addition to prior acid-base learning experiences at the primary level, while Form 4 and Form 6 students covered further acid-base chemistry in the middle of their year.

The IAI and IAC questionnaires were used to collect data on the acid-base knowledge gained from these accumulated learning experiences in order to answer the first research question:

> What are the attributes of students' mental models for selected acid-base chemistry concepts at given Malaysian levels of schooling in relation to their applications of the Phenomenological, Arrhenius, Brønsted-Lowry, and Lewis models?

The students' responses to the questions (their expressed models) were examined for indications of the attributes of their mental models. Those attributes identified were then examined to establish whether any links could be made to the four acid-base models (i.e., Phenomenological, Arrhenius, Brønsted-Lowry, and Lewis). A summary of the acid-base chemistry concepts, the focus content (i.e., the focus content knowledge from the selected acid-base chemistry concepts), and the corresponding acid-base models for this research is presented in Table 4.2.

Table 4.2: Acid-base chemistry concepts with the corresponding acid-base models

Selected acid- base chemistry concepts	Schooling level	Focus content	Acid-base models
Macroscopic Properties	Form 2	Macroscopic properties of acids and bases	Phenomenological
Neutralisation	Form 2	Acid-base reaction producing salt and water	Arrhenius
	Form 4	Hydrogen-hydroxide acid-base reaction	Arrhenius
Acid-Strength	Form 4 Form 6	Degree of dissociation to produce hydrogen/hydroxide ions	Arrhenius
Acid-Base Equilibrium	Form 6	Acid-conjugate base	Brønsted-Lowry
Buffers	Form 6	Weak acid/ weak base with its salt or acid-conjugate base pair	Arrhenius Brønsted-Lowry
Acid-Base Electron Pair Bonding	Form 6	Acid-base reaction involving electron pair transfer	Lewis

Next, the students' mental models attributes are discussed.

4.2.1 Students' Mental Model Attributes

This section presents the attributes of students' mental models for each of the selected acid-base chemistry concepts at Forms 2, 4, and 6 levels of schooling.

4.2.1.1 Students' mental model attributes for the Macroscopic Properties Concept

To gain insight into all attributes of students' mental models for the Macroscopic Properties of acids and bases, Question Card 1 (Figure 4.1) was used to identify whether students agreed with certain statements about acid-base Macroscopic Properties.

Question Card 1

a. Acids are corrosive
b. Bases tastes bitter
c. Acids are harmful
d. Fruits are basic
e. Bases are slippery
f. Acids produce bubbles
g. Bases turn blue litmus paper to red

Do you agree with the statements above? Can you please tell me what you think?

Figure 4.1: Statements presented to students in Question Card 1

Nine different explanatory themes were revealed by students' responses to the statements exploring their understanding of the acid-base chemistry concept of Macroscopic Properties. They were: *senses*; *source reference*; *pH value*; *physical strength*; *scientific test*; *reactions*; *sub-microscopic; use of acid or base;* and *unsure*.

The discussion below illustrates, using one instance, how the attributes were determined, along with examples of student/s responses. For other acid-base chemistry concepts the attributes are discussed and examples of responses can be obtained from Appendix F, which presents a complete list of students' pseudonyms and their responses.

The process of determining the attributes of students' mental models for the Macroscopic Properties concept is now described.

4.2.1.2 Process of determining the attributes of students' mental models for the Macroscopic Properties concept

The rationale for each of the nine attributes for the Macroscopic Properties acid-base chemistry concepts are explained below, accompanied by examples of students' responses (highlighted). The complete responses are presented in Appendix F.

- *Senses:* All 24 students (100%) mentioned the use of their sensory perceptions when identifying acids and bases. The students identified acids and bases using the sense of taste, sight, or touch. 'Acid tastes sour' and 'bases taste bitter' were the common responses by students. The second most common response was the 'sense of touch'. For example, some students mentioned that acids can hurt the skin.

  > Acid tastes sour like lime juice when we drink it and it taste so sour. (SF2h)

- *Source reference*: Seven out of 24 (29%) of all students with this attribute identified acids and bases from knowledge learnt from books, newspapers, or teachers. Five students (SF2c, SF2d, SF6a, SF6e, and SF6h) mentioned their responses were based on books and two students (SF2g, SF6b) said they learnt to identify acids and bases from teachers.

  > I think it taste bitter but I never try because we learn from book. (SF6a)

- *pH value*: Eleven out of 24 (46%) students associated acids and bases with pH value (i.e., they explained macroscopic properties using the pH scale). Acids were described as stronger and more corrosive when the pH value is nearing 1 and bases as stronger when the pH value is nearing 14. Students' responses linked with this attribute were mainly from Form 4 and Form 6.

  > Bases with pH 13 are corrosive (SF6f)

  > Acids are corrosive when pH is very low. If the pH is 1 means it is very acidic and corrosive. (SF6h)

- *Physical strength*: Five out of 24 students' (21%) responses were classified as physical strength because their responses indicated they assumed the word 'strong' is associated with acids. These students thought that acids are strong while alkalis are not harmful and corrosive.

  > Acid can make us hurt but alkali I don't think it can hurt us. (SF2h)

- *Scientific test:* All 24 students (100%) indicated the use of a litmus test to identify acids and bases. Out of 24, 23 students correctly identified that acids turns blue litmus paper to red, while one Form 6 student (SF6g) identified the opposite.

  > (Soap) when we test with red litmus paper it turns blue. (SF2h)

- *Reactions:* Five out of 24 students (21%) described macroscopic properties in terms of chemical reactions, especially acids' ability to produce bubbles or neutralise a base. Other responses mentioned hydrogen gas as bubbles formed when a reaction occurred.

  > ... during reaction with something which gives out hydrogen gas especially in electrolysis. During reaction hydrochloric acid in the beaker will release the hydrogen gas which will be bubbles. (SF6e)

- *Sub-microscopic*: Six out of 24 students (25%) students responded by saying that the properties of acids were based on concentration of ions (e.g., concentration of hydrogen ions). The six students who exhibited this attribute were Form 4 and Form 6 students.

  Base produce hydroxide ions. (SF4e)

- *Use of acids or bases*: Two out of 24 students (8%) believed that an acid or a base could be determined from their use. For example, milk is an alkali because milk is use to reduce pain in the stomach.

  Alkali, because example milk of magnesia for stomach pains. (SF2d)

- *Unsure*: Six out of 24 (25%) of responses by students indicated they were not able to provide a response because they did not know. Three out of these 6 students were Form 6 students. An example of an *unsure* attribute was that given by SF6b when asked if bases were slippery.

  I don't know (bases are slippery). (SF6b)

The attributes identified above that are aligned with the Phenomenological model include *senses* (i.e., acids are sour, bases are bitter), and *scientific test* (i.e., uses litmus paper) (see Section 2.5.1). However, one attribute (i.e., *sub-microscopic*) is not aligned with the Phenomenological model but with the Arrhenius model. The other attributes were considered not to be associated with the appropriate model.

In the next section, the frequency of attributes' distribution across levels of education for Macroscopic Properties concept is described.

4.2.1.3 Frequency of attributes' distribution across levels of education for the Macroscopic Properties concept

The most common and correct attributes associated with Macroscopic Properties, which all students in the study to identify acids and bases, were *scientific test* and *senses.* All students (except student SF6g) were able to recognize the correct colour change for acid-base reactions using litmus (i.e., from blue to red in acid using blue litmus paper, or red to blue in base using red litmus paper). As anticipated by the curricular model, all students (i.e., 24 out of 24 students) were able to identify acids and bases using the *senses* and *scientific test* attributes, which are embedded features of the Phenomenological model (Table 4.3).

Table 4.3: Distribution of all students' attributes for Macroscopic Properties concept

Students' mental model attributes	SF2a	SF2b	SF2c	SF2d	SF2e	SF2f	SF2g	SF2h	SF4a	SF4b	SF4c	SF4d	SF4e	SF4f	SF4g	SF4h	SF6a	SF6b	SF6c	SF6d	SF6e	SF6f	SF6g	SF6h	Frequency /24 (n%)
*Senses	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24 (100)
*Scientific test	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24 (100)
* pH value		■								■			■	■		■		■	■		■	■	■	■	11 (46)
Source Reference			■	■			■										■	■			■			■	7 (29)
Sub-microscopic										■			■	■				■	■	■					6 (25)
Physical strength								■	■	■	■		■												5 (21)
Reactions																■	■		■	■	■				5 (21)
Use of acids or bases				■																		■			2 (8)
Unsure	■		■												■			■				■		■	6 (25)
Total	3	3	4	4	2	2	3	3	3	5	3	2	5	4	3	4	4	6	5	4	5	5	3	5	
Phenomenological model attributes	2	3	2	2	2	2	2	2	2	3	2	2	3	3	2	3	2	3	3	2	3	3	3	3	

Note: * Where attributes are aligned with the scientific Phenomenological model (i.e., senses, scientific test, and pH value). Shaded area indicates attributes the students provided.

The next most common attribute was *pH value*. The idea that students used the pH scale to determine the acid-base nature of a substance indicated they regarded pH as a macroscopic property. This reasoning demonstrated that they were able to correctly associate acids as solutions with pH measures of 1 to 6 and a base with pH 8 to 14. It is noteworthy that students SF4e and SF6h revealed misconceptions when they stated that pH scale for bases is 8 to 12 and 8 to 13, respectively, instead of 8 to 14. For this thesis study, the *pH value* attribute, discovered by Søren Sørenson, is considered as a convention which can be linked to the Phenomenological and Arrhenius models.

Key points for the Macroscopic Properties concept are now presented.

4.2.1.4 Key points

- All 24 students demonstrated the use of at least two attributes and up to six for one student while five attributes for students at the senior level (students SF4e, SF6b, SF6e, SF6h), which is expected for students of a higher level of education.
- Only three out of the 10 identified attributes (i.e., *senses, scientific test and pH value)* were found to be aligned with the Phenomenological model. Other attributes were considered as non-scientific such as *source reference, use of acids or bases* and *unsure*.
- All 24 students displayed the use of the Phenomenological model to explain macroscopic properties by their use of the three scientific attributes (i.e., *senses, scientific test, and pH value*).

In section 4.2.2, students' mental model attributes for the Neutralisation concept are described.

4.2.2 Students' Mental Model Attributes for the Neutralisation Concept

To identify students' attributes for the Neutralisation acid-base chemistry concept, all 24 students were asked "What happens when an acid and a base are put together?" (Figure 4.2).

Question Card 3

What do you think takes place when an acid and an alkali are put together?

Can you please write or draw what you think?

Question Card 4

How do you reduce the acidity of an acidic soil?

Can you please tell me what you think?

Figure 4.2: Question Card 3 and 4

For the Neutralisation concept, twelve attributes were expressed by students. They were: *product formation*, *reactant*, *neutralisation*, *properties change*, *sub-microscopic*, *heat*, *experiment*, *pH value*, *equation*, *physical mixing*, and *unsure*.

In the following section, the process of determining the attributes of students' mental models for the Neutralisation concept is discussed.

4.2.2.1 Process of determining the attributes of students' mental models for the Neutralisation concept

The twelve attributes for the Neutralisation concept are elaborated below. For examples of students' responses for each attribute refer to Appendix F.

- *Product Formation:* Twenty three out of 24 (96%) students said that when an acid and a base react together products are formed, which include salt and water, salt or water, and others. Only student SF4c did not state any salt or water formation, but mentioned that a bee sting may be neutralised by using a bitter substance.

- *Reactant:* Eighteen out of 24 students (75%) mentioned a base, when added to an acidic soil, may react to neutralise the soil or reduce the acidity.
- *Senses:* Two out of 24 (8%) students' responses to this question associated neutralisation with the sense of taste. For example, student SF4a assumed that when an acid (which is sour) and an alkali (which is bitter) react together, a tasteless substance is produced.
- *Neutralisation:* Two out of 24 students *(*8%) said that an acid can neutralise a base and that a base can neutralise an acid.

> If acid and base are combined it will neutralise each other, like if we are stung by a bee we take bitter particles to neutralise the toxin. (SF4c)

- *Properties change:* Four out of 24 (17%) student responses linked the Neutralisation concept with a loss of acidic properties to form a neutral solution.

> ... properties of acids disappear when dissolved in water because there is no hydrogen or hydroxide ions in NaCl. (SF4e)

- *Sub-microscopic***:** Four out of 24 students (17%) related the Neutralisation concept to ions (the submicroscopic level). Only two Form 4 and two Form 6 students mentioned hydrogen and hydroxide ions in their responses.
- *Heat*: One out of 24 students (4%) identified acid and base reactions with exothermic reactions and added that the acid-base reaction forms salt and water.
- *Experiment:* Seven out of 24 students (28%) explained the reaction of an acid and a base in terms of experimenting. Students that displayed this attribute described various experimental methods to explain a reaction

between an acid and a base, including the addition of an acid to a base in a beaker or a conical flask. Student SF2e described an experiment using lemon and bitter gourd (i.e., a bitter type of vegetable). Students SF2g, SF6f, and SF6g described the titration process including the use of a burette, but none of the Form 4 students mentioned a titration process.

- *pH value:* Ten out of 24 students (42%) used pH value to determine whether an acid-base reaction had occurred. An acid was perceived to be from pH 1 to 6, a base pH 8 to 14, and when they react together will form a solution with pH 7. Students using this attribute mentioned that pH 7 indicated a tasteless and neutralised solution. Student SF4c explained that a solution of pH 1 to 6 when combined with a solution of pH 8 to 14 reacts, resulting in a solution with pH 7. However, student SF6d argued that pH 7 is not always achieved in an acid-base reaction, but that the final pH was dependent on the concentration of the acid or the base.
- *Equation:* Thirteen out of 24 students (52%) depicted acid-base reactions using word or symbolic equations to show their understanding of Neutralisation. Student SF2f appeared to equate a chemical equation with a mathematical equation by using an equal sign.
- *Physical mixing:* One out of 24 students (4%) described adding a basic soil to neutralise the acidic soil, suggesting a physical mixing of the soils.
- *Unsure*: Three out of 24 students (13%) indicated that they were not sure how to apply the opposite role of acids and bases to reduce acidic soil.

The attributes above that are aligned with the Arrhenius model are *reactant*, *neutralisation*, *pH value*, *sub-microscopic*, *product formation*, *experiment*, and *equation*. Additionally, the Arrhenius model maintains that a strong acid completely neutralises a strong base when the concentration and volume of the acid and the base are the same. However, none of the students mentioned this relationship in their responses.

The frequency of attribute distribution across levels of education for Neutralisation concept is now explored.

4.2.2.2 Frequency of attribute distribution across levels of education for the Neutralisation concept

The attribute *product formation* was the most frequently expressed attribute to describe a neutralisation reaction (23 out of 24 students), followed by *reactant* (18 out of 24 students) and *pH* value (10 out of 24 students) - see Table 4.4.

Table 4.4: Distribution of All Students' Attributes for Neutralisation Concept

Attributes	SF2a	SF2b	SF2c	SF2d	SF2e	SF2f	SF2g	SF2h	SF4a	SF4b	SF4c	SF4d	SF4e	SF4f	SF4g	SF4h	SF6a	SF6b	SF6c	SF6d	SF6e	SF6f	SF6g	SF6h	Frequency/24 n (%)
*Product Formation	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	23 (96)
*Reactant	■					■	■	■	■	■		■	■	■	■	■	■	■	■	■		■	■	■	18 (75)
*Equation	■	■		■		■						■	■	■	■	■	■	■	■			■			13 (52)
pH value	■	■	■			■	■		■		■						■	■		■					10 (42)
*Experiment		■			■		■			■		■										■	■		7 (28)
Properties change	■											■	■	■											4 (17)
*Sub microscopic													■			■	■				■				4 (17)
Senses						■			■																2 (8)
*Neutralisation											■					■									2 (8)
Heat																					■				1 (4)
Physical mixing				■																					1 (4)
Unsure		■	■		■																				3 (13)
Total	5	5	3	3	3	5	4	2	4	3	2	5	5	4	3	5	5	4	3	3	3	4	3	2	
Arrhenius Model attributes	4	4	2	2	2	4	4	2	3	3	2	4	4	3	3	5	5	4	3	3	2	4	3	2	

Note. *Attributes that are aligned with the scientific Arrhenius model (i.e., product formation, reactant, neutralisation, sub-microscopic, pH value, experiment, and equation. Shaded cells indicate attributes the students provided.

Table 4.4 shows the highest number of occurrences for *product formation* indicated that most students used the attributes of the Arrhenius model to explain the Neutralisation concept, while attributes other than *reactant, neutralisation, sub-microscopic, experiment, pH value and equation* attributes are misconceptions.

Key points for the Neutralisation concept are now presented.

4.2.2.3 Key points

- Students across the three levels of schooling revealed 12 attributes for the Neutralisation concept. Seven of these attributes (i.e., *product formation*, *reactant*, *neutralisation*, *sub-microscopic*, *experiment*, *pH value*, and *equation*) can be directly linked to explanations based on the Arrhenius model.
- All 24 students used at least one Arrhenius model attribute to explain Neutralisation, but the maximum number of Arrhenius attributes used by individual students was 5, which student SF4h and SF6a displayed.
- The other five attributes were considered as misconceptions.

The next section examines students' mental model attributes for Acid-Strength concept.

4.2.3 Students' Mental Model Attributes for the Acid-Strength Concept

For the concept of Acid-Strength, students were asked to explain what they understood by the phrases 'strong acid', 'weak acid', 'strong base' and 'weak base'. Additionally, Question Card 7 (Figure 4.3) was shown to further probe students' understanding of the concept of Acid-Strength.

Question Card 7

a. Please choose what you think is the strongest acid solution from the three options below.
i. 0.4 mol L^{-1} HCl(aq) ii. 0.04 mol L^{-1} HCl(aq)
iii. 0.004 mol L^{-1} HCl(aq)

b. Please choose what you think is the stronger acid from the two options below.
i. 0.04 mol L^{-1} HCl(aq) ii. 0.4 mol L^{-1} CH_3COOH(aq)

c. Please choose what you think is the stronger acid from the two options below.
i. 0.004 mol L^{-1} H_2SO_4(aq) ii. 0.004 mol L^{-1} H_3PO_4(aq)

Note: HCl is hydrochloric acid — CH_3COOH is ethanoic acid
H_2SO_4 is sulfuric acid — H_3PO_4 is phosphoric acid

Can you please tell me what you think?

Figure 4.3: Question Card 7

The responses for Acid-Strength concept displayed six attributes (Table 4.5): *concentration of ions*, *dissociation*, *physical strength based on pH*, *physical strength based on macroscopic properties*, *molar concentration*, and *unsure*.

Section 4.2.3.1 presents the process for determining the attributes of students' mental models for the Acid-Strength concept is discussed.

4.2.3.1 Process for determining the attributes of students' mental models for the Acid-Strength concept

The discussion below describes the attributes identified in students' responses to questions related to the concept of Acid-Strength.

- *Concentration of ions:* Seven out of 16 students (44%) associated acid-base strength with concentration of ions. However, not all of the seven students were able to explain that high concentrations of ions were caused by complete dissociation of acids or bases.

- *Degree of dissociation:* Fourteen out of 16 students (88%) associated the term *strength of an acid* with complete or partial dissociation.. This group of students described a strong acid as an acid that ionizes completely in water to produce hydrogen ions and a strong base as one that ionizes completely in water to produce hydroxide ions.
- *Physical strength based on pH:* Three out of 16 students (18%) associated the Acid-Strength concept with the pH scale. For these students, when the pH value of an acid is lower, the acid is stronger and it is more corrosive.
- *Physical strength based on macroscopic properties:* Only one student (SF4h) out of 16 (6%) associated the Acid-Strength concept with the nature of the acid, such as strong acids having corrosive properties and weak acids and bases having less corrosive properties. This response indicated student SF4h may have a different understanding of the word strong, and not one to do with the degree of dissociation.
- *Molar concentration:* Fourteen out of 16 students (88%) commented that a strong acid is more concentrated than a weak acid. A concentrated acid is thought to be a stronger acid by these students.
- *Unsure:* Three out of 16 students (19%) were not sure whether H_3PO_4 is stronger than H_2SO_4 or vice versa.

Only one of the attributes presented in Table 4.5 is aligned with the Arrhenius model (i.e., *degree of dissociation),* which is called electrolytic dissociation in the Arrhenius's model.

In the following section the frequency of attribute distribution across levels of education for the Acid-Strength concept is now examined.

4.2.3.2 Frequency of attribute distribution across Form 4 and Form 6 students for the Acid-Strength concept

Seven out of eight Form 4 and two out of eight Form 6 students at each schooling level used an attribute aligned with the Arrhenius model, that is, the strength of an acid is based on its degree of dissociation into hydrogen ions, and for bases its degree of dissociation into hydroxide ions (Table 4.5).

Table 4.5: Distribution of Form 4 and Form 6 students' attributes for the Acid-Strength Concept

Attributes	SF4a	SF4b	SF4c	SF4d	SF4e	SF4f	SF4g	SF4h	SF6a	SF6b	SF6c	SF6d	SF6e	SF6f	SF6g	SF6h	Frequency/24 n (%)
*Degree of dissociation		■	■	■	■	■	■	■	■	■	■	■	■	■		■	14 (88)
Molar concentration	■	■	■	■	■	■	■	■	■		■	■	■	■	■		14 (88)
Concentration of ions	■	■		■			■	■		■			■				7 (44)
Physical strength based on pH						■		■	■								3 (18)
Physical strength based on macroscopic properties								■									1 (6)
Unsure									■						■	■	3 (19)
Total	2	3	2	3	2	3	3	5	4	2	2	2	3	2	2	2	
Arrhenius Model attribute	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	

Note: * Attributes that are aligned with the scientific Arrhenius model (i.e., dissociation). Shaded areas indicate attributes the students provided.

Fourteen out of the 16 (88%) Form 4 and 6 students displayed use of the Arrhenius model attribute *degree of dissociation ions* to explain Acid-Strength and the attribute *molar concentration* to explain the Acid-Strength concept. The *molar concentration* attribute, however, is a misconception. Interestingly, one of the two students who did not use the *degree of dissociation* attribute to explain the Acid-Strength concept was a Form 6 student.

The key points for the Acid-Strength concept are now presented.

4.2.3.3 Key points

- Fourteen out of the 16 Form 4 and 6 students were able to associate the Acid-Strength concept with a key attribute from the Arrhenius model.
- Fourteen out of the 16 Form 4 and 6 students used the concept of molar concentration to explain the Acid-Strength concept, which is a misconception.
- Student SF6g displayed no attributes from the scientific Arrhenius model.

Students' mental model attributes for Acid-Base Equilibrium concept are now explored.

4.2.4 Students' Mental Model Attributes for the Acid-Base Equilibrium Concept

For the concept of the Acid-Base Equilibrium, Form 6 students were asked to explain what they understood by the phrase *Acid-Base Equilibrium*. Additionally, Question Card 10 was used to further probe students' understanding (see Figure 4.4).

Question Card 10

> I mix aqueous solution of NaOH (sodium hydroxide) with an aqueous solution of CH_3COOH (ethanoic acid) in equal volume and concentration, do you think the concentration of $[H_3O^+]$ be same, higher or lower than the concentration of $[OH^-]$ ions in the resulting solution?

Can you please tell me what you think?

Figure 4.4: Question Card 10

The responses revealed five main attributes (Table 4.6). However, none of the eight students mentioned any attributes aligned with the Brønsted-Lowry model.

The next section examines the process of determining the attributes of students' mental models for the Acid-Base Equilibrium concept.

4.2.4.1 Process of determining the attributes of students' mental models for the Acid-Base Equilibrium concept

Form 6 students responses displayed five attributes for the Acid-Base Equilibrium concept. They were: *reversible action, degree of dissociation ions, strong base weak acid, quantity of matter,* and *unsure*.

- *Reversible reaction:* Only one out of eight Form 6 students (13%) associated the Acid-Base Equilibrium concept with a reversible reaction and for this reason student SF6a was unsure how to determine the higher concentration of the two ions.
- *Degree of dissociation:* Only student SF6c (13%) explained that sodium hydroxide (NaOH) is a base that fully dissociates to produce a high concentration of OH^- ions, resulting in more hydroxide ions than hydrogen ions.
- *Strong base weak acid:* Four out of the eight Form 6 students stated that the OH^- ion concentation will be higher than H_3O^+ because sodium hydroxide (NaOH) is a strong alkali and can fully dissociate to produce more OH^- ions than ethanoic acid (CH_3COOH) which partially dissociates to produce fewer H^+ ions.
- *Quantity of matter:* Two out of eight students (25%) stated that the quantity of moles determined the concentration of ions present.
- *Unsure:* Six Form 6 students interviewed were not sure what Acid-Base Equilibrium referred to and resorted to saying "I don't know" or "I am not sure."

None of the five attributes in Table 4.6 were aligned with the Brønsted-Lowry model. However, the *degree of dissociation ions* and the *strong base weak acid* attributes demonstrated the use of the Arrhenius model. According to the Brønsted-Lowry model, acids donate protons while bases accept protons and the concept of a conjugate acid and a conjugate base was also developed in this model. However, students did not explain the Acid-Base Equilibrium concept using the Brønsted-Lowry model. As a result, none of the students mentioned an acid as a proton donor or the ethanoate ions as a conjugate base and the role the ethanoate ions play in determining the concentration of hydroxide ions (see Section 2.9.4).

The frequency of attribute distribution across Form 6 students for the Acid-Base Equilibrium concept is now examined.

4.2.4.2 Frequency of attribute distribution across Form 6 students for the Acid-Base Equilibrium Concept

Two Form 6 students demonstrated the use of at least one attribute while six expressed two attributes (Table 4.6). None of the Form 6 students were able to display more than two attributes.

Table 4.6: Distribution of Form 6 students' attributes for the Acid-Base Equilibrium Concept

Attributes	SF6a	SF6b	SF6c	SF6d	SF6e	SF6f	SF6g	SF6h	Frequency /24 (n%)
Strong base weak acid		■			■	■		■	4 (50)
Quantity of matter				■			■		2 (25)
Reversible reaction	■								1 (13)
Degree of dissociation			■						1 (13)
Unsure	■	■		■		■	■	■	6 (75)
Total	2	2	1	2	1	2	2	2	
Brønsted-Lowry Model attribute	0	0	0	0	0	0	0	0	

Note: Brønsted-Lowry model attributes are not demonstrated by students. Shaded areas indicate which attributes the students provided.

Table 4.6 shows that none of the Form 6 students were able to use Brønsted-Lowry model attributes to explain Acid-Base Equilibrium concept.

Key points for the Acid-Base Equilibrium concept are now presented.

4.2.4.3 Key points

- Form 6 students were not able to use the acid-conjugate base pair concept, which is a key feature of the Brønsted-Lowry model, to explain the Acid-base Equilibrium concept.
- Form 6 students were using *degree of dissociation ions*, and the *strong base weak acid* attributes, which are attributes of the Arrhenius model, in explaining the Acid-Base Equilibrium concept.

In section 4.2.5, students' mental model attributes for the Buffers concept are now examined.

4.2.5 Students' Mental Model Attributes for the Buffers Concept

To gain an understanding of students' mental model attributes for the Buffers concept, Form 6 students were asked "What makes a buffer solution ?" Question Card 11 was used to further probe students' understanding (Figure 4.5).

Question Card 11

a. A buffer is only formed by the combination of a weak acid and its salt.
b. A buffer can be formed by a combination of an acid and its conjugate base.
c. A buffer can be formed by a combination of hydrochloric acid (HCl) and sodium chloride (NaCl).

Do you agree with the statements above? Can you please tell me what you think?

Figure 4.5: Question Card 11

The eight Form 6 students' responses yielded six attributes. They were: *reactant, acidity change, resist pH change, improper conjugate ideas, neutralisation* and *unsure* (see Table 4.7).

The process of determining the attributes of students' mental models for Buffers concept is now discussed.

4.2.5.1 Process of determining the attributes of students' mental models for the Buffers concept

The following section is a description of students' responses for the Buffer concept. The attributes displayed by students responses are *reactants, acidity change, resisting pH change, improper conjugate ideas, neutralisation,* and *unsure.*

- *Reactant*: Five out of eight students (63%) made varied responses of substances involved in forming a buffer solution. One student assumed that a solution with a small amount of acid and base present is a buffer solution.
- *Acidity change:* One out of eight Form 6 students (13%) (student SF6c) associated the Buffers concept with acidity change i.e., the buffer increases or decreases acidity.
- *Resisting pH change:* Two students out of eight (25%) (students SF6d, SF6h) associated the Buffers concept with resisting pH change; however, they did not explain what forms a buffer solution and how it was formed.
- *Improper conjugate ideas:* Three out of eight students (38%) displayed a misunderstanding of the term conjugate. Student SF6a mentioned that a conjugate base is hydrogen ions.
- *Neutralisation:* Two out of eight students (25%) revealed that the reaction of an acid with its salt is an acid-base reaction, and considered it a neutralisation reaction. Student SF6b maintained that because an acid and a salt is present the reaction of hydrochloric acid (HCl) and sodium chloride (NaCl) is a neutralisation reaction.
- *Unsure:* None of the eight Form 6 students (100%) were able to explain the Buffers concept using the Brønsted-Lowry model.

The frequency of attribute distribution across Form 6 Students for the Buffers concept is now explored.

4.2.5.2 Frequency of attribute distribution across Form 6 students for the Buffers concept

All Form 6 students exhibited a minimum of one attribute to describe buffers (see Table 4.7). Six of the eight students displayed more than one attribute and two of the eight students displayed four attributes.

Table 4.7: Distribution of Form 6 students' attributes for the Buffers Concept

Attributes	SF6a	SF6b	SF6c	SF6d	SF6e	SF6f	SF6g	SF6h	Frequency /24 (n%)
Reactant	■	■	■		■			■	5 (63)
Improper conjugate ideas	■		■		■				3 (38)
Resist pH change				■				■	2 (25)
Neutralisation	■	■							2 (25)
Acidity change			■						1 (13)
Unsure	■	■	■	■	■	■	■	■	8 (100)
Attributes	4	3	4	2	3	1	1	3	
Brønsted-Lowry attribute	-	#	-	-	-	-	-	-	

Note. *Brønsted-Lowry model attributes are scientific attributes (i.e., weak acid with its conjugate acid or weak base with its conjugate base) where shading indicates students with their respective attributes.
Student SF6b mentioned the attribute reactant but was not able to relate to acid-conjugate base pairs or weak acid-salt

Table 4.7 shows that none of the attributes expressed by the Form 6 students are aligned with the Brønsted-Lowry model. The attribute *neutralisation* indicates the use of the Arrhenius model attribute but none of the students mentioned attributes suggesting acids are proton donors or bases proton acceptors. Although, prompted by statement (b) in Question Card 11 about a conjugate base, students were not able to describe correctly the meaning of conjugate base.

Key point for the Buffers concept is now presented.

4.2.5.3 Key points

- All attributes used by students in their explanations about Buffers are considered misconceptions.
- Form 6 students were not able to explain the concept of Buffers using attributes of the Brønsted-Lowry model.
- Two Form 6 students used the Arrhenius model attribute (*neutralisation*) but inappropriately.

In section 4.2.6, students' mental model attributes for the Acid-Base Electron Pair Bonding concept are explained.

4.2.6 Students' Mental Model Attributes for the Acid-Base Electron Pair Bonding Concept

The final acid-base chemistry concept to be investigated was the Acid-Base Electron Pair Bonding. For this concept, students were given Question Card 7c (Figure 4.6) to elicit their understanding.

Question Card 7c

$$BH_3(g) + NH_3(g) \rightarrow H_3B\,NH_3(s)$$

Can you please tell me what you think will happen when BH_3 is added to NH_3?

Figure 4.6: Question Card 7c

Form 6 students displayed five attributes. They were: *strong acid-weak base reaction*, an *acid-acid* reaction, an *base -unknown* reaction, *dative bonding*, and *unsure* (Table 4.8).

A discussion of the process of determining the attributes of students' mental models for the Acid-Base Electron Pair Bonding concept is now presented.

4.2.6.1 Process of determining the attributes of students' mental models for the Acid-Base Electron Pair Bonding concept

The attributes for electron pair bonding that students displayed in their responses are identified and explained below.

- *Strong acid weak base reaction:* One student out of eight (13%) associated electron pair bonding concept with a reaction between an acid (boron trihidride (BH_3) and an alkali (ammonia (NH_3)).
- *Acid-acid reaction:* Three out of eight students (38%) said the reaction between boron trihidride (BH_3) and ammonia (NH_3) is an acid-acid reaction because both boron trihidride (BH_3) and ammonia (NH_3) contain hydrogen atoms.
- *Base-unknown reaction***:** One out of eight students (13 %) mentioned that they were unsure if boron trihidride (BH_3) was an acid or a base but knew ammonia (NH_3) was a base.
- *Dative bonding:* One out of eight Form 6 students (13%) was able to relate acid-base reactions with electron pair bonding. Student SF6d mentioned that the reaction is like a dative bond because the reaction involves donating an electron pair. However, student SF6d was unsure how to elaborate.
- *Unsure:* Two out of eight (25%) Form 6 students (SF6c, SF6e) were not sure how to explain the reaction.

Only the attribute *dative bonding* is aligned with the Lewis model because when one atom donates an electron pair to another atom a type of covalent bond termed dative bond is formed (see Section 2.9.7).

In the next section, frequency of attribute distribution of attributes across Form 6 students for the Acid-Base Electron Pair Bonding concept is examined.

4.2.6.2 Frequency of attribute distribution of attributes across Form 6 students for the Acid-Base Electron Pair Bonding concept

All Form 6 students expressed one attribute in their explanations about the Acid-Base Electron Pair Bonding concept. The most common attribute displayed by the Form 6 students was *acid-acid reaction* followed by the *unsure* attribute (see Table 4.8).

Table 4.8: Distribution of Form 6 Students' attributes for Acid-base Electron Pair Bonding Concept

Attributes	SF6a	SF6b	SF6c	SF6d	SF6e	SF6f	SF6g	SF6h	Frequency /24 (n%
Acid-acid reaction						■	■	■	3 (38)
Strong acid-Weak base reaction	■								1 (13)
Base- unknown reaction		■							1 (13)
*Dative bonding				■					1 (13)
Unsure			■		■				2 (25)
Total attributes	1	1	1	1	1	1	1	1	
Lewis Model	-	-	-	#	-	-	-	-	

Note. *Lewis model attributes are scientific attributes (i.e., acid is an electron pair acceptor, base is an electron pair donor). Shading indicates which attributes the students display
Student SF6d mentioned but explained incorrectly

Out of eight students, only one student (SF6d) was able to identify an electron pair bonding reaction, while others identified boron trihidride (BH_3) and ammonia (NH_3) using the criteria of the presence of hydrogen atoms which is incorrect. The majority of students showed no use of the Lewis model in their explanations.

The next section presents the key point for the Acid-Base Electron Pair Bonding concept.

4.2.6.3 Key points

- The majority of students showed no links to the Lewis models in their explanations.
- Seven out of eight Form 6 students were not able to identify ammonia (NH_3) as a Lewis base that donates an electron pair in an acid-base reation. These students showed no understanding of the Acid-Base Electron Pair Bonding concept.

The next section discusses the links between students' mental models and scientific models.

4.3 Links between Students' Mental Models and Scientific Models

Question Card 2 was developed to elicit how students determine whether a substance is an acid or a base. The card is used as an extra tool or probing questions to confirm students understanding and how appropriately they used the scientific models in their reasoning to identify a substance as acids and bases. The list was designed in a way to anticipate how students identify substances as they progressed through the schooling levels and the use of a more sophisticated models. The card contained a list of substances arranged in order of complexity from those commonly encountered in the Form 2 level of schooling, such as milk and vinegar, to those used in Form 6 chemistry classes, such as ethanoate ions (CH_3COO^-) ions and carbon dioxide (CO_2) (Appendix G).

The links to the Phenomenological model is discussed next.

4.3.1 Links to the Phenomenological Model

To determine what linkages students might be making to the scientific Phenomenological model, they were asked to identify each item from the following list as an acid or base: milk, vinegar, lemon juice, soap, floor cleaner, baking soda, soda drinks, water, sodium hydroxide, and hydrochloric acid (Figure 4.7).

Question Card 2

No	Item	Acid	Alkali	Other (specify)	pH			Reason
1	Milk				1-6	7	8-14	
2	Vinegar				1-6	7	8-14	
3	Lemon Juice				1-6	7	8-14	
4	Soap				1-6	7	8-14	
5	Floor cleaner				1-6	7	8-14	
6	Baking soda solution				1-6	7	8-14	
7	Soda drinks				1-6	7	8-14	
8	Water				1-6	7	8-14	
9	Sodium Hydroxide				1-6	7	8-14	
10	Hydrochloric acid				1-6	7	8-14	

Figure 4.7: Question Card 2 for Form 2 students and teachers

Based on these ten substances, ten attributes were generated (see Table 4.9).

The attributes that explore linkages to the Phenomenological Model are now described.

4.3.1.1 Attributes that explore linkages to the Phenomenological Model

The students' attributes aligned with the Phenomenological model are *senses* (i.e., acids are sour, bases are bitter), and *scientific test* (i.e., uses litmus paper) (see Section 2.5.1). The other eight attributes are considered misconceptions because they are not aligned with attributes found in the scientific Phenomenological model. The *pH value* attribute that some students were using to identify acids and bases was not aligned with any acid-base models.

The following descriptions illustrate the ways students identified acids and bases and are coded as particular attributes. .

- *pH value:* Seven out of 24 students (29%) used *pH value* to reason that an acid and a base have particular pH values. They identified milk, vinegar and soap as acids or bases according to their respective pH values.
- *Senses:* All 24 students (100%) displayed their use of the Phenomenological model when they said that acid is sour and a base is bitter. These students mainly used macroscopic properties detected through the sense of touch and taste.
- *Use of acids and bases:* Seven out of 24 students (29%) based their identification of bases on their use as a medicine or a cleaning agent.

  This attribute would not be considered usage of a macroscopic property to identify acids and bases since it is not a property but rather a use of these substances.

- *Scientific test:* Eight out of 24 students (33%) displayed the knowledge that acids and bases can be determined through a litmus paper test which is a macroscopic property. Four Form 2, three Form 4, and one Form 6 students displayed this attribute.
- *Properties of acids and bases:* Five out of 24 students (21%) used the characteristic of acids or bases to identify a substance as an acid or a base. Soap is a base because it is slippery as stated by SF6f.
- *Sub-microscopic:* One out of 24 (4%) students said that water is neutral and pure water does not have any fluorine ions.
- *Neutralisation:* One out of 24 (4%) maintained that when an acid and a base are combined salt and neutral water are formed.
- *Constituents:* Five out of 24 (21%) students mentioned particular ingredients in a substance could be used to identify acids and bases in a substance. For example, student SF6c stated that soda drinks are acids because it contains carbonic acid.
- *Physical strength:* One out of 24 (4%) determined that a substance is an acid if the substance hurts.
- *Unsure*: Fifteen out of 24 students (63%) stated they did not know how to determine whether milk is an acid or a base, so they are considered not to be using macroscopic properties to identify acids and bases.

Next, the number of students identifying each of the substances as acids or bases is described (see Appendix H).

Milk is known to have a pH of 6.7 and, therefore, slightly acidic (Helmenstine, 2014). The results indicated nine out of 24 students correctly identified milk as an acid using the Phenomenological model.

For the substance vinegar, 23 out of 24 students correctly identified vinegar as an acid. Twenty out of 24 students noted the sour taste of vinegar, while students SF2h, SF4b, and SF4e used the *scientific test* attribute to identify vinegar as an acid. All 24 students demonstrated using the *senses* and *scientific test* attributes and nine students used the *pH value* attributes, which are directly linked to the scientific Phenomenological model. However, student SF2e incorrectly identified vinegar as alkali, although the student stated vinegar tastes bitter, the Phenomenological model was being used to justify the choice.

For lemon juice, all 24 students correctly identified lemon juice as an acid because it tastes sour, displaying use of the Phenomenological model. Thirteen students identified soap as an alkali because of its slippery property; one student (SF4h) stated the cleaning effect of a base, while student SF6b used the *physical strength* attribute to identify soap as a base. Nineteen students used at least one attribute (i.e., *senses*,) and two students used the *scientific test* attribute that could be linked to the Phenomenological model to identify soap as a base.

Fourteen students correctly identified floor cleaner as a base with 13 out of 24 students using the Phenomenological model and one student (SF4e) using the Arrhenius model. For baking soda, only three students correctly classified baking soda as an alkali. Student SF2b used the Phenomenological model when the student stated using *scientific test* attribute; student SF4d stated baking soda tastes bitter, displaying the use of senses attribute to identify baking soda as a base. Student SF4f did not think baking soda was sour and inferred that baking soda was a base.

Three out of 24 students correctly stated that soda drinks are acids. All the three students indicated that soda drinks are acids because soda drinks are sour. These three students all applied the Phenomenological model to identify soda drinks as acids.

For water, six Form 2 students noted that water is neutral, which is considered a correct concept at Form 2. Students SF2a and SF2h used the *pH* value attribute when they stated that water is neutral indicated by pH 7. However, the *pH value* attribute is not an attribute of any acid-base model. Other Form 2 students stated water is neutral because it is tasteless, displaying the use of Phenomenological model. For Form 4, seven of the eight students, stated water is neutral because it is tasteless, demonstrating the use of the Phenomenological model. This response is considered correct at the Form 4 schooling level because students are not exposed to the Brønsted-Lowry model. All Form 6 students stated water is neutral. Students SF6a and SF6g decided water is neutral because there are no changes in the colour of litmus paper, while students SF6b, SF6d, and SF6f stated water is neutral because it is tasteless. Student SF6e indicated water as neutral if there are no Fluorine ions, showing the student did not use any model to determine water as neutral but was attempting to explain at the submicroscopic level. Another student (SF6h) stated when an acid and base combines neutral water is formed displaying the use of the Arrhenius model because this model states that H^+ ions from the acid combines with the OH^- from the base to form neutral water molecules. However, this is true for pure water when the concentration of H^+ and OH^- are equal at 25°C. The results showed that Form 6 students still held on to the idea that water is neutral although they have learnt that water can be an acid or a base according to the Brønsted-Lowry model, which the Form 6 students were required to learn as intended by the curriculum. It appears students may be confused about water as a neutral substance (i.e., macroscopic view) and water as molecules (i.e., sub-microscopic view).

For sodium hydroxide, two out of eight Form 2 students identified sodium hydroxide as an alkali where student SF2b used the *scientific test* attribute, and student SF2d used the *senses* attribute exhibiting the use of the Phenomenological model. For hydrochloric acid, only student SF2b stated hydrochloric acid as an acid because it tastes sour.

In the following section, the frequency of attribute distribution across schooling levels related to the scientific Phenomenological model is now explored.

4.3.1.2 Frequency of attribute distribution across schooling levels related to the Phenomenological Model

The frequency of distribution across schooling levels related to the scientific Phenomenological model is presented in Table 4.9.

Table 4.9: Distribution of all students' attributes for the Phenomenological model

	SF2a	SF2b	SF2c	SF2d	SF2e	SF2f	SF2g	SF2h	SF4a	SF4b	SF4c	SF4d	SF4e	SF4f	SF4g	SF4h	SF6a	SF6b	SF6c	SF6d	SF6e	SF6f	SF6g	SF6h	Frequency /24 (n%
*Senses	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24 (100)
*Scientific test		■			■		■	■		■	■		■										■		8 (33)
Uses of acids and bases				■					■			■	■			■			■			■			7 (29)
pH value	■							■			■		■	■						■			■		7 (29)
Properties of acids and bases												■	■					■	■			■			5 (21)
Constituents			■													■	■		■	■					5 (21)
Sub-microscopic																					■				1 (4)
Neutralisation																								■	1 (4)
Physical strength								■																	1 (4)
Unsure			■		■	■	■	■	■		■		■		■	■		■			■	■	■	■	15 (63)
Total attributes	2	2	3	2	3	2	3	5	3	2	4	3	6	2	2	4	2	3	4	3	3	4	4	3	
Phenomenological attributes	1	2	1	1	2	1	2	2	1	2	2	1	2	1	1	1	1	1	1	1	1	1	2	1	

Note. *Phenomenological model attributes are scientific attributes (i.e., senses, litmus,). Shaded boxes indicate non-Phenomenological attributes which the students provided

Table 4.9 shows that eight students demonstrated the use of two attributes which are considered directly related to the scientific Phenomenological model, and the majority (n=16) articulated one attribute. This result showed that all students were able to describe at least one attribute for macroscopic properties from the Phenomenological model to identify everyday life substances as acids or bases. Section 4.3.2 describes the links to the Arrhenius model that students used to identify acids and bases.

4.3.2 Links to the Arrhenius Model

To gain insight into students' use of mental model attributes linked to the Arrhenius model, their responses for sodium hydroxide (NaOH), and hydrochloric acid (HCl), were collected using Question Card 2 (Figure 4.8). Ammonia (NH_3) was omitted because ammonia could not be identified as a base using the Arrhenius model.

Question Card 2

No	Item	Acid	Base	Other (specify)	pH			Reason
1	Milk				1-6	7	8-14	
2	Vinegar				1-6	7	8-14	
3	Lemon Juice				1-6	7	8-14	
4	Soap				1-6	7	8-14	
5	Floor cleaner				1-6	7	8-14	
6	Baking soda solution				1-6	7	8-14	
7	Soda drinks				1-6	7	8-14	
8	Water				1-6	7	8-14	
9	NaOH				1-6	7	8-14	
10	NH_3				1-6	7	8-14	
11	HCl				1-6	7	8-14	

Figure 4.8: Question Card 2 for Form 4 students and teachers showing linkage to the Arrhenius model

The attributes gathered were *pH value*, *scientific test*, *senses*, *hydrogen-hydroxide*, *properties of acids and bases*, *source reference*, *constituents*, *reaction*, and *unsure* (Table 4.10).

The attributes that explore linkages to the Arrhenius model are now discussed.

4.3.2.1 Attributes that explore linkages to the Arrhenius Model

The only attribute in Table 4.10 that is aligned with the Arrhenius model is *hydrogen-hydroxide ions*.

The descriptions below illustrate how the attributes gathered for the Arrhenius Model were used by students (Appendix G).

- *pH*: Two out of 16 students (13%) identified sodium hydroxide (NaOH) or hydrochloric acid (HCl) as an acid or a base in relation to their pH. None of the Form 4 students identified sodium hydroxide (NaOH) and hydrochloric acid (HCl) using pH.
- *Scientific test:* Two out of 16 students (13%) identified acids or base using the litmus test. One Form 6 student described using litmus paper as a method to identify an acid or a base.
- *Senses*: One out of 16 students (6%) identified hydrochloric acid (HCl) as acidic. For example, sudent SF4c stated that when hydrochloric acid (HCl) spills skin may be irritated.
- *Hydrogen Hydroxide*: Eleven out of 16 students (69%) mentioned hydrogen or hydroxide ions in determining an acid or a base. Acids were perceived as substances that produce hydrogen ions in an aqueous solution while bases are substances that produce hydroxide ions in an aqueous solution.
- *Properties of acids and bases:* Three out of 16 students (19%) referred their responses to the properties of acids and bases. For example, student SF6c said ammonia is a base because ammonia demonstrates the properties of an alkali because ammonia is used to neutralise weak acids.
- *Source Reference:* One out of 16 students (6%) indicated hydrochloric acid (HCl) is as a strong acid because student SF6b knew this information from prior knowledge.

- *Constituent*: One out of 16 students (6%) (SF4c) indicated sodium hydroxide (NaOH) was a base because sodium hydroxide contains sodium, which this student believes is indicative of a base: (i.e., bases contain sodium (Na).
- *Reaction*: One out of 16 students (6%) stated that hydrochloric acid (HCl) is an acid because it produces hydrogen gas.
- *Unsure*: One out of 16 students (6%) was not sure how to identify hydrochloric acid (HCl) or sodium hydroxide (NaOH) as an acid or a base. Student SF4d was unsure of how to identify sodium hydroxide and hydrochloric acid. Students SF6d and SF6g were unsure how to determine ammonia (NH_3).

Ten out 16 Form 4 and Form 6 students correctly identified sodium hydroxide (NaOH) as a base using attributes related to the scientific Arrhenius model; three students incorrectly identified sodium hydroxide (NaOH) as an acid using no model; and another two students used the attributes of the Phenomenological model.

Nine out 16 Form 4 and Form 6 students correctly identified hydrochloric acid (HCl) as an acid using the hydrogen hydroxide attribute of the Arrhenius model. Three students used the Phenomenological model and another four students did not use any model to explain.

In section 4.3.2.2 the frequency of attribute distribution across schooling levels related to the Arrhenius Model is now discussed.

4.3.2.2 Frequency of attribute distribution across schooling levels related to the Arrhenius model

The *hydrogen hydroxide* ions were the only attributes out of the nine identified attributes comprising students' mental models that are actually aligned to the scientific Arrhenius model.

The frequency of distribution across schooling levels related to the Arrhenius Model is shown in Table 4.10.

Table 4.10: Distribution of Form 4 and Form 6 Attributes for the Arrhenius Model

Attributes	SF4a	SF4b	SF4c	SF4d	SF4e	SF4f	SF4g	SF4h	SF6a	SF6b	SF6c	SF6d	SF6e	SF6f	SF6g	SF6h	Frequency /24 (n%
*Hydrogen hydroxide	■				■	■	■	■	■		■	■		■	■	■	11 (69)
Properties of acids and bases										■	■						2 (13)
pH value											■				■		2 (13)
Scientific test		■											■				2 (13)
Senses			■														1 (6)
Source Reference										■							1 (6)
Constituent			■														1 (6)
Reaction						■											1 (6)
Unsure				■													1 (6)
Total attributes	1	1	2	2	1	2	2	1	1	3	2	2	2	2	3	1	
Arrhenius Model attributes	1	0	0	1	1	1	1	1	1	1	1	1	0	1	1	1	

Note. *Arrhenius model attributes are scientific attributes (i.e., hydrogen hydroxide).Shading indicates which attributes the students provide.

In Table 4.10, six Form 4 and seven Form 6 students used the attribute of *hydrogen-hydroxide* to determine whether a substance was an acid or a base, which is expected, given the Arrhenius model is in the curriculum for these levels. Although, the Form 6 students were assumed to learn the Brønsted-Lowry theory as intended by the Form 6 curriculum, they did not explain that ammonia (NH_3) is a base because it accepts a proton.

The next section describes the links to the Brønsted-Lowry model.

4.3.3 Links to the Brønsted-Lowry Model

The next scientific acid-base model to be investigated for links with students' mental model attributes was the Brønsted-Lowry model. To check this link, the ethanoate ions (CH_3COO^-) was examined (Figure 4.9).

Question Card 2

No	Item	Acid	Base	Other (specify)	pH			Comment
1	Milk				1-6	7	8-14	
2	Vinegar				1-6	7	8-14	
3	Lemon Juice				1-6	7	8-14	
4	Soap				1-6	7	8-14	
5	Floor cleaner				1-6	7	8-14	
6	Baking soda solution				1-6	7	8-14	
7	Soda drinks				1-6	7	8-14	
8	Water				1-6	7	8-14	
9	NaOH				1-6	7	8-14	
10	HCl				1-6	7	8-14	
11	NH_3				1-6	7	8-14	
12	CO_2				1-6	7	8-14	
13	CH_3COO^-				1-6	7	8-14	

Figure 4.9: Question Card 2 for Form 6 students and teachers showing linkage to the Brønsted-Lowry and Lewis models

In the section 4.3.3.1 attributes that explore linkages to the Brønsted-Lowry Model are examined.

4.3.3.1 Attributes that explore linkages to the Brønsted-Lowry model

The responses revealed three attributes based on Form 6 students' responses to the ethanoate ions (CH_3COO^-) prompt. None of these attributes were aligned with the Brønsted-Lowry model as listed in in Table 4.11.

The following descriptions illustrate the students' reasoning for each attribute:

- *Hydrogen ions:* Four out of eight Form 6 students (50%) revealed this attribute. Students SF6e, and SF6f identified ethanoate ions (CH_3COO^-) as an acid because it contains hydrogen atoms or hydrogen ions. One of these two students (SF6e) stated that ethanoate ions (CH_3COO^-) is an acid because it contains hydrogen atoms in the CH_3 part. Students SF6b and SF6g stated ethanoate ions (CH_3COO^-) is neutral because ethanoate ions (CH_3COO^-) does not have the hydrogen ions. All these lines of reasoning are considered misconceptions.
- *Carbon or/and oxygen*: Two out of eight students (25%) which were SF6c, and SF6g indicated that the presence of COO^- ions or carbon or oxygen in the ethanoate ion makes it a weak acid. This response suggested the presence of carbon and oxygen were used to determine an acid or a base, which is incorrect.
- *Unsure:* Two out of eight students (25%) were not sure how to identify the ethanoate ions (CH_3COO^-) ion as an acid or a base.

The attributes indicated that students were not aware that the ethanoate ion (CH_3COO^-) is a conjugate base according to the Brønsted-Lowry model. For this reason, four Form 6 students identified ethanoate ions (CH_3COO^-) as acid, while another two (SF6b and SF6d) indicated that ethanoate ions (CH_3COO^-) were neutral and students SF6a and SF6h stated that they were unsure. None of the students could identify the ethanoate ions as a base.

In the following text, the frequency of attribute distribution for Form 6 students related to the Brønsted-Lowry model is now explored.

4.3.3.2 Frequency of attributes distribution across Form 6 students related to the Brønsted-Lowry model

The frequency of attribute distribution for Form 6 students in relation to the Brønsted-Lowry model is presented in Table 4.11.

Table 4.11: Distribution of Form 6 Students' Attributes for the Brønsted-Lowry Model

	SF6a	SF6b	SF6c	SF6d	SF6e	SF6f	SF6g	SF6h	Frequency /16 (n%)
Hydrogen ions		■		■	■	■			4 (50)
Carbon or /and oxygen			■				■		2 (25)
Unsure	■							■	2 (25)
Total attributes	1	1	1	1	1	1	1	1	
Brønsted-Lowry Model attributes	0	0	0	0	0	0	0	0	

Note. *Brønsted-Lowry model attributes are (i.e., conjugate acid-base pair). Shading indicates which attributes the students provided.

Form 6 students did not reason that ethanoate ions are bases according to the Brønsted-Lowry definition, but instead based their identification of an acid or a base on the attributes *hydrogen ions*, *carbon or/and oxygen,* or *unsure* as shown in Table 4.11, which is incorrect. This result indicates students still draw on the concept of *hydrogen* ions, and *carbon or oxygen* atoms to determine whether a substance is an acid or a base. None of the attributes students used to identify the ethanoate ions (CH_3COO^-) ions as acid or base were aligned with the Brønsted-Lowry model, indicating that they were unable to comprehend that ethanoate ions (CH_3COO^-) ions act as a conjugate base.

The links to the Lewis model is now examined.

4.3.4 Links to the Lewis Model

The substance carbon dioxide (CO_2) was used to probe students' use of the Lewis model (Table 4.12). The responses of the eight Form 6 students displayed three attributes: *scientific test*, *source reference* and *unsure*. Three of the students were not able to explain how an electron pair bonding reaction occurred using the Lewis model. Three students each described the Lewis model in terms of the lime water test, while two other students identified an acid or a base based on knowledge from books or teachers, neither of which were correct in terms of the Lewis model (Table 4.12).

The next section describes the attributes that explore linkages to the Lewis model.

4.3.4.1 Attributes that explore linkages to the Lewis model

According to the Lewis model, bases donate electrons while acids accept electrons. However, no aspects of this explanation were displayed in students' responses where none of the attributes matched the Lewis model (see Table 4.12).

The description below explains how students used these attributes to justify their *choices:*

- *Scientific test (lime water test):* Three out of the eight Form 6 students (38%) (SF6a, SF6e, and SF6f) associated the Lewis Model with the lime water test for a base, which is incorrect. These three Form 6 responses stated that the limewater was used to indicate an acid rather than its usual indication of the presence of carbon dioxide.
- *Source reference:* Two out of eight students (25%) (SF6c, & SF6d) identified acids or bases from knowledge gathered from textbooks or from teachers. Student SF6c described associated high levels of carbon dioxide in the blood may cause blood to be more acidic from reading it in a book.

Student SF6d explained how he knew from books that carbon dioxide is in Group 14 of the Periodic Table and possesses acidic properties.

- Unsure: Three out of eight Form 6 students (38%) were unsure how to identify carbon dioxide as an acid or a base.

Five Form 6 students indicated that carbon dioxide was an acid and another three students responded *not sure*, but none of the students used electron pair transfer to explain why carbon dioxide is an acid.

Section 4.3.4.2 reviews the frequency of attribute distribution for Form 6 students related to the Lewis model.

4.3.4.2 Frequency of distribution of attributes for Form 6 students related to the Lewis model

The frequency of attribute distribution across Form 6 students related to the Lewis model is displayed in Table 4.12.

Table 4.12: Distribution of Form 6 Students' Attributes for Lewis Model

Attributes	SF6a	SF6b	SF6c	SF6d	SF6e	SF6f	SF6g	SF6h	Frequency /8 (n%)
Scientific test (lime water test)									3 (38)
Source reference									2 (25)
Unsure									3 (38)
Total attributes	1	1	1	1	1	1	1	1	
Lewis model attributes	0	0	0	0	0	0	0	0	

Note. *Lewis model attributes are scientific attributes (i.e., electron pair bonding). Shading indicates which attributes the students provided.

Table 4.12 shows that none of the Form 6 students identified carbon dioxide based on electron pair bonding as an identifier of an acid. Some used their knowledge of the limewater test to (incorrectly) determine carbon dioxide as an acid. This result displayed that students were not aware of the Lewis Model and its definition of an acid and a base.

The next section provides a summary of the chapter.

4.4 Summary

This chapter provides an overview of the attributes that characterise students' mental models for the six selected acid-base chemistry concepts and the links between these attributes and the four scientific acid-base models. The attributes were displayed in responses by students across each schooling level. Identification of these attributes was gathered from questions designed to probe their understanding of selected acid-base chemistry concepts and acid-base models. The attributes were necessary to identify students' stages of mental models development, which will be shown in Chapter 5. The results indicated that all 24 students displayed use of the Phenomenological model. To explain the Neutralisation concept, almost all students used the *product formation* and the *pH value* attribute linked to the Arrhenius model and the *pH value* of the Phenomenological model . For the Acid-Strength concept, Form 4 and Form 6 students tended to describe this concept using the *degree of dissociation degree of dissociation ions* and *molar concentration* attributes. Form 6 students displayed the use of attributes such as *degree of dissociation* and *strong base weak acid*, which are attributes linked to the Arrhenius model to explain Acid-Base Equilibrium. For the Buffers and Acid-Base Electron Pair Bonding concepts, Form 6 students did not use attributes linked to the Brønsted-Lowry or the Lewis acid-base models.

The attributes revealed in responses to Question Card Two provided some information about how students identify a substance as acid or base. The responses showed that all students at the different schooling levels used the Phenomenological model but some students had difficulty identifying soda drinks as acids. In addition, a few Form 4 and Form 6 students indicated ammonia (NH_3) as acid because ammonia (NH_3) consisted of three hydrogen atoms in its structure. This response could be a misinterpretation of the Arrhenius model, which desribes an acid as a substance that produces hydrogen ions in an aqueous solution. Form 6 students were also found to have difficulty identifying ammonia (NH_3) as a base using the Brønsted-Lowry model, and all of them were did not accurately identify ethanoate ions (CH_3COO^-) as a base using the Brønsted-Lowry model. The Form 6 students were also unable to indicate carbon dioxide (CO_2) was acidic using the Lewis model. These findings suggest Form 6 students were not able to use the attributes of the Brønsted-Lowry and Lewis models to identify ammonia (NH_3) and ethanoate ions (CH_3COO^-) as bases and carbon dioxide (CO_2) as acids.

The next chapter describes the stages of students' mental models development that was identified on the basis of a classification system that was developed by the researcher in this study using the attributes revealed in this chapter.

Chapter 5. Results: Types of Student Mental Models

5.1 Chapter Overview

This chapter first presents a classification system for identifying types of mental models based on the students' attributes discussed in the previous chapter. The following sections describe how the classification system was developed, and its role in identifying different stages in students' mental model development for the six selected acid-base chemistry concepts. The classification system developed for the types of mental models students have for each of the selected acid-base concepts is now discussed.

5.2 Classification of Students' Mental Models for Acid-Base Chemistry Concepts based on attributes

This chapter sets out to answer Research Question 2:

> How can students' mental models for the six selected acid-base chemistry concepts be classified based on their attributes and used to identify students' mental models development at different stages of Malaysian schooling?

In order to identify different types of student mental models, the attributes revealed in students' responses to questions about acid-base chemistry concepts in Chapter 4 needed to be classified. It was decided in this study to begin by classifying the attributes into stages based on the levels at which each of the six selected acid-base concepts were first introduced into the curricular model (i.e., the Malaysian Science Curriculum). The stages are referred to as Stage 1, Stage 2 and Stage 3 corresponding to Forms 2, 4 and 6 of the Malaysian curriculum respectively. Thus, attributes in Stage 1 correspond to students' thinking about the acid-base chemistry concept of Macroscopic Properties; in Stage 2 the concepts of Neutralisation and Acid-Strength; and in Stage 3 the concepts of Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding. These stages reflect the intended learning outcomes of the curricular model. The stages are then further classified into sub-stages by examining the students' attributes to see if and how students used the four scientific acid-base models (i.e., Phenomenological, Arrhenius, Brønsted-Lowry, and Lewis) in their line of reasoning as they attempted to answer the questions on the Question Cards. In other words, the students' mental model attributes were compared with the attributes of the scientific acid-base models (see Table 5.1 below) and the similarities and/or differences were used to devise the sub-stages in students' mental model development for each of the six selected acid-base concepts.

Table 5.1: Key attributes of scientific acid-base models

Phenomenological	Arrhenius	Brønsted-Lowry	Lewis
Based on observable sensory perceptions, for example: • Acids are sour, bases are slippery and bitter; • Acids and Bases change the colour of indicators, • pH measurements • Reduce or removing acid or a base properties by a base or an acid	Based on the hydrogen and hydroxide ions for example: • Acid and base react to produce salt and water; • Acids are substances that dissociate to produce hydrogen ions in water; • Bases are substances that dissociate to produce hydroxide ions in water; • Acid-Strength is dependent on degree of dissociation of the hydrogen or hydroxide ions in water.	Based on proton transfer • Acid as proton donor; • Base as proton acceptor; • Conjugate base; (e.g., CH_3COO^-); • Conjugate acid; (e.g., H_3O^+); • Weak acid produces a relative strong conjugate base; • Strong acid produces a relative weak conjugate base.	Based on electron pair transfer • Lewis acid accepts an electron pair; • Lewis base donates an electron pair; • Metal cations are Lewis acids; (e.g., Mg^{2+}); • Molecules containing multiple bonds between two atoms of different electronegativities are Lewis acids; (e.g., CO_2); • An atom, ion, or molecule with a lone pair be a Lewis base; (e.g., NH_3); • Anions are Lewis bases; (e.g.,CH_3COO^-).

As mentioned earlier, the attributes were organised into a classification system that comprised three stages of mental model development. Each level is centred on one or more of the selected acid-base concepts which was determined by the level at which those concepts were introduced in the curricular model. The stages also correspond to specific acid-base models which the curricular model deems appropriate for explaining and understanding the concepts. For example, the curricular model introduces the Phenomenological model as a means of understanding the concept of Macroscopic Properties at the Form 2 level of the curriculum, that is, students in Form 2 schooling level would be expected by the curricular model to grasp the acid-base chemistry concepts of Macroscopic

Properties using the scientific explanation provided by the Phenomenological model. The mental models that students develop for Macroscopic Properties are categorised as Stage 1 mental models and the explanations they provide (as revealed by their attributes) are used to determine the sub-stages. Thus, the classification system for students' mental models in this study is based on links between acid-base concepts, acid-base models and students' mental model attributes.

Continuing the description of the classification system, it can be seen for Stage 2 mental models the curricular expectation is that students use the Arrhenius model for explaining the concepts of Neutralisation and Acid-Strength; and for Stage 3 the Brønsted-Lowry model for the concepts of Acid-Base Equilibrium and Buffers and the Lewis model for the Acid-Base Electron Pair Bonding concept. The curricular model requires Form 4 students to build on their Stage 1 mental models for Macroscopic Properties to form Stage 2 mental models for the concepts of Neutralisation and Acid-Strength using the scientific explanation provided by the Arrhenius model. In turn, Form 6 students will be required to further develop their Stage 1 and Stage 2 mental models by building Stage 3 mental models for the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts using the scientific explanations embedded in the Brønsted-Lowry and Lewis models. (Note: the Form 2 curricular model does introduce Form 2 students to the concept of Neutralisation, but only in terms of a word equation). Students are only expected to understand Neutralisation concept using the Phenomenological model (i.e., evaporation of salt solution or using indicators) indicating a misalignment between the introduction of concepts and the explanatory scientific acid-base model in the curricular model (i.e., Neutralisation concept is introduced with a brief description of the Arrhenius model). As a result, when a Form 2 student described Neutralisation concept in terms of a word equation, the researcher made a decision to classify the response as using the Arrhenius model and the student's mental model was assigned as a Stage 2 mental model.

To encompass students' multitude of responses and explanations, the stages were further divided into fifteen sub-stages as shown in Table 5.2. The complete set of students' responses with the assigned stages of mental models can be seen in Appendix F.

Table 5.2: Characteristics of students' mental models related to their use or non-use of attributes from scientific models, which have been developed from this research

Stage	Sub-stage	Description
Stage 1		Student use of the Phenomenological model to describe or explain Macroscopic Properties
	1a	Students do not use the Phenomenological model to answer probe questions
	1b	Students use the Phenomenological model, which results in a wrong answer to probe questions
	1c	Students use the Phenomenological model, which results in a right answer to probe questions
	1d	Students use another acid-base model, which results in a wrong answer to probe questions
	1e	Students use another acid-base model, which results in a right answer to probe questions
Stage 2		Students' use of the Arrhenius model to describe or explain Neutralisation and Acid-Strength concept
	2a	Students do not use the Arrhenius model to answer probe questions
	2b	Students use the Arrhenius model, which results in a wrong answer to probe questions
	2c	Students use the Arrhenius model, which results in a right answer to probe questions
	2d	Students use another acid-base model, which results in a wrong answer to probe questions
	2e	Students use another acid-base model, which results in a right answer to probe questions
Stage 3		Students' use of the Brønsted-Lowry model to describe and/or explain Acid-Base Equilibrium and Buffers and the Lewis model to describe and/or explain Acid-Base Electron Pair Bonding
	3a	Students do not use the Brønsted-Lowry and Lewis model to answer probe questions
	3b	Students use the Brønsted-Lowry and Lewis models, which results in a wrong answer to probe questions
	3c	Students use the Brønsted-Lowry and Lewis models, which results in a right answer to probe questions
	3d	Students use another acid-base model, which results in a wrong answer to probe questions
	3e	Students use another acid-base model, which results in a right answer to probe questions

Table 5.2 shows the sub-stages ending with 'c' used the appropriate acid-base model with a right answer while sub-stages ending with 'b' used the appropriate acid-base model but with a wrong answer. Sub-stages ending with 'e' were assigned to students using other acid-base models with a right answer and sub-stages ending with 'd' to students using other acid-base models with a wrong

answer. Finally, students who did not use any acid-base model were assigned a sub-stage ending with an 'a'.

The distribution of students' Stage 1 mental models for acid-base chemistry concepts is now described in greater detail. The first concept is Macroscopic Properties.

5.3 Stage 1 Acid-base Chemistry Concept (Macroscopic Properties)

For the Macroscopic Properties concept, results were classified into nine different attributes overall and five sub-stages of mental models in students' thinking were present. The distribution of attributes and their assigned sub-stages are presented in Table 5.3.

Table 5.3: Distribution of students' attributes for the Macroscopic Properties concept according to sub-stages of mental model development

Attributes	Sub-stages of Mental Models				
	1a	1b	1c	1d	1e
Senses			24		
Source reference	7				
pH value	11				
Physical strength		4			1
Scientific test		1	23		
Reactions	1	1		1	2
Sub-microscopic			1	5	
Use of acids or bases					2
Unsure	6				

Note: Numbers may not add up to 24 because students may display the use of more than one attribute in their responses

The nine student attributes in Table 5.3, were classified into the Stage 1 mental model because these attributes were identified in students' responses to probe questions about Macroscopic Properties concept. Three of the student attributes, *senses*, *pH value* and *scientific test*, were aligned with the scientific attributes of the Phenomenological model while their other attributes were not aligned.

The findings showed that a high proportion of students displayed the use of the Phenomenological model in their Stage 1 mental models for the Macroscopic Properties concept, with all 24 students displaying the *scientific test* and *senses* attributes, a sub-stage 1c mental model, indicating that most students were using important aspects of the Phenomenological model appropriately to describe or explain Macroscopic Properties concept.

Eleven students used an attribute describing the macroscopic properties of acids and bases (i.e., the *pH value* attribute), considered as an attribute of the Phenomenological acid-base model.. Six students' thinking was assigned to a sub-stage 1a mental model category for their *unsure* attribute and seven more to the same category for their *source reference* attribute because they did not use the Phenomenological model to answer probe questions. This classification of their mental models suggests they were not sure how to use the Phenomenological model to explain Macroscopic Properties concept. The frequency of the *sub-microscopic* student attribute showed that two Form 4 and three Form 6 students were able to explain aspects of Macroscopic Properties concept at a microscopic or abstract level by using the Arrhenius model. For example, one student (SF6d) mentioned that hydrogen ions turn into hydrogen gas in the form of bubbles, displaying a sub-stage 1d, implying that acids produce bubbles.

Four out of the five students who displayed the *physical strength* attribute were assigned a sub-stage 1b mental model (i.e., they stated acids and bases are corrosive or harmful) because this attribute does not correspond to an attribute of the scientific Phenomenological model. The fifth student (SF4e) reasoned that an acid consisted of hydrogen ions that corrode buildings. This student used the

Arrhenius model, but explained that hydrogen ions caused buildings to corrode, which was correct, and so was assigned a sub-stage 1e.

The distribution of selected acid-base chemistry concepts at Stage 2 of the classification system (i.e., Neutralisation and Acid Strength concepts) is now described.

5.3.1 Stage 2 Acid-base Chemistry Concepts (Neutralisation and Acid Strength)

For the Neutralisation concept, the finding revealed twelve different attributes overall in students' thinking and four sub-stages of mental models were devised based on their attributes. The distribution of attributes and their assigned sub-stages are presented in Table 5.4.

Table 5.4: Distribution of students' attributes for the Neutralisation concept according to stages of mental model development

Attributes	Sub-stages of Mental Models				
	2a	2b	2c	2d	2e
Product Formation	4		19		
Reactant		1	17		
Senses				2	
Neutralisation			2		
Properties change		4			
Submicroscopic			4		
Heat	1				
Experiment		1	6		
pH value	10				
Equation		1	12		
Physical Mixing	1				
Unsure	3				

Note: Numbers may not add up to 24 because students may use more than one attribute in their responses

Seven of the students' attributes shown above (i.e., *product formation, reactant, equation, sub-microscopic, experiment, and neutralisation)* were aligned with the scientific attributes of the Arrhenius model, while their other attributes were not aligned.

The findings showed that a high proportion of students displayed the use of the Arrhenius model in their Stage 2 mental model for the Neutralisation concept, when they presented attributes directly linked to the Arrhenius model. For example, almost all 24 students used the *product formation* attribute; 18 out of the 24 students used the *reactant* attribute; 12 students the *equation* attribute (i.e., acid + alkali→ salt and water); and seven students the *experiment* attribute. Six students were assigned to a sub-stage 2c mental model category for their *experiment* student attribute and another student with sub-stage 2b mental model for the same attribute explained that a new substance 'acikalic' is formed when lemon juice (i.e., an acid) and bitter gourd (i.e., a base) react together. Two Form 6 and two Form 4 students stated that in an acid and base reaction, hydrogen ions react with hydroxide ions, revealing the student *sub-microscopic* attribute, which indicates a sub-stage 2c mental model. The high number of students classified as sub-stage 2c indicates that the majority of students were using the attributes of the Arrhenius model to explain the Neutralisation concept.

In contrast, the occurrence of other mental models indicates that students were not always developing appropriate understanding of the concepts. For example, four out of the 24 students who revealed the *Properties change* student attribute were assigned a sub-stage 2b mental model because they used the Arrhenius model incorrectly. The students tried to link the result of the reaction of an acid and a base (i.e., an attribute of the Arrhenius model) to the properties of acids and bases (i.e., the Phenomenological model).

The next selected acid-base chemistry concept under investigation is the Acid-Strength. For this concept, six different attributes and four sub-stages of mental models were developed from the students' attributes. The distribution of attributes and their assigned stages are presented in Table 5.5.

Table 5.5: Distribution of students' attributes for the Acid-Strength concept according to stages of mental model development

Attributes	Sub-stages of Mental Models				
	2a	2b	2c	2d	2e
Concentration of ions		7			
Degree of dissociation			14		
Physical strength based on pH	3				
Physical strength based on properties				1	
Molar concentration	14				
Unsure	3				

Note: Numbers may not add up to 16 because students may use more than one attribute in their responses

One of the students' attributes shown above (*degree of dissociation degree of dissociation ions)* were aligned with the scientific attributes of the Arrhenius model while other attributes were considered not aligned with the Arrhenius model.

The findings showed that the majority of students used the Arrhenius model in their Stage 2 mental model for Acid-Strength concept when the attributes they presented directly linked to the Arrhenius model. For example, 14 students out of 16 revealed the *degree of dissociation* attribute, denoting a sub-stage 2c.

However, other mental models indicate that students developed a different understanding of Acid-Strength concept. For example, 14 out of 16 Form 4 and Form 6 students were assigned to sub-stage 2a because they did not use the Arrhenius model to explain the concept of Acid-Strength but used the attribute of *molar concentration*. Other student attributes which are not aligned with the Arrhenius model are *physical strength based on pH,* and *physical strength based* *on properties.* For example, three out of 16 students presented the *physical strength based on pH* attribute; one student (SF4h) out of 16 who revealed the *physical strength based on properties* student attribute was assigned a sub-stage 2d mental model denoting the incorrect use of Arrhenius model when the student said that a strong acid has a corrosive property and followed by a statement that a strong acid ionises completely in water suggesting student SF4h was using one acid-base model and one non-acid-base model to describe Acid-Strength concept.

The next selected acid-base concept at Stage 3 classification system is the Acid-Base Equilibrium.

5.3.2 Stage 3 Acid-base Chemistry Concept (Acid-Base Equilibrium, Buffers, Acid-Base Electron Pair Bonding)

For the Acid-Base Equilibrium concept, the findings showed five different attributes and two sub-stages of mental models. Table 5.6 presents the attributes and their assigned sub-stages.

Table 5.6: Distribution of students' attributes for the Acid-Base Equilibrium concept according to stages of mental models development

Attributes	Sub-stages of Mental Models				
	3a	3b	3c	3d	3e
Reversible Reaction	1				
Degree of dissociation					1
Strong base weak acid					4
Quantity of matter	2				
Unsure	6				

Note: Numbers may not add up to eight because students may use more than one attribute in their responses

None of the students' attributes shown in Table 5.6 were aligned with the scientific attributes of the Brønsted-Lowry model.

The findings showed that no students used the Brønsted-Lowry model in their Stage 2 mental models as their attributes were not linked to the Brønsted-Lowry model. For example, six students presented the *unsure* attribute; four out of eight students used the *strong base weak acid* attribute; two students used *quantity of moles* attribute; and one student each used *reversible reaction and degree of dissociation ions* attributes. However, the *degree of dissociation* and *strong base weak acid* students' attributes, linked to the Arrhenius model, was assigned to a sub-stage 3e mental model.

The next selected concept is Buffers.

For the Buffers concept, six different attributes in students' thinking and three sub-stages of mental models were developed. The assigned attributes and their stages are presented in Table 5.7.

Table 5.7: Distribution of students' attributes for the Buffers concept according to stages of mental models development

Attributes	Sub-stages of Mental Models				
	3a	3b	3c	3d	3e
Reactant				5	
Acidity change	1				
Resist pH change	2				
Improper conjugate ideas		3			
Neutralisation				2	
Unsure	8				

Note: Numbers may not add up to eight because students may use more than one attribute in their responses

The students' attributes (i.e., *improper conjugate ideas*) showed that three students recognised the term 'conjugate' but were not able to explain further. A sub-stage 3b mental model was assigned to three students displaying the *improper conjugate ideas* student attribute who attempted to use the Brønsted-Lowry model but provided a wrong explanation. The three students tended to think a conjugate base is an acid and a conjugate acid is a base. This inability to correctly use the term conjugate meant that no Form 6 students - displayed the appropriate use of the Brønsted-Lowry model in their Stage 3 mental model for the Buffers concept.

The students' use of other attributes not aligned with the scientific attributes of the Brønsted-Lowry model also reflected their lack of understanding of the Bronsted-Lowry model. For example, eight students presented the *unsure* attribute; five students used the *reactant* attribute; two the *resist pH change* attribute. Five out of the eight students (i.e., *reactant* attribute) explained that a buffer solution is a reaction between any acid and a base while another two students (i.e., *neutralisation* attribute) explained that a buffer solution is a neutralisation process resulting in a pH 7 solution. Both these groups of students used the attributes of the Arrhenius model but provided an incorrect description because the students did not state that a buffer solution consists of a solution of a weak acid and a salt ,denoting sub-stage 3d mental models.

Next, the Acid-Base Electron Pair Bonding chemistry concept is discussed.

For the Acid-Base Electron Pair Bonding concept, five attributes and three sub-stages of mental models were displayed. The attributes and their assigned sub-stages are presented in Table 5.8.

Table 5.8: Distribution of students' attributes for the Acid-Base Electron Pair Bonding concept according to stages of mental model development

Attributes	Sub-stages of Mental Model				
	3a	3b	3c	3d	3e
Strong acid-weak base reaction				1	
Acid-acid reaction				3	
Base-unknown reaction				1	
Dative bonding		1			
Unsure	2				

Note: Numbers may not add up to eight because students may use more than one attribute in their responses

Only one out of six of the students' attributes (i.e., *dative bonding)* was aligned with the Lewis model while all their other attributes were not aligned. The student that displayed a *dative bonding* attribute used the Lewis model when stating that a

Lewis acid donates an electron pair, a sub-stage 3b mental model. However, the student did not realize that a Lewis acid accepts an electron pair and does not donate an electron pair.

The findings showed that only one of eight Form 6 students t displayed the use of Lewis model in their Stage 3 mental model for the Acid-Base Electron Pair Bonding concept. For example, three students presented the *acid-acid reaction* attribute; two students the *alkali and unknown reaction*; 2 students the *strong acid weak base reaction;* two students the *base and unknown reaction* attribute. The use of the *unsure* attribute established that two students were not able to use any acid-base model to explain Acid-Base Electron Pair Bonding concepts, which assigned them to a sub-stage 3a mental model.

The stages of mental models development will now be discussed.

5.4 Description of the Stages of Mental Model Development

A system was developed to classify students' mental models based on the students' attributes in the previous chapter. These were classified into three stages of mental models development identified as Stage 1, Stage 2, and Stage 3. The links between the stages of mental models, acid-base chemistry concepts, representational level and acid-base model are presented in Figure 5.1.

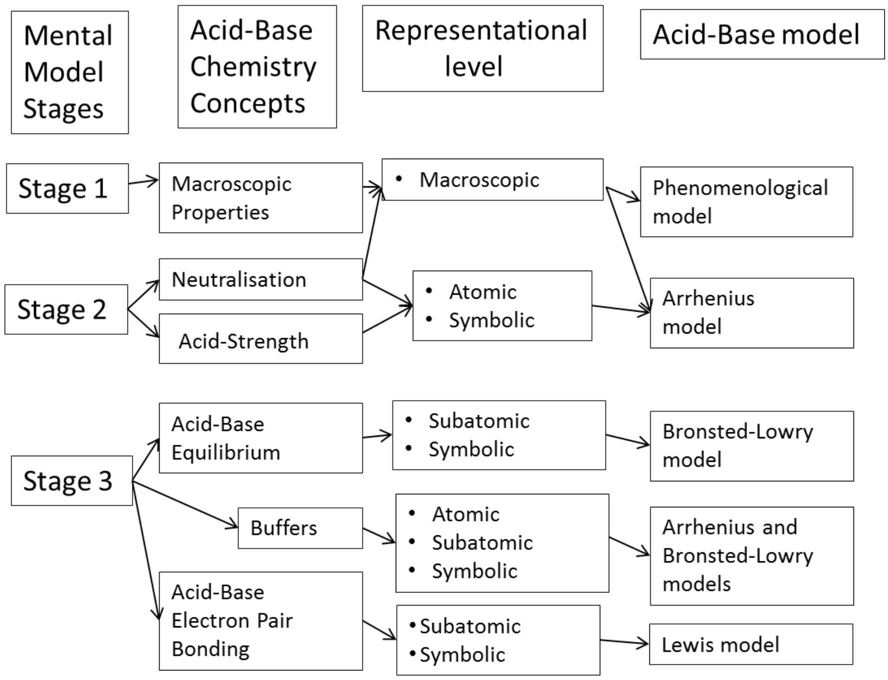

Figure 5.1: Link between the stages, acid-base chemistry concepts representational level, and acid-base model

Figure 5.1 shows that a Stage 1 mental model represents an understanding of the Macroscopic Properties acid-base concept and comprises five sub-stages (i.e., sub-stages, 1a, 1b, 1c, 1d, and 1e). At Stage 1, the mental models represent students' ideas of the Macroscopic Properties concept in relation to their use of the scientific attributes of the Phenomenological model (see Table 5.9).

Stage 2 mental models, represent understandings of the Neutralisation and Acid-Strength concepts with reference to students' use of the Arrhenius model. At the Form 2 schooling level, a Stage 2 mental model is limited to the macroscopic features of the Neutralisation concept and a word equation (i.e., a reaction between an acid and a base producing salt and water). For Forms 4 and 6 schooling level, students had been introduced to the notion of hydrogen and hydroxide ions in acids and bases resulting in the use of atomic and symbolic representational levels of thinking. This stage of mental models comprised five sub-stages (i.e., sub-stages, 2a, 2b, 2c, 2d, and 2e). For the Neutralisation concept, students in this thesis study held a minimum of one and a maximum of three sub-types of mental models. For the Acid-Strength concept almost all students held two mental model sub-stages (i.e., 2a and 2c). These two mental models feature the *degree of dissociation ions* and *molar concentration* attributes.

Stage 3 mental models demonstrate students' ability to use more sophisticated acid-base models in their thinking. For example, use of the Brønsted Lowry model to explain Acid-Base Equilibrium; the Brønsted-Lowry and Arrhenius models to explain the components of Buffers; and the Lewis model to explain Acid-Base Electron Pair Bonding concepts. At Stage 3 of mental model development students explain concepts at a subatomic level including particles such as protons and electrons in addition to features indicating the symbolic representational level. The main difference between Stage 2 and Stage 3 mental models rests in the understanding of acid-base concepts at different representational levels. At Stage 2, Form 4 and Form 6 students explained acid-base concepts at the atomic level (i.e., ions) while at Stage 3, Form 6 students explained the Acid-Base Equilibrium concept at the atomic and subatomic levels (i.e., ions and protons) using the Brønsted-Lowry model. With Stage 3 mental models Form 6 students were ideally expected to explain the Acid-Base Electron Pair Bonding concept at the subatomic level (i.e., electron pair) using the Lewis model.

5.5 Distribution of Students' Stages of Mental Model Development for Six Acid-Base Chemistry Concepts

Table 5.9 provides information on students and their respective stages of acid-base chemistry concepts according to their use of acid-base models in their explanations. Typically, students owning sub-stages 'c' demonstrated using the appropriate acid-base model to explain the six selected acid-base chemistry concepts. Additionally, a sub-stage ending with the letters 'd' and 'e' indicated students using other acid-base models to explain acid-base concepts, while 'a' denotes the students not using any acid-base models to explain the selected acid-base chemistry concepts.

Table 5.9: Distribution of students' mental models for six selected acid-base chemistry concepts

Students	Macroscopic Properties	Neutralisation	Acid-Strength	Acid-Base Equilibrium	Buffers	Acid-Base Electron Pair Bonding	Total
SF2a	1a,1c	2a,2b,2c*					5
SF2b	1c,1a	2a,2c*					4
SF2c	1a,1c	2a,2c*					4
SF2d	1a,1c,1e	2a,2c*					5
SF2e	1c	2a,2b					3
SF2f	1c	2a,2b,2d					4
SF2g	1a,1c	2a,2c*					4
SF2h	1b,1c	2c*					3
SF4a	1b,1c	2a,2c, 2d	2a,2b				7
SF4b	1a,1b,1c,1d,	2c	2a,2b,2c				8
SF4c	1b,1c	2a,2c	2a,2c				6
SF4d	1c	2b,2c	2a,2b,2c				6
SF4e	1a,1c,1d,1e	2b,2c	2a,2c				7
SF4f	1a,1c,1d	2b,2c	2a,2c				7
SF4g	1a,1c	2c	2a,2b,2c				6
SF4h	1a,1c,1e	2c	2a,2b,2c,2d				8
SF6a	1a,1c	2a,2c	2a,2b, 2c	3a	3a,3b,3d	3d	12
SF6b	1a,1c,1d	2a,2c	2b,2c	3a,3e	3a,3d	3d	12
SF6c	1a,1b, 1c,1d	2c	2a,2c	3e	3a,3b,3d	3a	12
SF6d	1c,1d,1e	2a,2c	2a,2c	3a	3a	3b	10
SF6e	1a,1c,1d	2a,2c	2a,2b,2c	3e	3a,3b,3d	3a	13
SF6f	1a,1c, 1e,	2c	2a,2c	3a,3e	3a	3d	10
SF6g	1a,1b,1c	2c	2a	3a	3a	3d	8
SF6h	1a,1c	2c	2a,2c	3a,3e	3a,3d	3d	10

Note:
Sub-stage 1a where students were not using the Phenomenological model to reason probed questions
Sub-stage 1b where students attempted to use the Phenomenological model resulting in a wrong answer to probed questions
Sub-stage 1c where students attempted to use the Phenomenological model resulting in a right answer to probed questions
Sub-stage 1d where students attempted to use other acid-base models resulting in a wrong answer to probed questions
Sub-stage 1e where students attempted to use other acid-base models resulting in a right answer to probed questions
Sub-stage 2a where students were not using the Arrhenius model to reason probed questions
Sub-stage 2b where students attempted to use the Arrhenius model resulting in a wrong answer to probed questions
Sub-stage 2c where students attempted to use the Arrhenius model resulting in a right answer to probed questions
Sub-stage 2d where students attempted to use other acid-base models resulting in a wrong answer to probed questions
Sub-stage 2e where students attempted to use other acid-base models resulting in a right answer to probed questions
Sub-stage 3a where students were not using the Brønsted-Lowry or Lewis model to reason probed questions
Sub-stage 3b where students used the Brønsted-Lowry or Lewis model resulting in a wrong answer probed questions
Sub-stage 3c where students used the Brønsted-Lowry or Lewis model resulting in a right answer to probed questions
Sub-stage 3d where students attempted to use other acid-base models resulting in a wrong answer to probed questions
Sub-stage 3e where students used other acid-base model resulting in a right answer to probed questions
*Form 2 students assumed to demonstrate the use of the Arrhenius model

Table 5.9 shows that all students at Form 2 schooling level were using the Phenomenological model to explain the Macroscopic Properties concept, a sub-stage 1c mental model. The Form 2 students also displayed a sub-stage 2c mental model when using the Arrhenius model to explain the Neutralisation concept. Students demonstrating the sub-stages 1c and 2c indicated that they have comprehended the Macroscopic Properties and Neutralisation acid-base concepts.

At Form 4, a high proportion of students displayed a sub-stage 1c mental model for the Macroscopic Properties concept and a sub-stage 2c mental model for the Neutralisation concept. However, for the Acid-Strength concept, the result revealed sub-stages 2c and 2a mental models, indicating that not all students understood the concept. Overall the findings showed that Form 4 students were able to understand the Macroscopic Properties, and Neutralisation concepts but had some difficulties in comprehending the Acid-Strength concept.

At Form 6, the majority of students exhibited a sub-stage 1c mental model for the Macroscopic Properties concept and a sub-stage 2c mental model for the Neutralisation concept. However, for the Acid-Strength concept the students demonstrated both sub-stage 2c and 2a mental models, while for the Acid-Base Equilibrium concept the majority of the Form 6 students exhibited a sub-stage 3a (i.e., not using any model) and a sub-stage 3e mental model (i.e., using Arrhenius model but incorrect description). Also, the majority of the Form 6 students possessed a sub-stage 3a mental model, indicating that they were not using any acid-base model for explaining the components of the Buffer concept and displayed a sub-stage 3d mental model indicating the incorrect use of the Arrhenius model to explain the Acid-Base Electron Pair Bonding concept. Interestingly, student SF6d displayed a sub-stage 3b mental model to explain the Acid-Base Electron Pair Bonding showing recognition but incorrect use of the Lewis model. The findings show that the Form 6 students were able to grasp the Macroscopic Properties and Neutralisation concepts but were only partially grasping the Acid-Strength concept. In addition, the Form 6 students did not show understanding of the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts.

5.6 Summary of Students' Stages of Mental Models Development

This chapter presents the development of a classification system for students' mental models based on attributes from their expressed models of acid-base behaviour. The classification system included three stages of mental model development; Stage 1, Stage 2, and Stage 3. Stage 1 and its sub-stages were then assigned to students of the three schooling levels who demonstrated the use and non-use of the Phenomenological models, in their explanations of the Macroscopic Properties concept. The Stage 2 mental models focused on the Neutralisation and Acid-Strength concepts where all students were questioned on the Neutralisation concept component but only Form 4 and Form 6 students were questioned on the Acid-Strength concept. Form 6 students demonstrated their Stage 3 mental model development, which focused on the concepts of Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding.

The findings revealed that Form 2 students were able to develop Stage 1 and Stage 2 mental models as anticipated in the curricular model. However, Form 4 and Form 6 students only partially achieved Stage 2 mental models and none of the Form 6 students achieved the anticipated Stage 3 mental model indicating their inability to demonstrate the use of more sophisticated acid-base models (i.e., Brønsted-Lowry or Lewis models) to explain the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding acid-base chemistry concepts.

These results indicate that Form 6 students were partly able to shift from Stage 1 to Stage 2 mental models but were not able to shift from a Stage 2 to an appropriate Stage 3 mental model.

The next chapter discusses on the degree of alignment between the students' mental models,the teachers' mental models and the curricular model.

Chapter 6. Results: Curricular Models, and Teachers' and Students' Mental Models for Selected Acid-Base Chemistry Concepts

6.1 Chapter Overview

This chapter presents an overview of findings for the third research question, that is, the similarities and differences between curricular models, and teachers' and students' mental models. The chapter begins with background information on the national science curricula in Malaysia, followed by the process of determining curricular models, and teachers' and students' mental models at the Form 2 level of schooling. Next, the frequency of similarities and differences between the three models is described. In the same manner, the Form 4 and Form 6 models are discussed. Finally, a comparison of the curricular models, and the teachers' and students' mental models provide an understanding of the layers of curriculum interpretation as discussed in Section 2.13.1.

6.2 Introduction

In order to answer research question three (i.e., in what ways do the attributes of scientific models, curricular models, and teachers' and students' mental models for selected acid-base chemistry concepts compare at different schooling levels?) it is necessary to describe how the curricular model, and teachers' and students' mental models were determined in this study. The curricular models for this thesis study consist of learning outcomes for selected acid-base chemistry concepts (e.g., Neutralisation, and Buffers concepts) taken from the curriculum documents that exist for each schooling level, while the teachers' and students' mental models were identified using responses to some of the interview questions used to answer the first two research questions. The teachers' and students' responses were cross matched with the selected learning outcomes in the curricular model to identify similarities or differences between the three models. The full responses from teachers and students to the probe questions can be found in Appendix I.

6.3 Science Education in Malaysia

Science education in Malaysia is based on a national curriculum designed by the Ministry of Education, Malaysia. The curriculum document, *The Malaysian Curriculum Specifications Guide,* covers each schooling level from Standard One (seven year olds) through Form 6 (nineteen year olds). For this study, the three curriculum documents analysed are those for the Form 2, Form 4 and Form 6 schooling levels. The respective curriculum document is closely adhered to by science and chemistry teachers at each schooling level to ensure the teaching and learning of science and chemistry are standardized for all schools. *The Malaysian Curriculum Specifications Guide for Forms Two* and *Four* prepared by the Ministry of Education, consists of learning objectives, suggested learning activities, learning outcomes, notes, and associated vocabulary (MoE, 2002, 2005). For the Form 6 schooling level, the curricular model is contained in the *Syllabus and Specimen Papers* document prepared by the Malaysian Examination Council. This Form 6 curricular model is formatted in three columns headed topic, teaching period and learning outcomes. The absence of content in the Form 6 curricular model suggests that the model is more skeletal than the Form 2 and Form 4 curricular models. Also notable, the Malaysian curriculum objectives are focused on a science-technology-society (STS) perspective and exclude the nature of science in the curricular models at all schooling levels (MEC, 2012; MoE, 2002, 2005).

Thus, the *Malaysian Curriculum Specifications Guide for Forms Two and Four* and *Syllabus and Specimen Papers for Form Six* provide only a brief description of the intended curricular models. As a result of the lack in specificity, an assumption is made in this study that teachers' mental models are considered aligned with the curricular models when teachers' explanations are consistent with scientific definitions of the acid-base chemistry concepts as outlined in Section 2.9 in the literature chapter. This study needed to refer to the scientific literature to fill the content gaps in the skeleton curricular model. The learning outcomes selected were based on their connection to the selected acid-base chemistry concepts. For example, the learning outcome *describe acid-base titration* from the curriculum document is considered a component of the Neutralisation acid-base chemistry concept. For Form 2, the learning outcomes identified in the curricular model include *identify properties of acids and alkalis* (linked to the Macroscopic Properties concept) and *explain the meaning of Neutralisation*, *write an equation in words to describe the Neutralisation process*, and *explain through examples the uses of Neutralisation in daily life* (linked with the concept of Neutralisation). At the Form 4 level, the learning outcome of *relating strong or weak acid with degree of dissociation* is associated with the Acid Strength concept and for the Neutralisation concept the corresponding learning outcomes are *explanation of Neutralisation*, *describing Neutralisation in daily life* and *describing acid-base titration*. The learning outcome related to the Acid-base Equilibrium concept is *explain changes in pH during Acid-base titrations*, and *define buffer solution* is associated with the concept of Buffer. The *use of Arrhenius, Brønsted-Lowry and*

Lewis theories learning outcome is linked to the concept of Acid-Base Electron Pair Bonding.

The next section describes the Form 2 curricular model.

6.4 Form 2 Curricular Model

The learning objective underpinning the Form 2 curricular model is '*Analysing Acid and Alkali'* (Table 6.1). For the purpose of this study, the selected Form 2 learning outcomes listed below comprise the Form 2 curricular model:

- *Identify the properties of acids, and alkalis*;
- *Explain the meaning of Neutralisation*;
- *Write an equation in words to describe the Neutralisation process*; and
- *Explain through examples the uses of Neutralisation in daily life*.

These learning outcomes are underlined in Table 6.1.

Table 6.1: The Malaysian Form 2 Curriculum Specifications Guide (MoE, 2002)

Learning Objectives	Suggested Learning Activities	Learning Outcome	Notes	Vocabulary
Analysing acid & alkali	Carry out activities to study: • * properties of acid in terms of pH value, taste, corrosive nature, effect on litmus paper, reaction with metals such as magnesium and zinc • The characteristics of alkali in terms of pH value, taste, corrosive nature, effect on litmus paper Carry out discussion to define acid and alkali operationally Carry out activities to determine the acidic and alkaline substances in daily life Gather information on the usage of acid and alkali in everyday life such as in agriculture and industry. Discuss the meaning of Neutralisation. #Discuss the application of neutralisation in daily life e.g., using shampoo and conditioner and, insect bites.	A student is able to: • *Identify the properties of acid, identify the properties of alkali, • State that acid and alkali only show their properties in the presence of water • Explain through examples the definition of acid and alkali, • Identify the substances which are acidic or alkaline in everyday life • State the uses of acid and alkali in daily life • Explain the meaning of Neutralisation, • Write an equation in words to describe the Neutralisation process, • #Explain through examples the uses of Neutralisation in daily life.	Caution: Chemicals in the laboratory should not be tasted Use only dilute acid and dilute alkali Do not use active metals such as Potassium and Sodium in the reaction with acid	Active metal - *logam aktif* Alkaline substance - *bahan beralkali* Concentration - *kepekatan* Concentrated acid - *asid pekat* Concentrated alkali - *alkali pekat* Corrosive *mengkakis* Dilute acid - *asid cair* Dilute alkali - *alkali cair* Equation in words - *persamaan Perkataan* Hydrochloric acid *asid hidroklorik* Litmus paper *kertas litmus* Metal - *logam* Neutralisation *Peneutralan* Operational definition - *definasi secara operasi* Potassium - *kalium* Sodium - *natrium* Sodium hydroxide - *natrium hidroksida*

Notes: Underlined sentences are the learning outcomes for Form 2 discussed for this thesis study
* Asterisk and # hatch are links between the selected learning outcomes and suggested learning activities

Table 6.1 also contains a further description of two intended learning outcomes which are *identify the properties of acids, and alkalis* marked as * and *explain* *through examples the uses of Neutralisation in daily life* marked as #, which are briefly presented in the suggested learning activities column.

The Form 2 curricular model was then examined to identify similarities and differences with the Form 2 teachers' mental models. The Form 2 curricular model and teachers' mental models were then compared with the Form 2 students' mental models to determine the extent to which the students were able to demonstrate an understanding of the four selected learning outcomes found in the curricular model. In this study, an assumption is made that a frequency of five or more similarities between students' mental models, and curricular models would indicate that students had achieved the learning objectives required by the curricular model. This assumption is made because five out of eight students (63%) is greater than 50 percent and provides a more reasonable measurement to identify the degree of alignment. Also, a partial alignment is referred to when one out of two teachers used similar descriptions to that of the description for the selected learning outcome in the curricular model.

The process of determining the Form 2 teachers' and students' mental models is described in the next section.

6.4.1 Process of Determining the Form 2 Teachers' and Students' Mental Models

A series of questions was asked to probe the participants' understanding of the four selected learning outcomes from the Form 2 curricular model. The two teachers interviewed were TF2a and TF2b. Teacher TF2a taught students SF2a, SF2b, SF2d, and SF2e: teacher TF2b taught students SF2c, SF2f, SF2g, and SF2h. To determine teachers' and students' degree of alignment with the *identify the properties of acids, and alkalis* learning outcome, they were first asked "What are the properties of acids and alkalis?" Then, to probe the learning outcomes of *explain the meaning of Neutralisation* and *write an equation in words to describe the Neutralisation process*, Question Card 3 (Figure 6.1) was shown.

Question Card 3

What do you think takes place when an acid and an alkali are put together?

Can you please write or draw what you think?

Figure 6.1: Question Card 3 to probe *explain the meaning of Neutralisation*

For the next selected learning outcome of *explain through examples the uses of Neutralisation in daily life*, participants were asked "Can you please tell me every day uses of acids and bases (alkalis)?" The responses gathered from students and teachers for the questions gave insights into the students' and teachers' mental models.

The next section provides a description of the teachers' and students' mental models used to identify the properties of acids and alkalis.

6.4.2 Teachers' and Students' Mental Models Used to Identify the Properties of Acid and Alkalis

The first teacher described acids as sour; bases as bitter; acid changing blue litmus to red; acids and alkalis showing their properties only in the presence of water; and acid having a pH 1 to 6 and alkali 8 to 14. Three of the first teachers' students displayed a similar understanding of the properties of acids and alkalis while the fourth student was unsure. The second teacher was not able to describe the selected learning outcome for *identify the properties of acids, and alkalis*, but all four of the teacher's students were able to *identify the properties of acids, and* *alkalis* displaying a misalignment between students' mental models and their teacher's mental models.

The findings indicated that there was a high degree of alignment between the students' mental models and the curricular model because seven out of eight students showed similar attributes to the curricular model. However, only three out of eight students' mental models were similar to the teachers' mental models, displaying a misalignment. In addition, only one out of two teachers provided a description similar to the curricular model, displaying a partial alignment between the teachers' mental model and the curricular model (Table 6.2).

Section 6.4.3 describes teachers' and students' mental models for the learning outcome of *explain the meaning of Neutralisation*.

6.4.3 Teachers' and Students' Mental Models Used to Explain the Meaning of Neutralisation

For the learning outcome of *explain the meaning of Neutralisation*, the first teacher stated that Neutralisation is a process to neutralise acidic and alkaline properties forming a neutral substance(s) and, when probed further, the first teacher explained that Neutralisation produces sodium chloride and water where both the products are neutral. Three of the first teacher's students (i.e., students SF2a, SF2b, & SF2d) showed consistency with their teacher's response while another student stated that 'acikali' is formed, indicating a misalignment.

The second teacher said that an acid and an alkali produce a neutral salt and water, a similar response to two of the students (SF2c & SF2f). However, another student knew the reaction would produce something neutral but was not able to identify the product formed. The fourth student stated that only salt is produced.

This finding showed that five out of eight students' mental models were similar to the teachers' mental models and to the curricular model displaying a high degree of alignment between the students' and teachers' mental models and students' mental models with the curricular model. In addition, the teachers' mental models showed high consistency with the curricular model.

In the next section, teachers' and students' mental models for *write an equation in words to describe the Neutralisation process* learning outcome are discussed.

6.4.4 Teachers' and Students' Mental Models for Writing an Equation in Words to Describe the Neutralisation Process

Both Form 2 teachers were able to *write an equation describing the Neutralisation process*, (i.e., "acid + alkali → salt and water") learning outcome. Thus, the teachers' mental model showed complete alignment with the curricular model because both teachers displayed similar Neutralisation concept equations to that in the curricular model.

Three students of the first teacher showed similar equations to that of the first teacher while the other student (SF2e) mentioned a product 'acikali' being formed as a replacement for salt and water, showing a mental model misalignment with their teacher's mental model and the curricular model. Students SF2c and SF2g stated they did not know of any equation, while another student wrote a mathematical equation (i.e., acid + alkali = salt + water) which is not consistent with the second teacher's mental model. The fourth student stated only salt is produced in an acid-base reaction. Consequently, all four of the second teacher's students' responses were inconsistent with their teacher's mental model and the curricular model.

For the learning outcome of *write an equation in words to describe the Neutralisation* process, only three Form 2 students' mental models were found to be similar to the teachers' mental models and curricular model.

The next selected teachers' and students' mental models for *explain through examples the uses of Neutralisation in daily life* learning outcome is discussed in the next section.

6.4.5 Teachers' and Students' Mental Models for Explaining through Examples of Neutralisation in Daily Life

In the next learning outcome, the curricular model stated that students should be able to *explain through examples the uses of Neutralisation in daily life*. As an example of the learning outcome for *explain through examples the uses of Neutralisation in daily life*, the first teacher described how when stung by an acidic sting of an insect a cream is applied to reduce acidity. This teacher also described using shampoo to neutralise hair that may be acidic. Both these examples were included in the curricular model. However, none of the first teacher's students explanations showed similarities with that of their teacher. The second teacher gave a suitable example of milk of magnesia to reduce acidity in stomach: however, only two out of four of the second teacher's students were able to provide appropriate examples. The two students (SF2f & SF2g) gave examples of using toothpaste to clean the teeth while the other two students were not able to provide any examples indicating a complete misalignment with the teacher's mental model. Also, one teacher's mental model displayed partial alignment with the curricular model because this teacher said an example of neutralisation is drinking milk of magnesia to reduce the acidity in a stomach.

To summarize, a high degree of inconsistency was displayed between the students' mental models, the teachers' mental models and the curricular model.

The frequency of similarities and differences between the curricular model, and teachers' and students' mental models is now explored.

6.4.6 Frequency of Similarities and Differences between the Curricular Model, and Teachers' and Students' Mental Models

The frequency of the similarities and differences for the selected Form 2 learning outcomes between the students' mental models, the teachers' mental models and the curricular model is presented in Table 6.2. For example, the horizontal row labelled TF2b (teacher 'b', Form 2) for *identify the properties of acids, and alkalis* shows that the teacher had an inability to state the properties of acids and bases (i.e., 1, 2), indicating a partial mismatch between the curricular model and the teacher's mental model. Similarly, for the same learning outcome, three out of eight Form 2 students showed consistency between their mental models and the teachers' mental models (i.e., 3, 8), and seven out of eight students showed similarities between their mental models and the curricular model (i.e., 7, 8).

Table 6.2: Frequency of similarities and differences between curricular models, teachers and students' mental models for Form 2 selected learning outcomes

Respondents	*Identify the properties of acids, and alkalis*			*Explain the meaning of Neutralisation*			*Write an equation in words to describe the Neutralisation process*			*Explain through examples the uses of Neutralisation in daily life*		
	C*	T*	S*	C	T	S	C	T	S	C	T	S
TF2a@	/			/			/			/		
SF2a	/	/		/	/		/	/		x	x	
SF2b	x	x		/	/		/	/		x	x	
SF2d	/	/		/	/		/	/		x	x	
SF2e	/	/		x	x		x	x		x	x	
TF2b	x			/			/			x		
SF2c	/	x		/	/		x	x		x	x	
SF2f	/	x		/	/		x	x		x	x	
SF2g	/	x		x	x		x	x		x	x	
SF2h	/	x		x	x		x	x		x	x	
Teachers	1#,2+			2, 2			2, 2			1, 2		
Students	7, 8	3, 8		5, 8	5, 8		3, 8	3, 8		0, 8	0, 8	

Notes: / indicates responses were similar to the curricular model, X indicates responses were different from curricular model, and shaded indicates 'not applicable'.

* indicates either Curricular model, Teachers' mental model, or Students' mental model, # indicates the number of teachers (students) that are consistent with the curricular model or student (teachers) model and + is total number of teachers (students).

@ respondents are coded, where T indicates Teacher, S indicates students, F2 indicates Form 2, and letters 'a' to 'h' indicate individual participants.

Teacher TF2a taught students a ,b, d and e, and teacher TF2b taught students c, f, g, and h

Table 6.2 indicates that students' mental models were aligned with the curricular model for the two learning outcomes (i.e., *identify the properties of acids, and alkalis*, and *explain the meaning of Neutralisation*). A complete misalignment between the students' mental models with the teachers' mental model and the curricular model was demonstrated for the *explain through examples the uses of Neutralisation in daily life* learning outcomes, while for the *write an equation describing the Neutralisation process* learning outcome, four students responses were not aligned with their second teacher's mental model and one student response was not aligned with the first teacher's response. For the learning outcome of *identify the properties of acids, and alkalis*, one teacher had an inability to state the properties of acids and bases (i.e., 1, 2), indicating a partial mismatch between the curricular model and the teachers' mental models. Three out of eight Form 2 students showed consistency between their mental models and their teachers' mental model (i.e., 3, 8), and seven out of eight students showed similarities between the students' mental models and the curricular model (i.e., 7, 8).

For the learning outcome of *explain the meaning of Neutralisation,* both teachers' responses indicated alignment with the curricular model. Three students demonstrated differences, while another five students' mental models showed consistency with the curricular model and their teachers' mental model.

The mental models displayed by both Form 2 teachers showed consistencies with the curricular model for the learning outcome of *write an equation describing the Neutralisation process* when both teachers were able to write a correct Neutralisation equation. However, five out of eight students' responses did not correlate with the curricular model and teachers' mental models. For the learning outcome of *explain through examples the uses of Neutralisation in daily life,* the responses to questions showed that the teachers' mental models were partially consistent with the curricular model. Six Form 2 students were not sure of examples of Neutralisation while two other students' responses were not similar to their teachers' mental models as the examples given by the teacher TF2b and students (SF2f & SF2g) differed. Therefore, the students' mental models indicated a complete misalignment with the curricular model and their teachers' mental models.

Key points arising from the Form 2 teachers' mental models and students' mental models are now examined.

6.4.7 Key Points Arising from the Form 2 Teachers' and Students' Mental Models

- One Form 2 (TF2b) teacher was not able to correctly identify the properties of acids, and alkalis and explain through examples the uses of Neutralisation in daily life learning outcomes denoting a partial alignment while the other two learning outcomes showed teachers' mental models were completely aligned with the curricular model.
- Five out of eight students' mental models showed consistency with the teachers' mental model for explain the meaning of Neutralisation while other learning outcomes showed a low correlation with the teachers' mental models.
- Seven out of eight Form 2 students were able to identify the properties of acids, and alkalis learning outcome as indicated in the curricular models; and five out of eight students showed similarities with the curricular model for explain the meaning of Neutralisation demonstrating the students' mental model was highly aligned with the curricular model Three out of eight Form 2 students were able to correctly write an equation describing the Neutralisation process learning outcome, indicating a low degree of consistency between the students' mental models to the curricular model; and
- None of the eight Form 2 students fulfilled the requirement of the learning outcome explain through examples the uses of Neutralisation in daily life. Thus, there was a complete mismatch between the students' mental model and the curricular model and teachers' mental models.

In summary, most Form 2 students achieved two out of four intended learning outcomes related to the curriculum objective analysing acids and alkalis. The Form 2 students' mental models displayed similarities with teachers' mental models and the curricular model for the learning outcome for e*xplain the meaning of Neutralisation.*

Section 6.5 discusses the Form 4 curricular model.

6.5 Form 4 Curricular Model

The learning objectives that form the basis of the curricular model under investigation for the Form 4 Malaysian curriculum is concerned with the concepts of strong acids, weak acids, strong alkalis and weak alkalis, and applying them to the concept of Neutralisation. The content of the curricular model comprises the underlined statement in the Learning Outcome column of Table 6.3. The selected learning outcomes that comprise the Form 4 curricular model for this study were identified as:

- *Relating strong or weak acid with degree of dissociation;*
- *Explanation of Neutralisation;*
- *Describing Neutralisation in daily life; and*
- *Describing acid-base titration.*

Table 6.3: The Malaysian Form 4 Curriculum Specifications Guide (MoE, 2005)

Learning Objectives	Suggested Learning Activities	Learning Outcome	Notes	Vocab
Synthesizing the concepts of strong acids, weak acids, strong alkalis & weak alkalis	Carry out an activity using pH scale to measure the pH of solutions used in daily life such as soap solution, carbonated water, tap water or fruit juice. Carry out an activity to measure the pH value of a few solutions with the same concentration. For example, hydrochloric acid, ethanoic acid, ammonia and sodium hydroxide with the use of indicators, pH meter or computer interface. Based on the data obtained from the activity above, discuss the relationship between: a. pH values and acidity or alkalinity of a substance b. concentration of hydrogen ions and the pH value c. concentration of hydroxide ions and the pH values d. *strong acids and their degree of dissociation e. *strong alkalis and their degree of dissociation f. *weak alkalis and their degree of dissociation	A student is able to: • state the use of a pH scale, • relate pH value with acidic or alkaline properties of a substance, • relate concentration of hydrogen ions with pH value, • relate concentration of hydroxide ions with pH value, • *relate strong or weak acid with degree of dissociation, • conceptualize qualitatively strong & weak acids, • conceptualise qualitatively strong & weak alkalis.	The formula pH= - log [H+] is not required Dissociation is also known as ionisation Neutralize soil using lime or ammonia, use of anti-acid. Teacher should emphasize using correct techniques	Dissociation - *penceraian* Ionization - *pengionan*
Analysing Neutralisation	^Collect and interpret data on Neutralisation and its application in daily life. Carry out activities to write equations for Neutralisation reactions. #Carry out acid-base titrations and determine the end point using indicators or computer interface. Carry out problem solving activities involving Neutralisation reactions to calculate either concentration or volume of solutions.	A student is able to: • ^ explain the meaning of Neutralisation, • ^explain the application of Neutralisation in daily life, • write equations for Neutralisation reactions • #describe acid-base titration, • determine the end point of titration during Neutralisation, • solve numerical problems involving Neutralisations reactions to calculate either concentration or volume of solutions.		

Notes: Underlined sentences are the learning outcomes for Form 4 discussed for this research
* # ^ are symbols in the suggested learning activities column corresponding to learning outcomes column

The suggested learning activities provided some additional information on the intended learning outcomes. To indicate a connection between the suggested learning activities and the intended learning outcome the symbols* # ^ are used (Table 6.3).

The Form 4 curricular model was then examined for similarities and differences from the teachers' mental models. These two models were then compared with the Form 4 students' mental models to identify to what extent the students were able to demonstrate an understanding of the four selected learning outcomes comprising the curricular model.

The next section explores the process of determining the Form 4 teachers' and students' mental models.

6.5.1 Process of Determining the Form 4 Teachers' and Students' Mental Models

To probe the participants' understanding of the curricular model, a series of questions were asked. Two teachers were interviewed (TF4a & TF4b). Teacher TF4a taught students SF4a, SF4b, SF4c, and SF4d: teacher TF4b taught students SF4e, SF4f, SF4g, and SF4h. To determine participants' understanding, eight Form 4 students and two Form 4 teachers were first asked "Can you please tell me what you think strong acid, weak acid, strong base and weak base means?" This question was used to probe participants' understanding about the concept of Acid-Strength in relation to the degree of dissociation. For the concept of Neutralisation, the following question was then asked "What do you think takes place when an acid and a base are put together?" (Figure 6.2).

Question Card 3

Can you please tell me what you think takes place when an acid and a base are put together?

Can you please write or draw what you think.

Figure 6.2: Question Card 3 to probe *explanation of Neutralisation*

This question sought to investigate students' understanding about the *explanation of Neutralisation*. The third question "Can you please tell me the everyday uses of acids and bases?" probed participants' understanding of the application of *describing Neutralisation in daily life*. Finally, to probe understanding of *describing acid-base titration*, Question Card 5 was used (Figure 6.3).

Question Card 5

$$NaOH(aq) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

Can you please draw for me what do you think will happen to the pH if 0.10M sodium hydroxide (NaOH) is gradually added to 10.0 ml of 0.10M hydrochloric acid (HCl)?

Figure 6.3: Question to probe *describing acid-base titration* learning outcome

The next section provides a description of the teachers' and students' mental models of strong and weak acids.

6.5.2 Teachers' and Students' Mental Models of Strong and Weak Acids

The two Form 4 teachers stated that strong acids ionise completely to produce a high concentration of hydrogen ions and strong bases ionise completely to produce high concentration of hydroxide ions, which show alignment with the curricular model. Four of the first teacher's students explained that strong acids dissociate and produce high concentrations of hydrogen (Table 6.4). One student (SF4f) of the second teacher associated a strong acid with a low pH and a weak acid with a high pH value. Another student (SF4g) described hydrochloric acid as a strong acid, ethanoic acid as a weak acid, sodium hydroxide as a strong base but considered ethanoic acid (CH_3COOH) or ethanoic acid to be a weak base indicating that the student did not know that ethanoic acid is CH_3COOH. Another two students had mental models similar to the second teacher's mental model. Thus, the findings displayed that six out of eight students' mental models were aligned with the teachers' mental models and the curricular model.

Teachers' and students' mental models for explanation of Neutralisation learning outcome are now briefly presented.

6.5.3 Teachers' and Students' Mental Models Used to Explain Neutralisation

For the next learning outcome, the first teacher commented that the products formed from the reaction are salt and water which is an idea aligned with the curricular model. However, SF4b stated that an acid neutralises a base, and SF4c stated that a neutralisation process results in a pH 7. The other students of this teacher gave responses similar to their teacher.

The second teacher stated that an acid and base reaction formed salt and water, which is consistent with the curricular model and all four of this teacher's students provided similar responses. Thus, all four mental models of the second teacher's students showed high consistency with the curricular model and the teachers' mental model.

For the *explanation of Neutralisation* learning outcome, the teachers' mental models were found to be highly consistent with the curricular model and the students' mental models indicated a high correlation with their teachers' mental models and thus, the curricular model.

In the following section, teachers' and student mental models for the learning outcome of *describing Neutralisation in daily life* is now examined.

6.5.4 Teachers' and Student Mental Models Used to Identify the Application of Neutralisation in Daily Life

The first teacher stated that an example of the application of the *describing Neutralisation in daily life* learning outcome is when calcium carbonate neutralises acid rain. However, the second teacher could not provide any examples. Both teachers' responses indicated that the teachers' mental models were not similar with the curricular model, suggesting a complete misalignment.

All four of the first teacher's students pointed out that a bee sting is either an alkali or an acid, and when either an acid or an alkali cream is applied the sting may be neutralised, indicating a misalignment with the teachers' mental models and the curricular model. The second teacher's student (SF4e) held the view that an alkaline floor cleaner neutralises a dirty floor, establishing a misalignment with the teachers' mental model. Another two of the second teacher's students described using toothpaste to neutralise the presence of acid in the mouth, while one student could not give an example. Thus, none of the students' mental models were similar to the teachers' mental models, displaying a misalignment. The curricular model provided an example that to neutralise acidic soil lime is used, but none of the Form 4 students used this example suggesting a misalignment also with the curricular model.

The teachers' and students' mental models to describe acid-base titration learning outcome are discussed next.

6.5.5 Teachers' and Students' Mental Models Used to Describe Acid-base Titration

For the *describing acid-base titration* learning outcome, the first teacher stated the effect of pH of an acid when alkali is added but did not describe how the process was carried out. The second teacher stated that 10.0mL of sodium hydroxide is needed to neutralise 10.0mL of hydrochloric acid (HCl) and continued describing the titration process appropriately. Thus, the teachers' mental models displayed a partial alignment with the curricular model.

One of the first teacher's four students stated that he had not experimented on acids and bases, while another student believed titration to be an experiment to test the solubility of salt. Pouring aqueous HCl (aq) into a test tube containing aqueous sodium hydroxide (NaOH) and using a pH meter to measure the pH was described by student SF4c as a titration method. Student SF4d held the view that acid–base titration is an experiment conducted using a beaker attached to two types of litmus paper. This findings indicated that students' were incapable of describing an acid-base titration suggesting they possesed incorrect scientific understanding for performing an acid-base titration. Thus, the students' mental models was misaligned with the teachers' mental models.

Two out of the second teacher's four students (SF4e & SF4h) described titration as a process where an acid (or a base) is added to a conical flask containing a solution of sodium hydroxide (or hydrochloric acid) which is similar to their teacher's view. One student (SF4f) described the titration method using a beaker and noted the pH for the solution formed is neutral. In the experiment described by student SF4g, sodium hydroxide was added to hydrochloric acid in a test tube and when the reaction reached the equivalence point the student used a new litmus paper at 30 second intervals to observe whether there was a colour change in the litmus paper. However, after probing, the student was confused and was not sure if that procedure was correct. Two of the four students responses were misaligned with their teachers' mental models.

Thus, for the learning outcome of *describing acid-base titration*, the students' mental models showed low consistency with the teachers' mental models and the curricular model while the teachers' mental models displayed a partial alignment with the curricular model.

In the section 6.5.6, the frequency of similarities and differences between curricular, teachers', and students' mental models is examined.

6.5.6 Frequency of Similarities and Differences between Curricular Model, and Teachers', and Students' Mental Models

The comparisons between the curricular models, and teachers' and students' mental models for Form 4 are presented below in Table 6.4. For example, in the horizontal row labelled TF4b (teacher 'b', Form 4) for *describing Neutralisation in daily life*, one teacher was not able to state any examples while the other teacher gave a different example to that presented in the curricular model, suggesting neither of the teachers' mental models was aligned with the curricular model (i.e., 0, 2). Similarly, none of the students' responses matched the curricular model (i.e., 0, 8) and none of the eight students showed similarities between their mental models and the teachers' mental models (i.e., 0, 8).

Table 6.4: Similarities and differences between curricular models, teachers', and students' mental models for Four Selected Form 4 learning outcomes

Respondents	*Relating strong or weak acid with degree of dissociation*			*Explanation of Neutralisation*			*Describing Neutralisation in daily life*			*Describing acid-base titration*		
	C*	T*	S*	C	T	S	C	T	S	C	T	S
TF4a	/			/			x			x		
SF4a	/	/		/	/		x	x		x	x	
SF4b	/	/		x	x		x	x		x	x	
SF4c	/	/		x	x		x	x		x	x	
SF4d	/	/		/	/		x	x		x	x	
TF4b	/			/			x			/		
SF4e	/	/		/	/		x	x		/	/	
SF4f	x	x		/	/		x	x		x	x	
SF4g	x	x		/	/		x	x		x	x	
SF4h	/	/		/	/		x	x		/	/	
Teachers	2#,2+			2,2			0,2			1,2		
Students	6,8	6,8		6,8	6,8		0,8	0,8		2,8	2,8	

Notes: / indicates responses were similar to the curricular model, X indicates responses were different from curricular model, and shaded indicates 'not applicable'.

* indicates either Curricular model, Teachers' mental model, or Student Mental model, # indicates the number of teachers (students) that are consistent with the curricular model or student (teachers) model and + is total number of teachers (students).

@ respondents are coded, where T indicates Teacher, S indicates students, F4 indicates Form 4, and letters a to h indicates individual participants.

Teacher TF4a taught students a, b, c, and d, and teacher TF4b taught students e, f, g, and h

In summary, students' mental models were not aligned with the teachers' mental models and the curricular model for two out the four learning outcomes. For the learning outcome of *relating strong or weak acid with degree of dissociation*, the results showed high consistency between the teachers' mental model and the curricular model, and similarly for students' mental models with the teachers' mental models and the curricular model. For the *explanation of Neutralisation* learning outcome, both teachers' mental models showed alignment with the curricular model as both teachers' mental models indicated that when an acid and a base react, water and salt are produced. However, two students showed differences from the teachers' mental models while the other six students showed similarities, indicating generally a high degree of correlation of the students' mental models with the teachers' mental models.

Neither of the two teachers' mental models was aligned with the curricular model for the learning outcome of *describing Neutralisation in daily life* and none of the students' mental models displayed any similarities with the teachers' mental models and curricular model. Only one teacher's mental model was aligned with the curricular model for the learning outcome of *describing acid-base titration* indicating a partial alignment. Only two out of the eight Form 4 students' mental models displayed similarities with the curricular model and teachers' mental models for this outcome.

Key points arising from the Form 4 teachers' and students' mental models are now presented.

6.5.7 Key Points Arising from the Form 4 Teachers' and Students' Mental Models

- The learning outcomes for explanation of Neutralisation and relating strong or weak acid with degree of dissociation showed a high correlation between students' mental models, the teachers' mental models and the curricular model.
- Students' mental models did not demonstrate alignment with teachers' mental models and the curricular model for the learning outcomes describing Neutralisation in daily life and describing acid-base titration.

Next, the Form 6 curricular model is described.

6.6 Form 6 Curricular Model

For Form 6, the curricular model is expressed in the *Syllabus and Specimen Papers* formulated by the Malaysian Examination Council. The learning objectives that formed the basis of the Form 6 curriculum under investigation for the selected acids and bases concepts are found in the *Equilibria* topic. The learning outcomes forming the Form 6 curricular model for this study are part of the Equilibria topic, specifically to do with Ionic Equilibria. These learning outcomes are the underlined sections in the Learning Outcomes column in Table 6.5. The learning outcomes are the *use of Arrhenius, Brønsted-Lowry, and Lewis models to explain acids and bases*, *explain changes in pH during acid-base titration*, and *define buffer solution* (Table 6.5).

Table 6.5: The Malaysian Form 6 Syllabus and Specimen Papers (MEC, 2012)

Learning Objective	Teaching Period	Learning Outcome
Ionic equilibria	10 hours	Candidate should be able to: (a) use Arrhenius, Brønsted-Lowry and Lewis theories to explain acids and bases; (b) identify conjugate acids and bases; (c) explain qualitatively the different properties of strong and weak electrolytes; (d) explain and calculate the terms pH, pOH, K_{sp}, pK_a, K_b, pK_b, K_w, and pK_w from given data; (e) explain changes in pH during Acid-base titrations; (f) explain the choice of suitable indicators for Acid-base titrations; (g) define buffer solutions; (h) calculate the pH of buffer solutions from given data; & (i) explain the use of buffer solutions and their importance in biological systems such as the role of H_2CO_3/HCO_3^- in controlling pH in blood.

Note: Underlined sentences are the learning outcomes for Form 6 discussed for this research

The Form 6 curricular model was compared with the Form 6 teachers' mental models. These two models were then compared with the Form 6 students' mental models to determine the extent of alignment between the three models.

The process of determining the Form 6 teachers' and students' mental models is presented in the next section.

6.6.1 Process of Determining the Form 6 Teachers' and Students' Mental Models

Of the two teachers interviewed, teacher TF6a taught students SF6a, SF6b, SF6c, and SF6d: teacher TF6b taught students SF6e, SF6f, SF6g, and SF6h. To determine participants' understanding of the *use of Arrhenius, Brønsted-Lowry, and Lewis models to explain acids and bases* the eight Form 6 and two Form 6 teachers were first asked the question shown in Question Card 6 (Figure 6.4).

Question Card 6

1. $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O\ (aq)$
2. $NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$
3. $BH_3(g) + NH_3(g) \rightarrow H_3B\ NH_3(s)$

Can you please tell me what species are acids and bases in each of the equation?

Figure 6.4: Probing questions for the Arrhenius, Brønsted-Lowry,and Lewis models to explain acids and bases

The next question posed to the participants was related to *explain changes in pH during acid-base titration* on Question Card 7b (Figure 6.5).

Question Card 7b.

$NaOH(aq) + CH_3COOH(aq) \rightleftharpoons CH_3COONa(aq) + H_2O(l)$

Can you please draw for me what do you think will happen to the pH if 0.10M sodium hydroxide (NaOH) is gradually added to 10.0 ml of 0.10M ethanoic acid (CH_3COOH)?

Figure 6.5: Probing question for the changes *explain changes in pH during acid-base titration*

Finally, the participants' learning outcome for *define buffer solution* was explored by asking the teachers and students the question "Can you please tell me what a buffer solution is?"

The next section provides a description of the teachers' and students' mental models when responding to probes about the learning outcome *use of Arrhenius, Brønsted-Lowry, and Lewis models to explain acids and bases*.

6.6.2 Teachers' and Students' Mental Models Used to Identify Usage of Arrhenius, Brønsted-Lowry and Lewis Models

Both Form 6 teachers were able to demonstrate appropriate use of the Arrhenius, Brønsted-Lowry, and Lewis model in their explanations. However, seven out of their eight Form 6 students were not able to identify acids and bases in the different equations shown on the Question Card given to them. A student (SF6d) indicated using hydrogen and hydroxide ions, and protons and electrons to explain, but was incorrect when he described ammonia (NH_3) as accepting the electron pair. His expressed model, thus, indicated some similarity with the teachers' mental model and the curricular model indicated as the symbol */ in Table 6.6.

The findings showed that the teachers' mental models indicated some alignment with the curricular model which they were able to demonstrate using the Arrhenius, Brønsted-Lowry and Lewis models to explain the acids and base behaviours. However, there was inconsistency between the students' mental models and the teachers' mental model and the curricular model.

The teachers' and students' mental models for the learning outcome of *explain changes in pH during acid-base titration* is described next.

6.6.3 Teachers' and Students' Mental Models Used to Identify Changes in pH during Acid-Base Titration

The first teacher stated that ethanoic acid (CH_3COOH) dissociates partially in water to produce low concentration of H^+ ions and as a result, the pH is quite high but lower than 7. The teacher added that when sodium hydroxide is added the OH^- ions reacts with the H^+ ions causing a gradual increase in pH because the OH^- ions neutralise the H^+ ions in the acid. This first teacher went on to explain that as more and more OH^- ions reacted with the hydrogen ions, the pH increased gradually. The teacher elaborated that when 10.0mL of sodium hydroxide is added, there is a sharp increase because all the H^+ ions have been neutralised by the OH^- ions but, because sodium hydroxide (NaOH) sodium hydroxide (NaOH) is a strong base, the equivalence point occurs at a pH that is more conducive for the base indicating a pH 8 to pH 10 of the final solution. Teacher TF6a explanation, however, was not aligned with the scientific model because the teacher did not mention the role of a conjugate base or the ethanoate ions (CH_3COO^-) in the reaction. Student SF6a of the first teacher stated that when sodium hydroxide (NaOH) is added the pH increased higher than 7; SF6b said the pH is 7. Another student noted that Neutralisation may occur but at a very slow pace; the fourth student stated that the pH of a solution increases rapidly when a strong base is added to a weak acid indicating two out of four students' mental models were misaligned with the first teacher's mental model.

The second teacher stated that a weak acid does not dissociate 100 percent causing a lower concentration of hydrogen ions. The teacher added that the low concentration of H^+ indicated a pH 2 or 3 if calculated using the formula the pH = $-\log [H^+]$. When more sodium hydroxide (NaOH) is added the pH increases gradually from pH 3 to pH 7 and reaches the end point at pH 8 to 10 when the reaction is completed. This description was not aligned with the curricular model because the teacher did not mention the role of a conjugate base ethanoate ions (CH_3COO^-) in the reaction. One of the second teacher's students (SF6e) noted that a strong base when reacting with a weak acid will form an alkaline salt, resulting in a pH higher than 7 because the concentration of hydroxide ions is higher than the concentration of hydrogen ions formed from the ethanoic acid, a correct answer but indicating a wrong reasoning. Another student (SF6f) maintained that when a weak acid reacts with a strong base, Neutralisation occurs resulting in a pH 7 solution. Student SF6g stated that the reaction in Question Card 7b is a reversible reaction and was not able to relate the reaction to the difference in pH. The fourth student of the second teacher stated that the number of H^+ ions produced is not equal to the number of OH^- ions, therefore, the solution is not neutralised, indicating that three out of four of the students' mental models were misaligned with the second teacher's mental model.

Although the teachers' were able to explain the changes in pH but they were unable to indicate that the ethanoate ions are conjugate bases (i.e., Brønsted-Lowry model) and its role in determining the higher concentration of hydroxide ions. Thus, the teachers' mental models indicated a complete inconsistency with the curricular model while the students' mental models displayed low correlations with their teachers' mental models and complete misalignment with the curricular model.

The next section briefly discusses teachers' and students' mental models for the *define buffer solution* learning outcome.

6.6.4 Teachers' and Students' Mental Models to Define a Buffer Solution

When compared to the scientific model, the curricular model does not give a full account of the scientific model and so this study uses attributes from the scientific model (as described in Section 2.9.5 of Chapter 2) to define Buffers for the purposes of comparison. Thus, the definition of a buffer solution is a solution that consists of a weak acid and its salt (or a conjugate base) and it has the ability to resist a pH change when strong acid or strong alkali is added.

Both Form 6 teachers were able to achieve *define buffer solution* learning outcome by describing buffers as made up of a weak acid and its salt and added that the buffer solution is able to resist any pH changes when a small amount of strong acid is added. One of the first teacher's students believed that a buffer solution is a solution containing a small amount of an acid and a base while a second student stated that a combination of an acid and a base is thought of as a buffer solution where both students were not able to indicate that a buffer solution consists of a weak acid or a weak base with its salt. Student SF6c stated that a buffer solution increases or decreases acidity while student SF6d stated that a buffer solution resisted a pH change, but was not able to describe the components of a buffer solution. All four students of the first teacher showed a complete misalignment with the first teacher's mental model. Three of the second teacher's students were unable to describe what a buffer solution was. The fourth student of the second teacher stated that a buffer solution contains salt and acid and when alkali is added pH does not change much, is incorrect because a buffer solution consist of a weak acid and not any acid. These four students of the the second teacher displayed a complete misalignment with their teacher.

The findings indicated that the teachers' mental models were aligned with the curricular model because both teachers indicated that a buffer solution consists of weak acid (or base) with its salt and functions to resist pH change when a strong acid or base is added. The students' mental models were completely misaligned with the teachers' mental models and the curricular model.

In the following discussion, the frequency of similarities and differences between curricular models, teachers' and students' mental models are explored.

6.6.5 Frequency of Similarities and Differences between Curricular, Teachers' and Students' Mental Models

The comparisons of responses by teachers and students for curricular, teacher and students' mental models for Form 6 are presented in Table 6.6.

Table 6.6: Similarities and differences between curricular models, teachers' and students' models for three selected Form 6 learning outcomes

Respondents	*Use of Arrhenius, Brønsted-Lowry, and Lewis models to explain acids and bases*			*Explain changes in pH during acid-base titration*			*Define buffer solution*		
	C	T	S	C	T	S	C	T	S
TF6a	/			x			/		
SF6a	x	X		x	/		x	x	
SF6b	x	X		x	x		x	x	
SF6c	x	X		x	x		x	x	
SF6d	*/	*/		x	/		x	x	
TF6b	/			x			/		
SF6e	x	X		x	/		x	x	
SF6f	x	X		x	x		x	x	
SF6g	x	X		x	x		x	x	
SF6h	x	X		x	x		x	x	
Teachers	2,2			0,2			2,2		
Students	0,8	0,8		0,8	3,8		0,8	0,8	

Notes: / indicates responses were similar to the curricular model, X indicates responses were different from curricular model, and shaded indicates 'not applicable', */ indicates partial similarity

[*] indicates either Curricular model, Teachers' mental model, or Student Mental model, [#] indicates the number of teachers (students) that are consistent with the curricular model or student (teachers) model and [+] is total number of teachers (students).

[@] respondents are coded, where T indicates Teacher, S indicates students, F2 indicates Form 2, and letters a to h indicates individual participants.

Teacher TF6a taught students a, b, c, and, and teacher TF6b taught students e, f, g, and h

Table 6.6 shows that the teachers' mental model (i.e., 2, 2) were aligned with two out of three learning outcomes in the curricular model. The students' mental models were not aligned with the teachers' mental models and the curricular model for all three learning outcomes. For the learning outcome of use of

Arrhenius, Brønsted-Lowry, and Lewis models to explain acids and bases models, none of the Form 6 students showed consistency between their mental models and the teachers' mental models (i.e., 0, 8), and none of the eight students showed similarities between their mental models and the curricular model (i.e., 0, 8). Additionally, the majority of the Form 6 students (i.e., seven out of eight) appeared not to use the three acid-base models that could explain the acid and base behaviours in the intended learning outcome. (see Appendix I). Thus, they were not able to explain the differences between the three equations. Also noteworthy was that student SF6d knew the three acid-base models but was not able to explain anwers to questions using the differences between them.

The teachers' responses to questions about *changes in pH during acid-base titration* were not similar to explanations offered by the curricular model suggesting that the teachers' mental models were not consistent with the curricular model. Similarly, five out of eight Form 6 students were not able to to explain the changes of a pH higher than 7 indicating a low consistency between students' mental models and both the teachers' mental models. Also, none of the students were able to match their explanation of the *changes in pH during acid-base titration* learning outcome with the curricular model displaying a complete misalignment with the curricular model.

None of the Form 6 students' mental models displayed similarity in the learning outcome for *define buffer solution* to the teachers' mental models and the curricular model. This very high inconsistency showed students' mental models were not aligned with teachers' mental models and the curricular model while the teachers' mental models were aligned with the curricular model.

The key points arising from the Form 6 teachers' mental models and students' mental models are now discussed.

6.6.6 Key Points Arising from the Form 6 Teachers' Mental Models and Students' Mental Models

- Teachers of Form 6 students did not use the three acid-base models appropriately (i.e., the Arrhenius, Brønsted-Lowry and Lewis models) to explain acid-base chemistry concepts for the probe questions;
- Form 6 students were not able to use the three acid-base models (i.e., the Arrhenius, Brønsted-Lowry and Lewis models) to explain acid-base chemistry concepts at this level; and
- Students' mental models displayed inconsistencies with the teachers' mental models and the curricular model for all three learning outcomes of the curricular model.

The next section summarizes the chapter.

6.7 Summary

This chapter provides information on selected learning outcomes gathered from the Form 2, Form 4, and Form 6 curricular models. The curricular model describes what is intended for students to achieve, the teachers' mental model gave an indication of what conceptual knowledge the teacher holds and students' mental models indicate what they may have learnt. The findings presented above gave an insight into the similarities and differences between the three models and is summarized in Table 6.7.

Table 6.7: Similarities and differences in selected learning outcomes at different levels of schooling of curricular, teachers' and students' mental models

No	Learning Outcomes	Alignment of Mental Models		
		Students' with Curricular	Students' with Teachers'	Teachers' with Curricular
	Form 2			
1	*Identify the properties of acids, and alkalis*	/	x	*/
2	*Explain the meaning of Neutralisation*	/	/	/
3	*Write an equation in words to describe the Neutralisation process*	x	x	/
4	*Explain through examples the uses of Neutralisation in daily life.*	x	x	*/
	Form 4			
4	*Relating strong or weak acid with degree of dissociation*	/	/	/
5	*Explanation of Neutralisation*	/	/	/
6	*Describing Neutralisation in daily life*	x	x	X
7	*Describing acid-base titration*	x	x	*/
	Form 6			
8	*Use of Arrhenius, Brønsted-Lowry, and Lewis models to explain acids and bases*	x	x	/
9	*Explain changes in pH during acid-base titration*	x	x	X
10	*Define buffer solution*	x	x	/

Note: / indicates similarities x indicates differences */ indicates 1 out of 2 teachers responses were similar with curricular model

Table 6.7 above shows, for example, a comparison of the three models for the learning outcome of *describing acid-base titration* at Form 4 schooling level. The students' mental models displayed one misalignment with the curricular model and one misalignment with the teachers' mental models (i.e., x). However, one of the two teachers' mental models showed partial alignment with the curricular model (i.e., */).

In summary, the Form 2 students' mental models showed some inconsistencies with the curricular model and the teachers' mental models in the learning outcomes of *write an equation in words to describe the Neutralisation process* and *explain through examples the uses of Neutralisation in daily life*. In addition, the teachers' mental models showed partial alignment with the curricular model for the learning outcomes of *identify the properties of acids, and alkalis* and *explain through examples the uses of Neutralisation in daily life*.

For two out of the four learning outcomes, the Form 4 findings indicated some inconsistencies between the students' mental models, and the curricular model and the teachers' mental models. The teachers' mental models displayed consistency with the curricular model for two learning outcomes which were *relating strong or weak acid with degree of dissociation* and *explanation of Neutralisation* but for the *describing acid-base titration* learning outcome, only one out of the two teachers and none of the teachers for *describing Neutralisation in daily life* learning outcome displayed similarities with the curricular model.

For Form 6 schooling levels, the results revealed students' lack of similarities in their mental models to the teachers' mental models and the curricular models for all learning outcomes investigated. The teachers' mental models showed a high correlation for two out of the three learning outcomes with the curricular model.

The next chapter presents the discussion chapter which attempts to interpret the findings from the previous three chapters.

Chapter 7. Discussion

7.1 Chapter Overview

This chapter begins with a revisit to the purpose of this study in order to provide a structure for a discussion of the findings presented in the previous three chapters. Once a structure is established the chapter discusses the main findings for each respective research question, by first linking the findings to pre-existing research and interpreting what these findings may mean about current Malaysian students' mental model development. This discussion is followed by some possible explanations for the students' mental model development. The chapter concludes with a summary of the discussion.

7.2 Introduction

This study is considered a naturalistic study within a constructivist or interpretive paradigm, which involved semi-structured individual interviews with 24 students and six teachers using the 'Interviews About Concepts' and "Interviews About Instances" data gathering techniques and an examination of the Malaysian national curriculum statement. The data gathered is organised to address the three research questions (RQ), which are:

1. What are the attributes of students' mental models for selected acid-base chemistry concepts at given Malaysian levels of schooling in relation to their applications of the Phenomenological, Arrhenius, Brønsted-Lowry and Lewis models?
2. How can students' mental models for the six selected acid-base chemistry concepts be classified based on their attributes and used to identify students' mental models development at different stages of Malaysian schooling?

3. In what ways do the attributes of scientific models, curricular models, and teachers' and students' mental models for selected acid-base chemistry concepts compare at different schooling levels?

The key objective of this cross sectional study is to understand the nature of Malaysian secondary students' mental models for selected acid-base chemistry concepts (i.e., Macroscopic Properties, Neutralisation, Acid-Strength, Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding) and at different secondary schooling levels in Malaysian schools. To achieve this objective stages of mental model development by students were identified (see Chapter 5) based on attributes of their thinking which were expressed when answering probe questions about the selected acid-base concepts (see Chapter 4).

In the next section, an overall discussion of the results presented in the previous chapters is provided, organised under the three sub-headings:

- The nature of students' mental models to address Research Question 1;
- The stages and sub-stages of students' mental model development to address Research Question 2; and
- The degree of alignment between scientific models, curricular models, teachers' and students' mental models to address Research Question 3.

Next, the nature of students' mental models is discussed.

7.3 RQ1: The Nature of Students' Mental Models

Using the Interview-About-Concepts approach, which indicated individuals' thinking about specific concepts (i.e., the target system), key themes in the student responses were pinpointed and identified as attributes. These attributes were used in turn to determine students' mental models which according to Mendonca and Justi (2014) can be generated to explicate students' understanding for each of the acid-base concepts at different schooling levels. The discussion in this section is organized around the main findings for each of the selected acid-base chemistry concepts, which are compared and contrasted with related findings from the research literature to give an account of the overarching finding.

7.3.1 Macroscopic Properties Concept

For the first concept, the main findings suggest that the majority of students at different schooling levels in this thesis study were able to explain the Macroscopic Properties concept using the correct scientific attributes linked to the Phenomenological model. This thesis study found similar evidence to a study done with Grade 10 (16 – 17 year olds) students in Turkey (Demircioğlu et al., 2005). This Turkish study investigated students' misconceptions about acids and bases during a teaching intervention and found that when identifying substances as acids or bases their students used sensory perceptions similar to the *senses* attribute demonstrated by the Malaysian students. This similarity in findings showed that both Malaysian and Turkish students were correctly using the macroscopic properties features to identify acids and bases.

The Malaysian students in this study used the *pH value* attribute to classify substances as acids or bases. For this thesis study, the pH value attribute is linked to the Phenomenological and the Arrhenius acid-base models. Similarly, studies conducted in France and Turkey studies of Grade 9 students' ideas on acid-base reactions by Cokelez (2010) found that these students also used pH value to identify acid, base and neutral substances. This finding showed that the use of the *pH value* attribute was an important attribute to help students identify acids and bases and they used it as a measure of acidity. Students in this thesis study also used the *physical strength* attribute when explaining the Macroscopic Properties concept, which is consistent with the findings of Lin and Chiu (2007) study. These researchers found that Grade 9 (15 year olds) Taiwanese students used the concept of toxicity and corrosiveness to determine whether substances were acids when investigating the characteristics of Grade 9 students' mental models in acid-base chemistry This *physical strength* attribute is also not considered to be a scientific attribute of the Phenomenological model (see Section 2.10.1). It is considered incorrect and termed a misconception because not all acids are corrosive, toxic or harmful.

The concept of Neutralisation is discussed next.

7.3.2 Neutralisation Concept

When explaining the Neutralisation concept, the Form 2 students were able to describe aspects of the concept using the Phenomenological model. A group of the Form 4 and Form 6 students did use appropriate attributes that suggest they understood this concept, for example, their appropriate use of the *product formation* and the *hydrogen-hydroxide* attributes, which is aligned with the scientific Arrhenius acid-base model while, another group of the Form 4 and Form 6 students describe Neutralisation as an extension of the macroscopic properties. However, when probed further it appears that students did not fully understand that a new product was formed using the attribute of *product formation*. Students' explanations for a neutralisation reaction appeared to be based on the idea that the salts formed were a different form of the reactants. Andersson (1986b, 1990) called this form of reasoning 'modification', since students perceived salts to be a modification of the original reactants. In Andersson's review of studies of 12 to

16 year old students' understanding of chemical reaction, he discovered that students reasoned that the salt formed in the neutralisation process continues to show some acidic properties. Interestingly one Form 2 student (SF2f) in this study believed that the salt formed in the neutralisation reaction was an acid and not a new substance, perhaps indicating that this student thought the original acid remained an acid. However, this explanation is scientifically not acceptable because a chemical reaction involves a chemical interaction that forms new substances (see Section 2.11) and not a modification or retention of an old substance. This finding is also comparable to that obtained in an investigation into Grade 10 and 11 (16 -17 year olds) American high school students' understanding of acid-base titrations, focusing on Neutralisation, and Acid-Base Strength concepts (Sheppard, 2006). Sheppard (2006) observed that 10 out of the 16 American high school chemistry students in the study viewed the Neutralisation concept as a reaction where the products formed were a modification of the reactants, which is a misconception. Thus, Malaysian students' use of the 'modification' view to explain the Neutralisation concept could be considered indicative of misconceptions forming on their part.

Of interest is that one Form 4 student used macroscopic properties (i.e., the Phenomenonolgical model) when explaining the Neutralisation concept. The student stated that acid, which is sour, and base, which is bitter, react to produce a tasteless or neutral substance, a similar finding to the study by Calatayud, Bárcenas, and Furió-Más (2007). These researchers investigated Grade 12 (17-18 years old) students' understanding of the properties of acids, bases, and salts based on their molecule or ionic composition. Their 2007 study found that a large number of Spanish students were confused about the Macroscopic and Arrhenius models when explaining the Neutralisation concept. The similar finding in this present study indicate that a small number of Malaysian students were not fully understanding the Neutralisation concept because macroscopic properties such as the *senses* attribute are not able to explain the Neutralisation concept.

This thesis study also found that three Form 4 Malaysian students explained the Neutralisation concept as a process to neutralise the properties of acid and base, which is a similar finding for the Grade 12 Spanish students in the Calatayud et al. 2007 study. Students in the Grade 12 study believed that the neutralisation reaction is a process to neutralise the properties of acids and bases and not a process that results in equal amounts of hydrogen and hydroxide ions in the final solution. A possible reason for this misconception occurring is that Malaysian and Spanish students did not comprehend that neutralisation requires thinking at a particulate level (i.e., atomic or subatomic reaction). The difficulty existed because students from both countries possibly believed the term ‘neutral’, as used in the neutralisation process, indicated that acids ‘consumed’ or wiped out bases (Schmidt, 1991; Schmidt, 1997). For this reason, the students tended to believe the resulting solution did not possess any acidic or basic properties.

In a question involving students’ application of the Neutralisation concept, results in this current study revealed two findings. The first finding indicated that the majority of all students used the *reactants* attribute, demonstrating their awareness of the opposite role of bases and acids (i.e., an acid has the opposite properties of a base). The first finding about the use of the *reactants* attribute did not support those from an investigation involving Tunisian Grade 10 students (Ouertatani et al., 2007). In the 2007 study, Ouertatani and colleagues researched the use of the Arrhenius model by students in their understanding of acids and bases. They found that some of their students thought the concept of base had no correlation with an acid. Unlike the Tunisian students, the Malaysian students in this study revealed they were able to establish a relationship between acids and bases (i.e., they distinguished the opposite role of bases to acids), for example, a base has the ability to reduce the acidity of an acidic soil.

A second finding showed a Form 2 student explaining that acidity can be reduced through the physical mixing of a basic soil with an acidic soil, a perspective which Anderson (1986b, 1990) described as a 'displacement' view. Anderson pointed out that with such a view students tended to believe the products formed are displaced reactants, a result of an acidic soil and a basic soil just mixing (i.e., they are displaced rather than reacting); This 'displacement' view finding is supported by the Sheppard (2006) study of Grade 10 and 11 students (16-17 year olds) students' understanding of acid-base titrations, Neutralisation and Acid-Base Strength concepts. The Sheppard (2006) study noted that six out of 16 American high school chemistry students described the Neutralisation concept as a "simple mixing of acid and base without any form of interaction between the particles" (p. 38). The student using the *physical mixing* attribute in this study is considered to be displaying a misconception because the scientific view is that when a base reduces the acidity in an acidic soil a chemical reaction has occurred between an acid and a base.

The next section discusses the Acid-Strength concept.

7.3.3 Acid-Strength Concept

For the next acid-base concept of Acid-Strength, this study revealed that a majority of the Forms 4 and 6 students used the *degree of dissociation* attribute (i.e., an Arrhenius scientific model attribute) and *molar concentration,* (i.e., a non-Arrhenius attribute) to explain the strength of an acid. The Malaysian students' use of these attributes mirrors previous findings by Sesen and Tarhan (2011), who conducted an intervention study of student-centred (i.e., experimental group) and teacher-centred (i.e., control group) methods of instruction. The study was performed with 45 Turkish students (17 years old) to determine the inpact of a pedagogical intervention on their understanding of acids and bases. The results revealed that six out of 25 students in the control group believed that the strength of an acid has a high correlation with molar concentration, while only one out of 21 students in the experimental group shared a similar understanding. The authors of the Turkish study believed that the learning of acids and bases utilising a teacher-centred approach produced a higher number of misconceptions amongst students than the experimental group. The high number of misconceptions formed by the Turkish students in the control group was a similar result to the Malaysian study, which may be significant from the Turkish study and this current Malaysian study indicated that Malaysian and Turkish students were able to form both scientifically appropriate concepts (i.e., *degree of dissociation* attribute) and misconception (i.e., *molar concentration* attribute). The use of the *molar concentration* attribute is a misconception because the strength of an acid is determined by the degree of *degree of dissociation* and not by the molarity of a solution measured in mol L^{-1}.

Another three students in this study (SF4f, SF4h, and SF6a) explained the Acid-Strength concept using the *physical strength based on pH* attribute (i.e., the lower the pH of an acidic solution, the more corrosive an acid is). The use of *physical strength based on pH* attribute was similar to the thinking of 16 and 17 years old American students in the study conducted by Sheppard (2006). Both the American and Malaysian students described that an acid with a lower pH is a strong acid. A similar result was obtained in a study involving Grade 10 (15 to 16 year olds)

Tunisian students by Ouertatani et al. (2007), who researched the students' use of the Arrhenius model in acid-base chemistry. However, in a more recent study, eight out of 27 Turkish high school students revealed the misconception that pH and pOH are a direct indicator of the strength of an acid (Kala et al., 2013). In their 2013 study, Kala et al. investigated high school students' understanding of the pH and pOH concepts, understanding of the strength of acids and bases at particle level, and differences between the strength and concentration of acids and bases. This Turkish study, indicated that the majority of their students believed a low pH represents strong acids. Collectively research findings indicate that groups of American, Tunisian, Turkish, and Malaysian students are confused about the concept of acidity and the strength of an acid. This finding from this Malaysian study confirms that students internationally have difficulty fully grasping the Acid-Strength concept.

In addition, a few Form 4 and Form 6 students in this thesis study used the attribute *physical strength based on properties* of acids and bases when describing the strength of an acid. These Form 4 and Form 6 students believed the strength of an acid was dependant on their properties, such as strong acids corrodes metal, and strong acids are harmful. This belief supports previous findings by Nakhleh and Krajcik (1994), who conducted a study into students' use of various technologies (i.e., pH meter, coloured indicators, and microcomputer). The Grade 11 (16 years old) study investigated American high school students' use of various technologies in understanding acids, bases, and pH concepts. In this American study, Grade 11 students tended to believe the word "strong" meant harmful, rather than the scientific attribute of *degree of dissociation* suggesting the Malaysian and American students had formed misconceptions.

Another finding from this thesis indicated that majority of the Malaysian students could recognise that a weak acid, such as ethanoic acid (CH_3COOH), partially dissociates forming hydrogen ions while a strong acid, such as hydrochloric acid (HCl), completely dissociates to form hydrogen ions. However, seven out of 16 students had difficulty identifying that H_2SO_4 is a stronger acid than H_3PO_4 acid. This difficulty showed that there appears to be a misunderstanding when it comes to differentiating H_2SO_4 and H_3PO_4 in terms of their strength. Students stated that H_3PO_4 is a strong acid because it contains more hydrogen atoms and consequently dissociates to produce more hydrogen ions. These students seem to equate higher numbers of H atoms in an acid formula with the ability to dissociate to a higher degree, which is scientifically not a correct conception. This finding was similar to a Taiwanese study (Lin & Chiu, 2007) which researched the characteristics and origins of students' mental models for acids and bases at Grade 9 (15 year olds). The Lin and Chiu (2007) study identified that the Taiwanese students also used the quantity of H (or OH) in a chemical formula to determine acid (or basic strength). This use of the quantity of H to determine Acid-Strength was also displayed by students who did not use a new student-centred teaching material (NTM) in the Turkish Grade 10 students (16 to 17 years old) (Demircioğlu et al., 2005). Their findings revealed that students who did use the intervention material indicated 0% misconceptions while 27% of the control group of students, who did not use the NTM, showed misconceptions. Turkish, Taiwanese and Malaysian students showed similar misconceptions indicating that students from the three nationalities had difficulty in comprehending Acid-Strength concept. This finding may suggest that difficulty in understanding the Acid-Strength concept is likely to be a problem in many countries.

As a summary for the Acid-Strength concept, this thesis study revealed that Malaysian students who used the *physical strength based on pH* and *physical strength based on properties* attributes in their explanations of the concept had misconceptions. A few Malaysian students did display correct understanding that a strong acid dissociates completely to form high concentration of hydrogen ions. However, they were not able to indicate that the strength of an acid is not directly related to the number of hydrogen atoms in the undissociated acid. The majority of the students also exhibited the *molar concentration* attribute in explaining the Acid-Strength concept, again indicating a misconception. Students' inability to fully grasp the Acid-Strength concept was found to be an international problem.

In the next section, the students' understanding of the concept of Acid-Base Equilibrium, the fourth acid-base concept, is considered.

7.3.4 Acid-Base Equilibrium Concept

For the acid-base chemistry concept of Acid-Base Equilibrium which is introduced at Form 6 in the Malaysian curriculum, none of the Form 6 students were able to demonstrate using the scientific attributes of the Brønsted-Lowry model recommended by the curriculum. All the Form 6 students were unable to comprehend that when sodium hydroxide is added to ethanoic acid, the hydroxide ions react with ethanoic acid to produce a conjugate base or ethanoate ions (i.e., CH_3COO^- ions) and water. Also, Form 6 students in this study did not take into consideration the auto-ionization (self-ionization) of water that produces hydronium (H_3O^+) and hydroxide ions (OH^-), thus, increasing the concentration of hydroxide ions and eventually producing a higher concentration of OH^- ions than the H_3O^+ ions (see Section 2.10.4). The absence of auto-ionization in their explanations was consistent with findings in a study of Grade 12 Greek high school students (approximately 17-18 years old) exploring alternative conceptions in Acid-Base Equilibrium. The Greek study of Grade 12 students by Demerouti et al.(2004) found that almost 80% of the Greek students ignored the importance of self-ionization of water in their reasoning. On the other hand, when identifying acid-conjugate base pairs, the findings from this thesis study contradict the findings from the Greek study because 90% of the Grade 12 students in that study were able to identify the acid-conjugate base pair (i.e., CH_3COOH and CH_3COO^-) compared to none of the Malaysian students. It seems the Malaysian students were unable to understand the acid-conjugate base pair relationship perhaps because of their inability to understand that the ethanoate ions (CH_3COO^-) ion is itself a base (see Section 4.3.3.1) and when reacted with water produces the hydroxide ions (see Section 2.10.4). Also, the findings in Section 4.3.3.1 showed that none of the Form 6 students were able to identify ethanoate ions (CH_3COO^-) ions as conjugate bases or Lewis bases which supports the idea that the students may not know about the acid-conjugate base pair concept.

In contrast, a few Form 6 students knew that the probe question indicated a reaction between sodium hydroxide (a strong base) and ethanoic acid (a weak acid). However, they concluded that the resulting solution produced a higher concentration of hydroxide ions based on the notion that a strong base naturally produces higher concentration of hydroxide ions. For example, student SF6b mentioned that the concentration of hydroxide ions is higher than hydrogen ions because a strong alkali produces a higher concentration of hydroxide ions than a weak acid which produces less concentration of hydrogen ions. This reasoning was similar to one of the mental models identified by Lin and Chiu (2007) in their study of Grade 9 (15 year olds) students' mental models in acids and bases. They reported, in their study on the characteristics and origins of students' mental models in acids and bases, that high achieving Grade 9 Taiwanese students tended to explain an acid-base reaction based on a strong-weak relationship. For example, "adding weak acids into strong bases will produce basic solutions". The basic solution produced is because the base is strong and naturally 'conquers' the weak. This line of thinking is not considered to be an attribute of a scientific acid-base model, but rather a misconception. Another Form 6 student in this research study thought that the reaction between a strong base and a weak acid always produced a solution with pH 7 because the student considered all acid and base reactions to be neutralisation reaction resulting in pH 7. Consequently, for this student the concept of pH 7 for all neutralisation reactions superceded all other understandings about strong base and weak acid reactions in Acid-Base Equilibrium. This Form 6 student, thus,had a misunderstanding of the Acid-Base Equilibrium concept.

Also notable, is that six out of the eight Form 6 students responded *unsure* in their responses for the concept of Acid-Base Equilibrium indicating they could not explain this acid-base chemistry concept. The *unsure* attribute revealed in this study showed that a high percentage of students were not grasping the Acid-base Equilibrium chemistry concept. One Form 6 student did describe that the reaction between sodium hydroxide and ethanoic acid produced salt and water, similar to a Neutralisation reaction between an acid and a base, but the student was not able to elaborate further. The student appeared to believe that only the presence of OH^- ions indicated bases and was unaware that ethanoate (CH_3COO^-) ions are conjugate bases, which are able to generate hydroxide ions (OH^-)_in water. This response again illustrates the non-use of the Brønsted-Lowry model in answering the probe question.

Technically the reaction between sodium hydroxide (NaOH) and ethanoic acid (CH_3COOH) is considered a strong base-weak acid reaction. However, Form 6 students in this current study were not aware that ethanoate ions are conjugate bases of ethanoic acid. As a result, Form 6 students were unable to recognise that when ethanoate ions react with water hydroxide ions results. This lack of acid-conjugate base pair knowledge caused students to form misconceptions when explaining this concept. Also, the use of the *strong base-weak acid* and the *unsure* attributes indicated that students had either formed misconceptions or had made no links at all to the Bronsted-Lowry model. Hence, the Form 6 students did not fully comprehend this concept.

7.3.5 Buffers Concept

For the concept of Buffers, the majority of students in this study stated that a buffer solution consists of an acid and a base. However, this statement is insufficient because the students were unable to explain that the Buffers are in fact composed of a weak acid/weak base with its salt, in the view of the Arrhenius model, or an acid with its conjugate base according to the Brønsted-Lowry model. All the Form 6 students were unable to identify that a conjugate base is linked to the concept of salt, indicating that they did not know this aspect of Buffers concept.

Also, when the probe questions introduced the word ‘conjugate’, students had difficulty in explaining the term, similar to the finding in the study by Schmidt and Chemie (1995) of Grade 11,12, and 13 high school students in Germany. Their 1995 study probed German high school students understanding of the Brønsted-Lowry model and found that the German students did not understand the acid-conjugate base or base-conjugate acid pair using the Brønsted-Lowry model.

In this thesis study, Form 6 students appeared not to know how to use appropriate scientific models to identify the component of buffers, but interestingly, three students knew that a buffer solution can resist a change in pH and increase or decrease the acidity of a solution. This finding appears to demonstrate that these students were able to recognize the function of a buffer solution but not its components.

The last section discusses students' understanding of the Acid-Base Electron Pair Bonding concept.

7.3.6 Acid-Base Electron Pair Bonding Concept

Similarly, for the Acid-Base Electron Pair Bonding concept, which is introduced at the Form 6 schooling level in the Malaysian National Curriculum, the findings displayed that Form 6 students could only recognise acids as substances containing hydrogen ions and bases as substances containing hydroxide ions. These definitions are attributes of the scientific Arrhenius model. The Form 6 students in the study did not seem to use the Lewis model in their responses to questions about the Acid-Base Electron Pair Bonding concept indicating that the students experienced some learning difficulties in understanding the concept, or had not been taught the concept in class. For example, three Form 6 students inferred ammonia (NH_3) to be an acid, not a base, which is incorrect even when applying the Arrhenius model. This difficulty in identifying ammonia (NH_3) as a base showed Form 6 students were not aware of the Arrhenius model limitation in the case of ammonia (NH_3) which does not contain OH^- ions. Perhaps these students believed in one model "fits all' acid-base reactions, a contrast to the way scientists understand the role of models (Coll & Lajium, 2011; Taber, 2003) and thought that the Arrhenius model was able to explain all acid-base chemistry concepts.

One Form 6 student did appear to have some knowledge of the Lewis model, but incorrectly stated that that an acid donates electrons to bases, rather than a base donates electrons to an acid. The confusion about an acid being an electron donor and not a base, is a similar finding to the Sesen and Tarhan (2011) study. They noted that almost 21% of Turkish students (17 year olds) considered acids transfer electrons to bases not bases transferring electrons to acids which is an incorrect interpretation of the Lewis model. In general, Form 6 students in this study indicated that they did not understand the scientific attributes of the Lewis model and, thus, the concept of Acid-Base Electron Pair Bonding.

In summary, the findings for Research Question One showed that the attributes of students' mental models in the study displayed close links to the attributes of scientific models for the concepts of Macroscopic Properties, and Neutralisation. Students had appropriate scientific understanding of these concepts and Form 2 students had no difficulty grasping the curriculum concepts introduced to them in the classroom. Form 4 students who were introduced to the Neutralisation and Acid-Strength concepts revealed no difficulty understanding the Neutralisation concept but showed some difficulty comprehending the Acid-Strength concept.

It was significant that the majority of the Form 6 students did not fully understand the Acid-Base Equilibrium, Buffers, and Acid-base Electron Pair Bonding concepts. The reason for these difficulties lies in the dissonance between students' mental model attributes and the scientific attributes of the acid-base models. To illustrate, for the Macroscopic Properties concept the use of the *senses* students' attribute was aligned with the sensory scientific attribute of the Phenomenological model. Similarly, for Neutralisation the students' attribute *product formation* was aligned with the Arrhenius model scientific attribute for Neutralisation when majority of students described in Neutralisation salt and water are formed.

In addition, for the concept of Acid-Strength, the students' use of the *degree of dissociation* attribute together with the *molar concentration* students' attribute displayed misalignment with the Arrhenius model, because while the *degree of dissociation* attribute is an Arrhenius model attribute the *molar concentration* attribute is not. Thus, students exhibited only one scientific attribute, and the other was non-scientific. For the last three acid-base concepts (i.e., Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding), the majority of the attributes for the mental models of the Form 6 students' were not consistent with the scientific attributes of the Brønsted-Lowry and Lewis models. This inconsistency is demonstrated through students' use of attributes such as *strong base-weak acid*, *degree of dissociation*, *acidity change*, and *acid-acid reactions* were not aligned with the scientific attributes. It can be concluded that they did not understand these three concepts.

To answer Research Question Two, the stages of mental models are now discussed.

7.4 RQ2: The Stages of Mental Models Development for Acid-base Chemistry Concepts

In Chapter 5, a classification system was developed to identify types of students' mental models based on attributes revealed in students' responses to questions about acid-base concepts (Chapter 4). The classification system subsequently described three different stages in students' mental model development for the target systems (i.e., six selected acid-base chemistry concepts) which are referred to as Stage 1, Stage 2, and Stage 3.

7.4.1 Stage 1 Mental Models

A Stage 1 mental model is based on the acid-base chemistry concept Macroscopic Properties that refers to the observable features of acids and bases. Such a model is grounded in students' everyday experiences and their ability to apply the scientific Phenomenological model in their descriptions about acidic and basic properties. Students who demonstrated ownership of a sub-stage 1c mental model showed a high correlation with the intended curriculum (i.e., the curricular model).

Almost all students were able to use the *senses* and *scientific test* attributes to identify acids and bases. Extending further, a few students used the agent-object explanation (Andersson, 1986a). For example, the more sour the lemon is (i.e., the agent), the more acidic a lemon is (i.e., the object). As evidence, student SF2b stated that when milk is left for a long time it becomes more sour implying the more acidic the milk becomes. The use of the agent-object explanation showed that all students comprehended the Macroscopic Properties concept using the observable and sensory features of acids and bases. This comprehension is displayed when students demonstrated a sub-stage 1c mental model which is considered to be using the Phenomenological model attributes.

In addition, owners of the Stage 1 mental model do not include any atomic or subatomic representational levels, however, three Form 4 and four Form 6 students did use attributes that revealed the use of atomic representational levels (i.e., the sub-microscopic world). These students explained aspects of the macroscopic properties using hydrogen and hydroxide ions which are sub-microscopic entities.

7.4.2 Stage 2 Mental Models

Students' possession of a Stage 2 mental model indicates their use of the Arrhenius model to explain the Neutralisation and Acid-Strength concepts. Owners of Stage 2 mental models in this study (i.e., Form 4 and all Form 6) began to use the sub-microscopic and symbolic levels following the introduction of H^+ and OH^- ions and ionic equations into their learning programmes. The introduction of the H^+ and OH^- ions marks a transition stage in mental model development from a macroscopic to an sub-microscopic representational level. Form 4 and Form 6 students in this second stage of mental model development viewed the Neutralisation concept as a chemical reaction between acids and bases to produce water and salt. However, their understanding of chemical reaction fell into two categories. The first category included an understanding that hydrogen ions and hydroxide ions reacted (i.e., disappear) when water is formed as stated by student SF4e when the student mentioned that there are no more hydrogen and hydroxide ions in the final solution. This 'disappearance' view is not aligned with the scientific explanation because when neutralisation occurs, equal amounts of hydrogen and hydroxide ions combine to form water. Andersson (1986b, 1990) also identified this 'disappearance' explanation of matter for neutralisation reactions which is not a scientific explanation. He categorised such an explanation as a misconception. In the second category, one Form 2 student viewed the salt produced as acidic, therefore, retaining some properties of acids in the final solution. Anderson (1986b, 1990) described this explanation as the 'modification' view where students tended to think some of the initial properties of the reactants still being present in the final product. Again this explanation is considered not to be scientifically acceptable because in a chemical reaction a new substance is formed with different properties to the reactants (see Sections 2.11).

Another acid-base concept that is a component of Stage 2 mental models is that of Acid-Strength. A Stage 2 mental model denotes another shift in thinking from the initial presence of hydrogen and hydroxide ions in the Neutralisation concept to the dissociation process of acids and bases in aqueous solution forming hydrogen and hydroxide ions respectively. This latter dissociation process underpins the Acid-Strength concept. The results indicated that the majority of Forms 4 and 6 students exhibited two sub-stages of Stage 2 (i.e., sub-stage 2c and 2a) suggesting the existence of two mental models in their mind. Clearly, owners of Stage 2 mental models showed they were able to use the scientific attributes of the Arrhenius model to explain the Neutralisation concept. On the other hand, not all Form 4 and Form 6 students were able to fully grasp the Acid-Strength concept because they perceived the strength of an acid directly related to the molar concentration of the resulting solution, not with the degree of dissociation. It could be argued that, Form 4 and Form 6 students tended to explain the strength of an acid from the perspective of an agent–object relationship, as identified by Anderson (1986a), where the relationship involves the dependency of an object on an agent. So, in Stage 2 mental models, the *molar concentration* and the *degree of dissociation* attributes acts as agents and the strength of an acid as the object. For example, when the agent (i.e., molar concentration or dissociation) increases, the object (i.e., the strength of an acid) also increased (i.e., a direct correlation). In other words, a strong acid dissociates completely while a weak acid dissociates partially. Thus, the degree of dissociation determines the strength of an acid. For this reason, students using the agent-object relationship exhibited correct explanations for the *degree of dissociation* attribute. On the other hand, a *molar* *concentration* attribute is perceived as a concentrated solution describing the quantity of matter such as 0.1mol L^{-1}. For example, a solution with a 0.2 mol L^{-1} is said to be more concentrated than a solution with 0.1mol L^{-1}. The findings indicated that students displayed the agent-object relationship in both the *degree of dissociation* and *molar concentration* attributes. In other words, the majority of students owned one correct conception (i.e., *degree of dissociation*) and one misconception (i.e., *molar concentration*).

In summary, for the Neutralisation concept, all students at all schooling levels were assigned a sub-stage 2c mental model, indicating their appropriate use of the Arrhenius model, as intended by the curriculum. However, for the Acid-Strength concept, the majority of Form 4 and Form 6 students displayed a combination of sub-stages 2c and 2a mental models, meaning their understanding was not completely aligned with the intended curriculum.

7.4.3 Stage 3 Mental Models

Development of Stage 3 mental models is based on students applying knowledge of the scientific attributes for the Brønsted-Lowry and Lewis models, in addition to the Arrhenius model, to explain the Form 6 curriculum concepts of Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding. However, none of the Form 6 students were able to explain these concepts, with the majority of them displaying a sub-stage 3a or 3d mental model. The sub-stage 3d mental model was assigned to students using the Arrhenius model attributes incorrectly while an *unsure* attribute was indicated a sub-stage 3a mental model. These findings showed that the Form 6 students were not utilizing appropriate acid-base model attributes to explain the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts. It seemed that Form 6 students were not adding the scientific attributes of the Brønsted-Lowry and Lewis models to their existing cognitive structures. However, four students used the *strong base-weak acid* attribute for Acid-Base Equilibrium concept and the *strong acid-weak base* attribute for the Acid-Base Electron Pair Bonding concept. The use of these attributes could indicate students think that any strong acidic or basic solution will retain its 'strong' properties after a chemical reaction. Thus, for a strong base-weak acid reaction the resulting solution will be basic.

The Stage 3 mental models that were developed (i.e., sub-stage 3a and 3d) indicated students' inability to use the Brønsted-Lowry and Lewis models to describe the selected concepts of Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts. It appeared that these mental models made them unable to explain the concepts at the subatomic representational level in their reasoning (i.e., using acid-conjugate pairs, proton transfer and/or electron pair transfer). As a result, this non-use of the Brønsted-Lowry and Lewis model attributes indicated a misalignment of their mental models with the intended curriculum.

7.5 RQ3: Comparison of the Curricular, Teachers', and Students' Mental Models

In Malaysia, all Malaysian teachers are expected to follow the Curriculum Specification Guides closely when teaching science and chemistry. This requirement reflected in the curriculum document, MoE (2005) that states:

> This science curriculum emphasises thoughtful learning based on thinking skills and scientific skills. Mastery of thinking skills and scientific skills are integrated with the acquisition of knowledge in the intended learning outcomes. Thus, in teaching and learning, teachers need to emphasise the mastery skills together with the acquisition of knowledge and the inculcation of noble values and scientific attitudes. (p.10)

A comparison of the curricular model, teachers' mental models and students' mental models gives an indication of the degree of alignment between these three types of education models. At the Form 2 schooling level students' mental models showed three misalignments with the teachers' mental models and two misalignments with the curricular model. Form 2 teachers' mental models showed two alignments and two partial alignments with the curricular model. This partial alignment occurred because only one out of the two teachers' mental models was aligned with the curricular model (see Table 6.7, previous). Teacher TF2b was able to describe *explain the meaning of Neutralisation* and *write an equation in words to describe the Neutralisation process* learning outcomes but was not able to *identify the properties of acids, and alkalis* and *explain through examples the uses of Neutralisation in daily life* learning outcomes. In other words, the finding suggests that teacher TF2b did not fully adhere to the curricular model.

At the Form 4 level, the teachers' mental models displayed one misalignment, one partial alignment, and two alignments with the curricular model. However, the students' mental models showed a low correlation with teachers' mental model because out of the four selected learning outcomes the findings indicated two misalignments each for their teachers' mental model and also the curricular model., For the Form 6 schooling level the teachers' mental models showed high correlation with the curricular model when two out of three selected learning outcomes were consistent with the curricular model learning outcomes. However, a complete misalignment occurred between the students' mental models and their teachers' mental models and the curricular model for the three selected learning outcomes was seen (see Table 6.7).

Significantly, these findings reveal that Form 2 and 4 mental models show students achieved two out of the four selected learning outcomes from the curriculum but the Form 6 students' did not achieve any of the selected learning outcome intended by the curricular model.

One of the possible reasons for the misalignment could be the lack in specificity of the curricular model as presented in the Malaysian Curriculum Specifications Guide for Forms Two and Four (MoE, 2002, 2005). The curricular model provides only a skeleton description of the intended curricular model via lists of specific learning outcomes. At the Form 2 level, the curricular model does provide some explanatory notes for the learning outcome of *identify the properties of acids, and alkalis* and *explain through examples the uses of Neutralisation in daily life,* but not for *explain the meaning of Neutralisation* and *write an equation in words to describe the Neutralisation process* learning outcomes. Such guidelines provide little information, especially to Form 2 teachers whose scientific knowledge appears to be weak. At the Form 6 schooling level, teachers' mental models were assumed by this study to be aligned with the curricular model when teachers' explanations were consistent with the chemistry content found in the literature chapter. The literature chapter helped the researcher match the teachers' explanations with scientific models in order to fill the gap in the skeleton curricular model.

The findings also showed that for Forms 2 and 4 students both the teachers' and students' mental models indicated understanding of Neutralisation concept but not the everyday use of the neutralisation process. It is highly likely that the teachers' inability to describe the application of Neutralisation is the cause of students' lack of recalling the application of Neutralisation.

Another misalignment at the Form 4 of schooling occurred between the students' mental models for the *describing acid-base titration* learning outcome and both their teachers' mental models and the curricular model. This misalignment could be caused by students' lack of practical or lab work in their early schooling learning experiences. Their difficulty in performing practical investigations and understanding concepts learnt through investigation may have its roots in the early years of the secondary school science programmes. An earlier study of Form One Malaysian students (13 year olds) by Fadzil and Saat (2014) revealed how Malaysian students had difficulties translating concepts learnt in the classroom to practical investigations. It was found students at lower Forms did perform practical work but were not able to apply relevant science concepts associated with the practical. Therefore, it is possible that the Form 4 students' earlier difficulties understanding the science in their practical investigations may have impacted on their later comprehension of acid-base titration at a higher schooling level.

Similarly, for the selected Form 4 *describe acid-base titration* learning outcome, the curricular model suggests a learning activity that involves determining the end point when performing acid-base titrations. The curricular model does not specify which type of acid-base titration (i.e., strong acid with strong base or other forms of titrations) and it appears that teachers are assumed to know which titration is to be carried out. In fact, the findings suggest that most students were not able to describe acid-base titrations. The lack of a practical aspect in most students learning was indicated by six out of eight students' inability to interpret an acid-base titration on their own. Further, one student, when probed in an interview, responded "I have not done this experiment so I do not know" displaying he/she had not perform an acid-base titration experiments in the laboratory. Students not performing acid-base experiment in schools was likely to be caused by teachers selecting investigations that were easily prepared, sufficient for students to complete their tasks or assignments and achieve a high percentage of success, (Taber, 2008).

In summary, for Form 6 the students' mental models showed complete misalignment with the teachers' mental models and the curricular models. Possible causes for this dissonance are elaborated on in Section 7.7.

The findings discussed in sections 7.3, 7.4, and 7.5 gave insights into Malaysian students' mental model development for six selected acid-base concepts and their use of four scientific acid-base models. Next, the trends in Malaysian students' stages of mental model development are discussed.

7.6 Trends in Malaysian Students' Stages of Mental Model Development

Students' explanation for the concepts of the Macroscopic Properties, Neutralisation and Acid-Strength, were based on reasoning as explained in Section 7.3 and 7.4. For the Macroscopic Properties concept, students tended to use the 'agent-object' form of reasoning. For the concept of Neutralisation, some students' forms of reasoning were based on the 'modification', the 'displacement' and the 'disappearance' views explanations. For the Acid-Strength concept it was found that, Form 4 and Form 6 students were inclined to use 'agent-object' reasoning to explain their understanding. However, for the Acid-Base Equilibrium, Buffers, and the Acid-Base Electron Pair Bonding concepts, the findings showed that students were not able to provide any explanation in response to the probe questions. The possible reasons for this inability are discussed in Section 7.7.2.

Consideration of the overall patterns in the Malaysian students' mental model development showed that they used multiple reasoning for the Macroscopic Properties, Neutralisation, and the Acid-Strength concepts. For example, the agent-object reasoning was evident in the senses attribute for Macroscopic Properties concept, while for the Acid-Strength concept 'agent-object' reasoning was reflected in students' attributes such as *degree of dissociation*, and *molar concentration* attributes. Students using the agent-object relationship is considered to demonstrate a correct reasoning for the *dissociation of ions* attribute but not for *molar concentration* attribute. This is because the degree of dissociation is highly correlated with the strength of an acid.

For the Neutralisation concept, the 'modification' and the 'disappearance' lines of reasoning were evident in the *product formation* attribute while the 'displacement' view was found in the *physical mixing* attribute. However, these lines of reasoning (i.e., 'modification' and 'disappearance') showed that a small proportion of the Malaysian students in the study formed misconceptions. For the Macroscopic Properties and Neutralisation concepts, however, a majority of the students established correct conceptions.

Another finding of note is that almost all students' mental models attributes were similar to scientific attributes when responding to questions requiring use of the Arrhenius and Phenomenological models. In contrast, Form 4 and Form 6 students partially grasped the Acid-Strength concept but the Form 6 students were unable to comprehend the concepts of Acid-Base Equilibrium, Buffers, and Electron Pair Bonding concepts. Before further explanation is provided, it must be noted that all students if they are to achieved the intended curriculum should ideally possess the 'c' sub-stage mental model at each stage of mental model development. For example, ideal Form 2 students' mental models are sub-stage 1c and sub-stage 2c mental model (i.e., for the concepts of Macroscopic Properties and Neutralisation) while Form 4 students should possess sub-stage 1c and sub-stage 2c mental models (i.e., for the concepts of Macroscopic Properties, Neutralisation, and Acid-Strength). Similarly, Form 6 students would ideally own sub-stage 1c, 2c, and 3c mental models (i.e., for all six selected acid-base concepts). The findings from this thesis study showed a range of sub-stages in students' mental models (see Table 5.9, previous). For example, student SF6a showed a sub-stage mental model 1a, 1c, 2a, 2b, 2c, 3a, 3b, and 3d suggesting this student had a mix of correct conceptions (i.e., 1c, 2c and 3c) and misconceptions (i.e., 1a, 2a, 2b, 3a, and 3d). In this thesis study, none of the Form 6 students held a sub-stage 3c indicating that Form 6 students were not learning the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts as intended by the curriculum.

A number of possible explanations for the learning difficulties Form 6 Malaysian students experience are discussed in the next section.

7.7 Possible Explanations for Form 6 Students' Inability to Form Stage 3c Mental Model

Examination of the findings showing comparisons between curricular models, and teachers' and students' mental models at Form 6 schooling level showed that teachers' mental models were almost similar to the curricular model, but students mental models were not. It is possible that the explanation for this mismatch might lie somewhere in the translation of the intended curriculum into the operational and/or student-experienced curriculums. In other words, students' misunderstandings were linked to their classroom teaching and learning experiences. However, because no classroom observations were undertaken in this study, aspects of the classroom teaching and learning environment that impacted on students' learning can only be speculative in nature. A number of possible scenarios regarding the operational and student-experienced curriculums are now discussed which could account for the formation of the acid-base mental models that students developed.

The findings displaying students' inability to grasp the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts may be the result of three possible scenarios. In the first scenario, Form 6 teachers did teach their students the appropriate scientific acid-base models but the majority of the students chose to use the Arrhenius model in their responses to questions. A second scenario could be that the Form 6 teachers did teach their students the appropriate scientific models but the students were unable to understand the scientific models, and, therefore, could not explain concepts using the Lewis and/or the Brønsted-Lowry models. In the third scenario, the Form 6 teachers simply did not teach the Brønsted-Lowry and Lewis acid-base models, hence, many of the Form 6 students did not use these models in their explanations. Each of these scenarios is discussed in turn from the perspective of issues around the curricular model, the Form 6 students' cognitive abilities, and teachers' content and pedagogical knowledge.

7.7.1 Issues with the Curricular Model

A possible cause for the misalignment between the Form 6 curricular model and Form 6 students' mental models is a curriculum that lacks explicit specifics about what is to be learned and how it should be taught. A comprehensive curricular model includes "general purposes, topics of domain, special aims of topics, and behavioural objectives, teaching and learning activities, teaching tools, learning results, assessment tools and methods" (cf. Demircioğlu et al., 2005, p. 40). Overall, the Malaysian curricular model does include general aims and objectives of science education, learning areas, learning objectives, suggested learning activities, learning outcomes, general aims and objectives, notes, and vocabulary. However, the exclusion of teaching tools and learning indicators, such as performance criteria, may be reasons why teachers were not interpreting the curricular model as intended. At the Form 6 level, the curricular model known as the 'Syllabus and Specimen Papers', is even more simplified and only covers general aims and objectives, topics, and teaching periods which is the number of interaction hours, and learning outcomes (MEC, 2012). Other components, (i.e., such as teaching and learning activities, learning results and assessment tools) are not present in the Form 6 curricular model requiring teachers' discretion when interpreting the curricular model.

It is also noteworthy that the Malaysian curriculum objectives focus on science-technology-society (STS) at the Form 2 and Form 4 levels rather than the nature of science (MoE, 2002, 2005). Thus, the role of models in science is not emphasized by curriculum developers and teachers.. As a result, many Form 6 Malaysian students may not come to realise or appreciate why different models exist and that certain models are applicable for explaining specific concepts. The historical development of atomic models and the Periodic Table were included in the Malaysian curriculum but not the development of acid-base chemistry models (MoE, 2005). The section on the development of atomic models and the Periodic Table provides information about how the current atomic models and Periodic Table evolved from obsolete models to how they are presently used. The development of current acid-base concepts requiring the use of four acid-base models for understanding and is not highlighted in the Malaysian Form 6 curriculum (MEC, 2012). It is possible that Form 6 students assumed that because only the Bohr atomic model is used to explain atomic structure, then surely one acid-base model was sufficient to understand acid-base chemistry (i.e., the Arrhenius model). This possibility is reflected in the finding that only attributes of the Arrhenius model are used by senior students to explain Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts.

Another point to consider is that a curricular model is a simplification of a scientific model (Gilbert, Boulter, et al., 2000), therefore, not all scientific knowledge may be transferred creating a gap. An even bigger gap may exist between the curricular and teachers' mental models because each teacher interprets the curricular model individually and may unknowingly include their own misconceptions during teaching and learning in the classroom (Banerjee, 1991). The transferring and misinterpretation of some information from one layer of curriculum to the next can be compared to the game "chinese whispers" (Taber, 2008, p. 189).

The possible explanation discussed above, related to students' non-use of multiple models in their acid-base chemistry, centres on the lack of detail in the curricular model about when and how the acid-base models are best applied to various acid-base concepts. As a result, teachers may not emphasize this point in their teaching, which in turn could have resulted in Form 6 students not understanding the concepts because they did not use appropriate scientific explanations.

In the next section, possible issues with students' cognitive capabilities are discussed.

7.7.2 Issues with Students' Cognitive Capabilities

As mentioned in section 7.7, three scenarios may account for the Form 6 students' inability to form appropriate Stage 3 mental models. In the first scenario where the Form 6 teachers taught the Form 6 students about different acid-base models, two established findings can be linked to this scenario. They are:

- Form 6 students' choice of the Arrhenius model over other acid-base models; and
- Form 6 students' problems when interchanging between the Arrhenius, Brønsted-Lowry, and Lewis models in their explanations for Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding acid-base concepts.

Both these findings could be the result of the first scenario.

One possible explanation for the students' use of the Arrhenius model in their explanations may be related to some aspect of their cognitive capabilities as indicated through the nature of their mental models. Erduran and Duschl (2004) pointed out that "a mental model is a cognitive representation of an event, object or a phenomenon" (p. 117). Thus, this study of students' acid-base mental models over progressive levels of schooling could be giving insights into students' cognitive capabilities in terms of their readiness to understand acid-base concepts, as reflected in the stages of their mental model development. For example, when developing a Stage 3 mental model, Form 6 students were exposed to more complex concepts requiring higher cognitive capabilities for explaining and understanding (Bretz & McClary, 2014; Chiou & Anderson, 2010) compared to Forms 2 and 4 concepts. Applying this argument to other findings in the study, it can be seen that Form 2 students held sub-stages 1c and 2c mental models for the

Macroscopic Properties and Neutralisation concepts allowing them to successfully use and explain these concepts (i.e., they had the cognitive ability to form appropriate mental models for understanding the concepts). Form 4 students also illustrated they had the intellectual ability to form appropriate Stage 1 and Stage 2 mental models for the Macroscopic Properties and Neutralisation concepts, but they had some difficulty grasping the second component of a Stage 2 mental model (i.e., the Acid-Strength concept). It could be interpreted that the Form 4 students lacked the capability to think at the cognitive level required for understanding the Acid-Strength concept. Similarly, Form 6 students easily grasped the Stage 1 and Stage 2 concepts of Macroscopic Properties and Neutralisation, but exhibited difficulties with the Acid-Strength, Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts for which they were unable to form appropriate Stage 3 mental models. In these instances, the cognitive level could be too high for the students to comprehend the Acid-Strength, Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts. This level of cognitive demand could be why the majority of Form 6 students' were determined to use the Arrhenius model to explain Acid-Strength, Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts.

The second outcome that can be linked to the first scenario where Form 6 teachers taught relevant scientific acid-base models was students' problems interchanging between the Arrhenius, Brønsted-Lowry, and Lewis models in their explanations about certain acid-base concepts. The ability to interchange between models is termed 'modelling ability' (Chittleborough & Treagust, 2007). The modelling ability difficulties (see Section 2.14) experienced by Form 6 students in this study appeared to have been caused by students considering one acid-base model as independent of other acid-base models (Coll & Lajium, 2011), such as their use of only the Arrhenius model attributes when answering questions. For example, the components of Buffers can be explained using weak acid and its salt (i.e., Arrhenius model) and an acid with its conjugate base (i.e., Brønsted-Lowry model) explanations.

Another contributing factor to students' lack of understanding could be linked to their inability to readily shift between levels of representations (Furió-Más et al., 2005; Kousathana et al., 2005; Nakhleh & Krajcik, 1994). To elaborate further, all students in this study had no difficulties shifting in their thinking from the macroscopic level to the sub-microscopic or specifically atomic levels of representation (e.g., hydrogen and hydroxide ions), but a further shift to a subatomic particulate level of representation (e.g., thinking of acids as proton and electron donors) saw some students experiencing difficulties. The difficulty in shifting between representational levels may arise because the particle nature of matter, introduced at Form 4 schooling level is not re-emphasized at the Form 6 level enabling them to explain advanced chemistry concepts. Another difficulty experienced by students is that many acid-base models are viewed in terms of layered models (de Vos & Pilot, 2001). In this study, the first layer may be considered the understanding that an acid is a sour substance (i.e., application of the Phenomenological model) while the second layer describes the role of hydrogen and hydroxide ions in aqueous solution (i.e., application of the Arrhenius model). The third layer considers the identification of acids and bases in terms of protons (i.e., application of the Brønsted-Lowry model) and the fourth layer explains an acid and base reaction as an electron pair transfer (i.e., application of the Lewis model). When these layers are not clearly defined and explained, incoherence between the layers exists and may contribute to Form 6 students' impediment in learning acid-base chemistry (de Vos & Pilot, 2001).

Another point worth considering is that since a mental model study involves cognitive representations that relate to students' cognitive abilities, then mental models could also be associated with information processed in the mind (Tsaparlis, 2014). It follows that Piaget's Theory of Cognitive Development (Piaget, 1953) and the Information Processing Model (Johnstone, 2006) could support this mental model study by providing another feasible explanation based on cognitive capability, explained next. The following explanations could help in understanding the reasons why students have limited cognitive ability, an elaboration for the second scenario.

In his Theory of Cognitive Development, Piaget (1953) stated that new elements, called schemata are added to a student's existing schema or cognitive structure (see Section 2.6.1) when students' learn or acquire new knowledge. It is important to note that a schema is considered to be a student's cognitive structure or knowledge organization (Taber, 2002) and a mental model is considered a mental representation (Vosniadou, 1994), very like a schemata. In the following explanation, the term schemata is synonymous with students' mental models.

When a student is learning, he/she is trying to assimilate new schema into his/her existing schemata and enters into an equilibrium phase when the new knowledge and the old knowledge are assimilated. For example, students in this thesis study first learn acid-base chemistry using the Phenomenological model at the Form 2 schooling level to form their first acid-base schemata. At Form 4 students learn how to use the Arrhenius model to explain Neutralisation and Acid-Strength concepts, forming what is considered new schema which are added to the old schemata that they already hold, (i.e., the Phenomenological model). When the new schema assimilates with the old schemata, new schemata are formed consisting of the old and new knowledge (i.e., the Phenomenological and Arrhenius model are now in equilibrium). The cycle should be repeated when Form 6 Malaysian students learn about the Brønsted-Lowry and Lewis models' and formed revised schemata. In other words, their new mental model is subsumed into their existing cognitive structure. However, in this study it was found that many Form 6 students only used the Arrhenius attributes to explain the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts. It appears they experienced difficulty when trying to achieve equilibrium between the Phenomenological and Arrhenius models on one hand and the Brønsted-Lowry and Lewis models on the other. This difficulty is reflected in their inability to use the scientific attributes of the Brønsted-Lowry and Lewis models to explain the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding acid-base chemistry concepts. This difficulty could provide an explanation for apparent limitations in students' cognitive abilities.

In contrast, the learning of new concepts from the perspective of the Information Processing Model of learning by Johnstone (2006), is seen as a process occurring in the Working Memory Space of the learner, where the new knowledge is temporarily stored (see Section 2.6.3). When new knowledge is received the Working Memory Space assimilates the new knowledge with old knowledge (i.e., from the long term memory) in order to comprehend the new knowledge. However, if the new knowledge is too complex or too much, the Working Memory Space may not be sufficient to process it and may be overloaded, described in the Information Processing model. As a result, the new knowledge is not processed and stored in the long-term memory. This failure of the processing and memory storage system is manifested in students' inability to grasp the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts and could be a reason for Form 6 students having difficulty forming a sub-stage 3c mental model. As a result, students may use the old knowledge (i.e., their understanding of the Arrhenius model) to explain Acid-Base Equilibrium, Buffers, and Acid-base Electron Pair Bonding concepts, an explanation for the second scenario.

Additionally, when Form 6 students were unable to answer or explain a question about acid-base concepts they often responded with the *unsure* attribute. This *unsure* attribute may suggest that students were not able to use the particular acid-base model necessary for explaining the acid-base concepts. The Form 6 students' inability to use these acid-base models can be related to Vygotsky's social cognitive theory. This theory pointed out that there is a gap in teachers' and their students' knowledge. The gap, also known as the Zone of Proximal Development (Vygotsky, 1978) caused the students to have difficulties in understanding acid-base models. Usually it is the teachers' role to help close the gap for students. The result in this study may suggest that Form 6 teachers did not sufficiently scaffold their students in using the acid-base models to explain concepts and subsequently students were not sure how to respond to probing questions.

Students' difficulty in using the Brønsted-Lowry and Lewis model may not just lie in their cognitive levels or their inability to process new information. Another explanation may be linked to the nature of their teachers' content and pedagogical knowledge which is discussed next.

7.7.3 Issues with Teachers' Content and Pedagogical Knowledge

Another reason that may contribute to the misalignment between teachers' mental models and students' mental models in this study could be the nature of the teachers' chemical knowledge, which is an important factor when helping students learn chemistry (Bradley & Mosimege, 1998; Erduran & Duschl, 2004). In this thesis study, Form 6 teachers when interviewed showed the knowledge to explain acids and bases using the Arrhenius, Brønsted-Lowry, and Lewis models but none of the students under their guidance were able to do the same for the selected learning outcomes of *using the Arrhenius, Brønsted-Lowry, and Lewis models to explain acids and bases.* This inconsistency between teachers' and students' mental models may demonstrate that, while teachers have sufficient knowledge about the different acid-base models, they may not have included the different acid-base models in their teaching as required by the curricular model. As a result, their students were unable to use the Brønsted-Lowry and the Lewis models to explain the Acid-Base Equilibrium, Buffers, and Acid-base Electron Pair Bonding concepts, and hence failed to comprehend the concepts (the third possible scenario).

The third possible scenario may also be a result of teachers not using teaching strategies that focus on models and modelling as found by Van Driel and Verloop (2002) in their study of experienced teachers knowledge of models and modelling. Van Driel and Verloop (2002) found that one subgroup of teachers had problems integrating their knowledge of models into their teaching and learning in the classroom. Similarly results were found in research by Drechsler and Van Driel (2008), who investigated teachers' pedagogical content knowledge when teaching acid-base models in chemistry classrooms. Their 2008 study found that only five out of the nine teachers knew about acid-base models, and none of these five teachers explained the use of the Ancient (Phenomenological), Arrhenius, and Brønsted-Lowry models during their classroom instruction. Similarly, but in a different context, Justi and Gilbert (2002) in their study of science teachers' views on the role of modelling in learning science in the classroom pointed out that teachers who knew about scientific models were reluctant to teach them, probably because they were not fully capable themselves of using the different models correctly in the classroom.

Another possible explanation that may have contributed to the inconsistencies between students' mental models and teachers' mental model could be teachers' use of traditional pedagogical methods (Daniel & Idris, 2007; Ültay & Çalık, 2012) in the learning of science in Malaysia. In the traditional method of teaching, Malaysian teachers use school textbooks in classrooms orally (i.e., they read them aloud) while students are involved in note taking (Atasoy, Akkus, & Kadayifci, 2009). Daniel and Idris (2007) noted that the traditional pedagogical approach (i.e., teacher focused learning) may hinder Malaysian students' understanding of science in the classroom. This traditional approach may be a result of teachers' perceiving themselves as transmitters of knowledge rather than as facilitators of learning in the classroom. As a result of such traditional instruction, students can resort to rote learning resulting in superficial learning of chemistry (Coll & Treagust, 2003).

7.8 Summary

The nature of Malaysian students' mental model development showed that Form 2 students exhibited little difficulty in understanding the curricular concepts of Macroscopic Properties and Neutralisation. In contrast, Form 4 students had difficulty grasping the Acid-Strength concept while Form 6 students did not achieve understanding of the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts. These difficulties are thought to be caused by:

1. The use of ‘modification’, ‘displacement’, and ‘disappearing’ forms of reasoning, which are not scientifically acceptable for explaining the Neutralisation concept;
2. The combination of the incorrect use of the *molar concentration* attribute and the correct use of the *degree of dissociation* attribute in describing the Acid-Strength concept by the Form 4 and Form 6 students using an ‘agent-object’ relationship;
3. The use of a non-scientific explanation when reasoning that a higher concentration of hydroxide ions forms a strong base weak acid reaction for the Acid-Base Equilibrium concept by the Form 6 students;
4. The inability of the Form 6 students to fully understand that the composition of a buffer solution can be explained using acid-conjugate base (i.e., Brønsted-Lowry model) or weak acid-salt pairs (i.e., Arrhenius model); and
5. The inability of all Form 6 students to explain the concept of Electron Pair Bonding using the electron pair transfer attribute in the Lewis model.

This study argues that these difficulties were because the Malaysian students were not using scientific reasoning or the appropriate scientific acid-base models attributes in their explanation of the acid-base concepts.

Almost all Forms 2, 4 and 6 Malaysian students held Stage 1 mental models. Some of those students tended to explain the macroscopic properties using the agent-object explanation. The use of the agent-object explanation was evident when the students related the more sour taste of a lemon to a high acid content. In the Neutralisation concept some students used the ‘modification’, ‘displacement’, or the 'disappearance' views to describe Neutralisation concept. Almost all Form 4 and Form 6 students used the agent-object reasoning to explain Acid-Strength, while Form 6 students had difficulty reaching a Stage 3 mental model. The difficulty in reaching a Stage 3 mental model is thought to be caused by the Form 6 students' use of the Arrhenius model attributes to explain the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts rather than Brønsted-Lowry and Lewis model attributes. In addition, Forms 2, 4 and 6 students showed the ability to appropriately use the Phenomenological and Arrhenius models to explain the Neutralisation concept while Form 6 students showed difficulties using the Brønsted-Lowry and Lewis models for explaining the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts as required by the curricular model. The difficulty that Form 6 students experience was also indicated when their mental models displayed complete misalignment with teachers' mental models and the curricular model for all three selected learning outcomes. The complete misalignment at Form 6 schooling level may be caused by lack of specificity of the curricular model, limited students' cognitive ability, and underdeveloped teachers' pedagogical knowledge.

The next chapter discusses the implications and limitations of the study's findings and suggestion for future research and conclusion.

Chapter 8. Implications and Conclusions

This chapter begins with the implications of the findings from this study for students' understanding of acid-base chemistry. This first section is followed by the recommendations to address problems highlighted from the implications. Next, the limitations of the inquiry are discussed, followed by suggestions for future research. The chapter ends with a conclusion of the study.

8.1 Introduction

The primary focus in this study was to investigate the nature of Malaysian students' mental models for six selected acid-base chemistry concepts. The students' mental models revealed their understanding of acid-base chemistry concepts using acid-base models in relations to relevant scientific acid-base models. Additionally, the study also sought to find Malaysian students' stages of mental models development for the six selected acid-base chemistry concepts over different levels of schooling. In order to determine stages of mental models a classification system for mental models was developed. Also, the study investigated the degree of alignment between students' mental models, teachers' mental models and the curricular model for selected learning outcomes.

8.2 Outcomes and Key Findings of the Study

A mental model study such as this thesis study provides further knowledge for helping students understand chemistry concepts using acid-base models. This thesis study can be used as an important resource and may provide teachers with:

- Knowledge of students' and scientific attributes of the acid-base models used to describe the six selected acid-base concepts;

- Knowledge of students' stages of mental models development in terms of their ability to use acid-base models to explain six selected acid-base chemistry concepts;
- Understanding of students' difficulties in learning acid-base concepts. For example, in this thesis study, the stages of mental models development demonstrated the difficulty Form 6 students experience shifting from the atomic to the subatomic levels; and
- Knowledge of students' ideas on the concept of matter in acid-base chemistry. For example, the 'agent-object' relationship to explain Macroscopic Properties and Acid-Strength concepts; and the use of the 'displacement' 'modification', and 'disappearance' forms of reasoning to explain Neutralisation concept.

Also, the finding suggests that the Form 2 students were largely able to grasp the acid-base concepts of the Macroscopic Properties and Neutralisation (i.e., Stage 1 and 2 mental models) as required by the curricular model. However, Form 4 and Form 6 Malaysian students were only partially able to comprehend the curricular concepts of Acid-Strength. Finally the study revealed that most Form 6 students were unable to grasp the curricular concepts of Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts. The inability of Form 6 students to comprehend the three acid-base concepts is probably caused by a misalignment between the students' mental models and the teachers' mental models. The students' mental models were also misaligned with the curricular model. However, there was no misalignment between the Form 6 teachers' mental model and the curricular model. The misalignment or dissonance between the students' mental models and both the teachers' mental model and the curricular model is a serious concern for teachers and curriculum planners.

The following section discusses some of the possible reasons for the dissonance.

8.3 Causes of the Dissonance

The findings in Chapter 7 revealed that the Malaysian students experienced some difficulties in understanding selected acid-base chemistry concepts particularly at Form 6 of their schooling levels. One of the difficulties in understanding these acid-base concepts is likely caused by the curricular model. In the curricular model the exclusion of the nature of science, including the role of models in science, reveals that the nature of science was not considered important by the curriculum developers, which may lead teachers to tend not to recognize the importance of acid-base models in their instructions. In addition, the lack of specificity in the curricular may cause teachers to incorrectly interpret the curricular model, thus, students were not able to achieve the desired learning outcome.

Another possible reason for the difficulty in understanding selected acid-base chemistry concepts is caused by the students' inability to comprehend the concepts because the teachers' did not teach the concepts in the classroom. For this reason, students could not use appropriate acid-base models causing them to form misconceptions. In another instance students reasoned using the scientifically incorrect 'modification', 'displacement', and 'disappearance' views in their explanation for the Neutralisation concept. Consequently, the use of these three forms of reasoning may have caused a barrier for students comprehending that in the Neutralisation concept new products are formed. Further, the students' inability to engage at a high cognitive level may provide another possible explanation why they were unable to explain the Acid-Base Electron Pair Bonding concept using the Lewis model.

The third reason why students had difficulties is likely to have been caused by their teachers' lack of content and pedagogy knowledge. Accordingly, Form 6 teachers may have not taught the Lewis acid-base model in the classroom, resulting in students' inability to use the Acid-Base Electron Pair Bonding concept in their explanations because of their lack of knowledge or awareness. Although, there is no evidence in this thesis study to support the claim that teachers lack pedagogy knowledge, it is recommended that teachers use mental modelling in the classroom. Gilbert (2011) argues that teachers should use "mental modelling overtly into our approach to teaching," (p. ix) because the study of mental models provides an in-depth understanding of science.

More importantly, the difficulties that students' experience learning acid-base chemistry concepts may contribute to students' poor performance in school examinations and may have some impact on Form 6 students furthering their study at tertiary level. Even passing school examinations with some understanding of the acid-base concepts may allow students to enter university, but may not be sufficient for them to be able to successfully pass their tertiary level exams. Without strong prior knowledge to help them understand more complex concepts their learning of acid-base chemistry is likely to be hindered. Hence, the findings in this thesis study highlight important concerns for curriculum developers, who need to review and evaluate the existing curriculum and for teacher educators to address Malaysian teachers' content and pedagogical knowledge.

Recommendations are now identified for stakeholders in chemistry education (i.e., curriculum developers, and science and chemistry teachers), discussed in the next section to address the issues presented in Chapter 7.

8.4 Recommendations

The difficulties in understanding selected acid-base concepts indicated that Form 6 students were not able to comprehend the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts. Two possible reasons for these difficulties suggested by this study is the lack of specificity in the curriculum and possibly teachers' insufficient pedagogical knowledge. Thus, the next two sections discuss the recommendations for the curriculum developers and teachers in reducing those difficulties.

8.4.1 Recommendations for Curriculum Developers

The understanding of chemistry concepts sometimes involves learning about models which aid students' learning of scientific knowledge. In an education context, a simplified version of the scientific knowledge that aids students understanding is called a curricular model (Gilbert, Boulter, et al., 2000). So, a curricular model that aids students' understanding provides some guidelines for teachers to achieve the intended learning outcomes. In this thesis study the findings showed a high degree of mismatch between the Form 6 curricular model and students' actual learning outcomes and a possible cause suggested by this study is the lack of content specificity in the current Malaysian curriculum. Hence, teachers are left to interpret the curriculum with little guidance and the likelihood of misinterpretation is a distinct possibility. From the findings in this study, it is recommended that Malaysian curriculum planners look into the possibility of a more content-specific curriculum. The inclusion of the nature of science (NOS) encompassing the role and function of models within the existing science-technology-society (STS) curricular model may be necessary to address the learning difficulties that Form 6 students experienced in this thesis study. The existence of the NOS in the curricular model should give emphasis to the importance of models in teaching science, and subsequently the use of acid-base models in understanding acid-base concepts. If a comprehensive curricular model is not feasible, then the development of additional documents to support the curriculum could provide teachers with more specific guidelines to help students to achieve learning outcomes as intended by the curriculum. These additional documents may act as a bridge to help teachers align their teaching and student learning more closely with the curricular model.

From another perspective, the findings may indicate that Form 6 students did not have sufficient cognitive ability to use the Lewis model. Therefore, it follows that the Lewis model may be better taught at the university level and not at secondary level. To support this argument, the Lewis model is not taught in chemistry in the last year of schooling in a number of countries like France (Cokelez, 2010), Greece (Demerouti et al., 2004) and New Zealand (MoE, 2007)– it appears that the model is not introduced to students until the tertiary level. The findings in this thesis study also indicate that Form 6 Malaysian students were not able to use the Brønsted-Lowry model to explain the Acid-Base Equilibrium concept, but evidence from 17 to 18 year olds Greek students indicated that students at this age are able to use the Brønsted-Lowry model to explain the Acid-Base Equilibrium concept (Demerouti et al., 2004). Therefore, it is arguable that the Brønsted-Lowry model could be successfully taught in the last year of schooling in Malaysia. For this reason, perhaps the Brønsted-Lowry model should be kept in the curricular model to explain the Acid-Base Equilibrium concept and Buffers concept at secondary schooling level. Accordingly, the Brønsted-Lowry model may provide sufficient knowledge in order for students to continue their tertiary education.

Thus, the implications of this study suggest a refinement of the Malaysian Form 6 chemistry curriculum as outlined above. This refinement may help curriculum developers in other countries to redesign their science curricula if students in their countries experience the same difficulties in using the Lewis model to explain the Acid-Base Electron Pair Bonding concept. The exclusion of the Lewis model in a revised Malaysian Form 6 curriculum may not place such a high cognitive demand on students trying to comprehend the Acid-Base Equilibrium and Buffers concepts. In other words, the application of acid-base models could mostly be focused on the three acid-base models that are not so cognitively demanding (i.e., Phenomenological, Arrhenius, and the Brønsted-Lowry models) in the Malaysian Secondary schools chemistry curriculum. The suggested curriculum may begin by introducing the properties of acids and bases using the Phenomenological model at Form 2 level, followed by the use of the Arrhenius model in explaining the Neutralisation and Acid-Strength concepts at the Form 4 level. At the Form 6 level, the Brønsted-Lowry model could be used to explain the Acid-Base Equilibrium concept, and Arrhenius and Brønsted-Lowry models to explain the components of Buffers.

In the next section, recommendations for teachers are discussed.

8.4.2 Recommendations for Teachers

It is important to note that there was no evidence if teachers did or did not teach their students the Brønsted-Lowry and Lewis models in the classroom, because no classroom observations and examination of teachers' lesson planning was performed in this research. Thus, a number of possibilities may account for Form 6 students' inability to comprehend the Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding concepts, as discussed in Section 7.7 of this thesis study. There are several suggestions in this section that may help teachers to enhance their pedagogical skills for the teaching of acid-base concepts.

To improve student learning, it is recommended that the teaching and learning of acid-base concepts should be constructed in a way that encourages students to apply a number of acid-base models to different acid-base chemistry concepts (Hinton & Nakhleh, 1999). Teachers could compare and contrast students' mental models attributes identified in this thesis study for the six selected acid-base chemistry concepts with their students' attributes for the same concepts and with the scientific attributes. The comparison and contrast between students' attributes and scientific attributes may allow teachers to help students become aware of their own misconceptions and subsequently, increase their understanding of the acid-base concepts. For this reason, teachers should be equipped with the strengths and limitations of each acid-base models to explain to their students the importance of using a number of acid-base models to explain concepts during instruction.

Another recommendation suggests that teachers inculcate their students into using acid-base model the way chemists realistically use models in their work (Coll & Lajium, 2011). In other words, informing students that there is no one perfect model and that a number of models are necessary to fully explain certain chemistry concepts. Consequently, thinking by using models like scientists do may lead to improved teaching and learning (Chamizo, 2013).

From another perspective, the results indicated that it is not an easy task to form conceptions aligned with the scientific concepts. Therefore, it is recommended that teachers use different teaching and learning strategies to learn acids and bases. For example, Tarhan and Sesen (2012) observed that learning acids and bases using the jigsaw method resulted in significant understanding of the acid-base models. Teaching strategies that incorporate misconceptions has been found useful for students to better grasp acid-base chemistry concepts (Atasoy et al., 2009; Demırcıoğlu, 2009). Another recommended approach includes using a computer interphase and pH meter to investigate and monitor acid-base related experiments in the laboratory. The use of this technological approach has been seen to enhance students' understanding and interest in acid-base chemistry (Demircioğlu et al., 2005).

The limitations of the inquiry are now discussed.

8.5 Limitations of the Inquiry

In Chapter 3, to ensure trustworthiness of the study, it is reported several measures were undertaken. However, a number of limitations needed to be clarified, for example, the findings are not intended to be generalized because of the small number of participants (Guba & Lincoln, 1989) consisting of eight students and two teachers at each schooling level.

In this thesis study, classroom observations and examination of teachers' lesson plan were not performed because of the difference in time when data was collected and the actual classroom teaching and learning of acids and bases.. Under those circumstances, the teachers' content and pedagogical knowledge could not be determined, therefore, only speculation can be made of what may have occurred in the classroom.

In order to elicit students' understanding of acid-base chemistry concepts, the use of the Interview-About-Concepts (IAC) and Interview-About-Instances (IAI) strategy for interviewing participants was undertaken. However, this approach for accessing students' mental models is considered to result in expressed models and may not fully represent all aspects of the students' mental models. Furthermore, some of the students, especially the Form 2 Malaysian students, were not capable of expressing themselves very well verbally (Shakir, 2009), which may have an impact on their expressed models. Also, because of the relatively large number of selected acid-base concepts investigated, particularly for Form 6 students, the depth to which students' thinking were probed for each of the acid-base concepts may have been somewhat compromised and students may have tended to respond briefly because of the time constraint.

In section 8.6, suggestions for future research are reviewed.

8.6 Suggestions for Future Research

For future research, it is suggested that researchers use larger sample sizes in their study for more generalisable findings. Furthermore, an intervention study denoting the use of the four acid-base models in two separate groups of Form 6 students (i.e., one treated and one not) could prove beneficial and provide substantial knowledge. This intervention study would be able to show if there is a significant difference between the group exposed to the explicit use of acid-base models (i.e., modelling) and the group not exposed to explicit use of acid-base models when explaining acid-base chemistry concepts. Additionally, conducting classroom observations and examining lesson plans should provide more insight into the operational curriculum and teaching models and the understanding of teachers' content and pedagogical knowledge, notably their pedagogical content knowledge (PCK) (Shulman, 1987).

Another area for future research may investigate prospective teachers and first year chemistry university students in terms of their use of acid-base models in understanding acid-base chemistry concepts. These two groups of participants may provide insights about how students at higher institutions and aspiring teachers use acid-base models to explain selected acid-base chemistry concepts. Similarly, a case study of Malaysian teachers' pedagogical content knowledge (PCK) may indicate how these teachers use of the acid-base models in the classroom and help their students recognize the importance of using multiple acid-base models in explaining acid-base concepts. As a result, students may be more likely to grasp the learning outcomes as intended by the curricular model.

8.7 Conclusion

The objective of this study was to understand the nature of Malaysian students' mental models about selected acid-base concepts, their stages of mental model development, and the degree of alignment between the curricular model, teachers' mental models and students' mental models. It is hoped that the outcomes from this thesis contributes to the literature surrounding the use of acid-base models to explain acid-base chemistry concepts and informs Malaysian curriculum developers of the need to restructure the Malaysian curriculum, specifically the exclusion of the Lewis model for Form 6 students.

By investigating students' mental models, the study found that the attributes for Forms 2, 4, and 6 students mental models were aligned with the Phenomenological model and the Arrhenius model but misalignment occurred with the Brønsted-Lowry and Lewis models for Form 6 students, thus, affecting their understanding of the Acid-Base Equilibrium, Buffers, and Acid-Base Pair Bonding concepts. The difficulties students faced are possibly caused by issues in curriculum, students' cognitive abilities, and teachers' content and pedagogical knowledge.

The stages of mental model development revealed in this thesis study showed that all students were able to use the scientific attributes of the Phenomenological and the Arrhenius model appropriately, indicating a majority of all Malaysian students achieved sub-stages 1c and 2c mental models (i.e., indicating desired learning). The thesis study also displayed that Form 6 students were unable to use the scientific attributes of the Brønsted-Lowry and Lewis models, exhibited by a large proportion of students owning a sub-stages 3a and 3d mental models (not indicators of desired learning).

From another perspective, the inconsistency between the Form 6 curricular models and students' mental models showed that the Form 6 students were not grasping the concepts of Acid-Base Equilibrium, Buffers, and Acid-Base Electron Pair Bonding because teachers are provided with skeleton curriculum which they must interpret themselves with little guidance to achieve the desired learning outcomes as intended in the curriculum. Hence, the Form 6 students were unlikely to understand the acid-base concepts fully.

Overall, the six acid-base concepts investigated in this thesis study provided knowledge about students' stages of mental models development and provide teachers with a framework for matching the attributes of the scientific models with their students' mental models attributes. The mismatch in this study between the scientific and students' attributes may shows the need for strategies for reducing misconceptions. A teaching approach that involves understanding multiple acid-base models may help students to be aware of the need to use the existing models interchangeably and the limitations of each model. Subsequently, students may be able to demonstrate using the scientific attributes of the acid-base models to help in their understanding of acid-base concepts.

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APPENDIX A. EPU approval letter

UNIT PERANCANG EKONOMI
Economic Planning Unit
JABATAN PERDANA MENTERI
Prime Minister's Department
BLOK B5 &B6
PUSAT PENTADBIRAN KERAJAAN PERSEKUTUAN
62502 PUTRAJAYA
MALAYSIA

Telefon :603-8888 3333
603-8872 5281 / 5272

Ruj. Tuan:
Your Ref.:

Ruj. Kami: **UPE: 40/200/2933**
Our Ref.:

Tarikh : 4 December 2012
Date

NELSON A/L CYRIL
37, JALAN GU 2/9,
TAMAN GARING UTAMA
48000 RAWANG SELANGOR
Email: nelmy172003@yahoo.com

APPLICATION TO CONDUCT RESEARCH IN MALAYSIA

With reference to your application, I am pleased to inform you that your application to conduct research in Malaysia has been *approved* by the **Research Promotion and Co-Ordination Committee, Economic Planning Unit, Prime Minister's Department.** The details of the approval are as follows:

Researcher's name :	**NELSON A/L CYRIL**
Passport No. / I. C No:	**710815-09-5095**
Nationality :	**MALAYSIAN**
Title of Research :	**"AN INVESTIGATION OF MALAYSIAN SECONDARY SCHOOL STUDENTS' MENTAL MODELS OF ACID BASE CHEMISTRY"**

Period of Research Approved: **4 YEARS**

2. Please collect your Research Pass in person from the **Economic Planning Unit, Prime Minister's Department, Parcel B, Level 4 Block B5, Federal Government Administrative Centre, 62502 Putrajaya** and bring along two (2) passport size photographs. You are also required to comply with the rules and regulations stipulated from time to time by the agencies with which you have dealings in the conduct of your research.

3. I would like to draw your attention to the undertaking signed by you that you will submit without cost to the Economic Planning Unit the following documents:

a) A brief summary of your research findings on completion of your research and before you leave Malaysia; and

b) Three (3) copies of your final dissertation/publication.

4. Lastly, please submit a copy of your preliminary and final report directly to the State Government where you carried out your research. Thank you.

Yours sincerely,

(**MUNIRAH ABD. MANAN**)
For Director General,
Economic Planning Unit.
E-mail: munirah@epu.gov.my
Tel: 88882809/2818
Fax: 88883798

ATTENTION

This letter is only to inform you the status of your application and **<u>cannot be used as a research pass</u>**.

C.c:

Ketua Setiausaha
Kementerian Pelajaran Malaysia
Bahagian Perancangan Dan Penyelidikan Dasar Pendidikan
Aras 1-4, Blok E-8
Kompleks Kerajaan Parcel E
Pusat Pentadbiran Kerajaan Persekutuan
62604 Putrajaya.
(u.p: Dr. Hj. Zabani Bin Darus) (Ruj.Tuan:KP(BPPDP)603/011Jld. 15(10

APPENDIX B. MOE approval letter

BAHAGIAN PERANCANGAN DAN PENYELIDIKAN DASAR PENDIDIKAN
KEMENTERIAN PELAJARAN MALAYSIA
ARAS 1-4, BLOK E-8
KOMPLEKS KERAJAAN PARCEL E
PUSAT PENTADBIRAN KERAJAAN PERSEKUTUAN
62604 PUTRAJAYA.

Telefon: 03-88846591
Faks : 03-88846579

Ruj. Kami : KP(BPPDP)603/011/Jld15(11)
Tarikh : 03 Disember 2012

Ketua Pengarah
Seksyen Ekonomi Makro
Unit Perancangan Ekonomi
Jabatan Perdana Menteri
Blok B5 Aras 4
Kompleks Jabatan Perdana Menteri
Pusat Pentadbiran Kerajaan Persekutuan
62502 PUTRAJAYA
(u.p. Pn. Munirah Bt. Abd. Manan)

Puan,

Permohonan Untuk Menjalankan Penyelidikan di Malaysia
Nama: NELSON CYRIL

Dengan hormatnya saya merujuk kepada perkara di atas.

2. Adalah saya diarahkan memaklumkan bahawa Bahagian ini tidak mempunyai apa-apa halangan dan menyokong cadangan yang dikemukakan oleh penyelidik berkenaan untuk menjalankan penyelidikan

Sekian dimaklumkan, terima kasih.

"BERKHIDMAT UNTUK NEGARA"

Saya yang menurut perintah,

(DR. HJ. ZABANI BIN DARUS)
Ketua Sektor
Sektor Penyelidikan dan Penilaian
b.p. Pengarah
Bahagian Perancangan dan Penyelidikan Dasar Pendidikan
Kementerian Pelajaran Malaysia

Zul/ulasan/upe/12

APPENDIX C. State approval letter

جابتن ڤلاجرن سلاڠور

JABATAN PELAJARAN SELANGOR

Jalan Jambu Bol 4/3E, Seksyen 4, 40604 Shah Alam,
Negeri Selangor Darul Ehsan

Rujukan Kami : JPNS.PPN 600-1/49 JLD.20(6)
Tarikh : 13/12/2012

NELSON A/L CYRIL
NO. 37, JALAN GU 2/9
TAMAN GARING UTAMA
48000 RAWANG
SELANGOR

Tuan,

AN INVESTIGATION OF MALAYSIAN SECONDARY SCHOOL STUDENTS MENTAL MODELS OF ACID BASE CHEMISTRY

Perkara di atas dengan segala hormatnya dirujuk.

2. Jabatan ini tiada halangan untuk pihak tuan menjalankan kajian/penyelidikan tersebut di sekolah-sekolah dalam Negeri Selangor seperti yang dinyatakan dalam surat permohonan.

3. Pihak tuan diingatkan agar mendapat persetujuan daripada Pengetua/Guru Besar supaya beliau dapat bekerjasama dan seterusnya memastikan bahawa penyelidikan dijalankan hanya bertujuan seperti yang dipohon. Kajian/Penyelidikan yang dijalankan juga tidak mengganggu perjalanan sekolah serta tiada sebarang unsur paksaan.

4. Tuan juga diminta menghantar senaskah hasil kajian ke Unit Perhubungan dan Pendaftaran Jabatan Pelajaran Selangor sebaik selesai penyelidikan/kajian.

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA"

Saya yang menurut perintah,

(HAJI MOHD MAHMUDI BIN BAKRI)
Penolong Pendaftar Institusi Pendidikan dan Guru,
Jabatan Pelajaran Selangor,
b.p. Ketua Pendaftar Institusi Pendidikan dan Guru,
Kementerian Pelajaran Malaysia.

s.k. 1. Fail

Kami mengamalkan Sistem Pengurusan Berkualiti Berasaskan MS ISO 9001: 2008

(Sila catatkan nombor rujukan apabila berurusan dengan kami)

JABATAN PELAJARAN SELANGOR — TERBILANG

No. Telefon: 03-55186500
No. Faksimili: 03-55102133
Email: jpn.selangor@moe.gov.my
Laman Web: http://www.moe.gov.my/jpnselangor

APPENDIX D. Ethics and Letters

APPENDIX D1 Permission Letter for Secondary School

Letter requesting permission to conduct research at respective secondary school

SMK Rawang Batu 16,
Km 25.6 Jalan Ipoh
48000, Rawang,
Selangor, Malaysia
Email: nc70@waikato.ac.nz
Phone: 0122636017

Centre for Science and Technology Education Research (CSTER)
The University of Waikato
Private Bag 3105
Hamilton, New Zealand
Phone: 64-7-838 4035 (Centre direct line)
Fax: 64-7-838 4272
Email: cster@waikato.ac.nz

Principal

___________*[name of school]*

Dear Sir,

Application for Permission To Conduct Research at ___________________________________*[name of school]*

With regard to the above matter, I am writing to formally request permission to conduct my research for my PhD study entitled "An Investigation of Malaysian Secondary School Students' Mental Models for Acid-base Chemistry" in your school. The study focuses on students' understanding of acid-base chemistry examined in form of mental models.

For the purpose of this study, data collection will involve interview of an hour per student, and completion of a written survey instrument of about 30 minutes duration of your Form 1, Form 2, Form 4 and Form 6(if any) students as summarized below.

Student Level	Students for the Interview
Form 2	10
Form 4	10
Form 6	10

For your information, students' participation is on a voluntary basis. Both the interviews and written survey instrument will be conducted as allowed by your school and at a time that is convenient for the students in order to avoid disruption of the teaching and learning activities

Approval from Education Planning and Research Division (EPRD), Economic Planning Unit (EPU), Selangor State Education Department and the research proposal, which details the ethical issues and how I will address them, are enclosed. I would appreciate it if you could sign the informed consent form granting your permission for me to conduct my study there. For any concerns or questions you can contact me or my supervisors, Professor Richard Coll (email: rcoll@waikato.ac.nz, Phone: 07 838 4100) or Dr. Chris Eames (email: c.eames@waikato.ac.nz, Phone: 078384466) at the University of Waikato in New Zealand.

I look forward to hearing from you.

Yours sincerely,
(Nelson Cyril)

APPENDIX D2 Ethics: School Principal

Research Consent Form – Secondary School Principal

I have read the attached letter of information.

I understand that:

1. My school's participation in the research is voluntary.
2. I have the right to withdraw my school from the research at any time.
3. Data collection involves interviews and survey completion of selected students only from Form 2, Form 4, Form 6 (Lower), and teachers.
4. Data may be collected from my school in the ways specified in the accompanying letter. This data will be kept confidential and securely stored. The data will be destroyed five years after research completion.
5. Data obtained during the research will be used for the purpose of writing of the thesis, reports, published papers and making presentations. This data will be reported without use of my name or identity, the names or identity of my staff, my students' names or identity, the community members' names or identity or the name or identity of the school. Any self-identifying statement will be excluded.

I can direct any questions/concerns about the study to, Nelson Cyril, at the Rawang Batu 16, Secondary School or University of Waikato (email: nc70@waikato.ac.nz Phone: 012-2636017).

For any unresolved issues I can contact Professor Richard Coll (email: rcoll@waikato.ac.nz, Phone: 078384100) or Dr. Chris Eames (email: c.eames@waikato.ac.nz, Phone: 078384357) at the University of Waikato in New Zealand.

I give consent for my school to be involved in the project under the conditions set out above.

Name:__________________________

Signed:_________________________

Date:___________________________

APPENDIX D3 Ethics: Principal Consent Form for Teachers

Research Consent Form (Teacher) - Principal

I have read the attached letter of information.

I give my consent for teachers to be interviewed for this study. I understand that:

1. The teacher's participation in the project is voluntary.

2. The teacher has the right to withdraw any or all of the information I have provided at any time up to two weeks after receiving a transcription of my/our interview.

3. Data may be collected from the teachers in the ways specified in the accompanying letter. This data will be kept confidential and securely stored.

4. Data obtained from the teachers during the research project may be used in the writing of the thesis, reports or published papers and making presentations about the project. This data will be reported without use of the teacher or the school's name or identity. Any self-identifying statement will be excluded.

I can direct any questions/concerns to the study, Nelson Cyril, at the Rawang Batu 16, Secondary School or University of Waikato (email: nc70@waikato.ac.nz, Phone: 012-2636017).

For any unresolved issues I can contact Professor Richard Coll (email: rcoll@waikato.ac.nz, Phone: 07 838 4100) or Dr. Chris Eames (email: c.eames@waikato.ac.nz, Phone: 078384357) at the University of Waikato in New Zealand.

Principal name :_________________________

Signed:___________________________________

Date:_____________________________________

APPENDIX D4 Informed Consent Letter by Principal for Teachers

Informed Consent Letter for Teacher By Principal

SMK Rawang Batu 16,
Km 25.6 Jalan Ipoh
48000, Rawang,
Selangor, Malaysia
Email: nc70@waikato.ac.nz
Phone: 0122636017

Centre for Science and Technology Education Research (CSTER)
The University of Waikato
Private Bag 3105
Hamilton, New Zealand
Phone: 64-7-838 4035 (Centre direct line)
Fax: 64-7-838 4272
Email: cster@waikato.ac.nz

[date]
The Principal
Dear ……… ,
A member of your staff, [teacher's name], has indicated an interest in participating in a research study that investigates students' idea about acid-base chemistry. This research hopes to understand students' ideas in acid-base chemistry. Subsequently this research may benefit the school in improving the students' understanding of acid-base chemistry.

I am writing to ask your permission to involve [teacher's name] in this study. This study involves investigating students' ideas about acid-base chemistry which lead to an understanding on students' mental models about acid-base. I hope that this study will gain better insights on students' development on acid-base chemistry and enhance teaching and learning across educational level.

I expect the interview to last about an hour. I would like to audio-record the interview. If suitable to you, I would like to interview the teacher in a private space in your school, and would arrange to conduct this interview at a time according to your consent, and convenient for the teacher.

Data collected during the interviews may be used in writing reports, publications or in presentations. I will not use the teacher's identity, the name of your school, in any publications or presentations but any data used in the reports will use pseudonyms. I will make sure that I store all the information that I gather securely. The teacher can decline to be involved in the research, and can withdraw any or all comments made in the interview at any time up to two weeks after receiving the interview transcription. If there is a withdrawal, I will destroy any data gathered from the teacher.

I would appreciate your permission for the teacher to be involved with this research project. If you need any more details about the study, or issues arise for you during the study, please contact Nelson Cyril (nc70@waikato.ac.nz, Phone: 012-2636017). If you have a concern about the project that you wish to discuss with someone else, please contact Professor Richard Coll (email: rcoll@waikato.ac.nz, Phone: 07 838 4100) or Dr. Chris Eames (email: c.eames@waikato.ac.nz, Phone: 078384357) at the University of Waikato.

If you agree for the teacher to participate in the study, please read and sign the attached research consent form. Please also call me at the above number for me to collect the consent form from you. The research will not begin without the approval of the Principal.

Yours sincerely
NelsonCyril

APPENDIX D5 Informed Consent Letter for Teachers

Informed Consent Letter for Teacher

SMK Rawang Batu 16,
Km 25.6 Jalan Ipoh
48000, Rawang,
Selangor, Malaysia
Email: nc70@waikato.ac.nz
Phone: 0122636017

Centre for Science and Technology Education Research (CSTER)
The University of Waikato
Private Bag 3105
Hamilton, New Zealand
Phone: 64-7-838 4035 (Centre direct line)
Fax: 64-7-838 4272
Email: cster@waikato.ac.nz

[date]

Dear ……… ,

I am writing to invite you to participate in my research study. This study involves investigating student learning on acid-base chemistry. To help me understand student learning, I would like to get your views about the teaching and learning of acid-base chemistry. I hope that this study will gain better insights on students' development on acid-base chemistry and enhance teaching and learning across educational level.

I would like to interview you about your ideas in acid-base chemistry. I expect the interview to last about an hour. I would like to audio-record the interview. I undertake to return a transcription of the interview to you to check or change any contents within a two week period after receiving the transcription. This transcription would be confidential to the persons interviewed.

If suitable to you, I would like to interview you in a private space in your school, and would arrange to conduct this interview at a time convenient to you (as also allowed by your principal). Alternatively, I can arrange a different interview space of mutual convenience and comfort. Data collected during the interviews may be used in writing reports, publications or in presentations. I will not use your or identity in any publications or presentations but any data used in the reports will use pseudonyms. I will make sure that I store all the information that I gather securely. You can decline to be involved in the research, and can withdraw any or all comments made in the interview at any time up to two weeks after receiving the interview transcription. If there is a withdrawal, I will destroy any data gathered from you.

I would appreciate if you would agree to be involved with this research project. If you need any more details about the study, or issues arise for you during the study, please contact Nelson Cyril (nc70@waikato.ac.nz, Phone: 012-2636017). If you have a concern about the project that you wish to discuss with someone else, please contact Professor Richard Coll (email: rcoll@waikato.ac.nz, Phone: 07 838 4100) or Dr. Chris Eames (email: c.eames@waikato.ac.nz, Phone: 078384357) at the University of Waikato.

If you agree to participate in the study, please read and sign the attached research information form. Please also call me at the number above, for me to collect the form and arrange a time and place for the interview. Thank you very much for your support.

Yours sincerely
Nelson Cyril

APPENDIX D6 Research Consent Form for Teachers

Research Consent Form - Teacher

I have read the attached letter of information.

I give my agreement as a teacher to be interviewed for this study. I understand that:

1. My participation in the project is voluntary.

2. I have the right to withdraw any or all of the information I have provided at any time up to two weeks after receiving a transcription of my/our interview.

3. Data may be collected from the teachers in the ways specified in the accompanying letter. This data will be kept confidential and securely stored.

4. Data obtained from me during the research project may be used in the writing of the thesis, reports or published papers and making presentations about the project. This data will be reported without use of my name or the school's name or identity. Any self-identifying statement will be excluded.

I can direct any questions/concerns to the study, Nelson Cyril, at the Rawang Batu 16, Secondary School or University of Waikato (email: nc70@waikato.ac.nz, Phone: 012-2636017).

For any unresolved issues I can contact Professor Richard Coll (email: rcoll@waikato.ac.nz, Phone: 07 838 4100) or Dr. Chris Eames (email: c.eames@waikato.ac.nz, Phone: 078384357) at the University of Waikato in New Zealand.

Teacher name :_________________________

Signed:__________________________________

Date:____________________________________

APPENDIX D7 Student Consent Letter

Informed Consent Letter for Student Participants

SMK Rawang Batu 16,
Km 25.6 Jalan Ipoh
48000, Rawang,
Selangor, Malaysia
Email: nc70@waikato.ac.nz
Phone: 0122636017

Centre for Science and Technology Education Research (CSTER)
The University of Waikato
Private Bag 3105
Hamilton, New Zealand
Phone: 64-7-838 4035 (Centre direct line)
Fax: 64-7-838 4272
Email: cster@waikato.ac.nz

[date]
Dear student,

I am writing to invite you to participate in my research study to help me understand students'. This study involves investigating students' ideas about acid-base chemistry to improve teaching and learning in schools.

I would like to interview you about your ideas in acid-base chemistry. I expect the interview to last about an hour. I would like to tape the interview and collect any drawings you make for later analysis. I undertake to return a transcription of the interview to you to check or change any contents within a two week period after receiving the transcription. This transcription would be confidential to the persons interviewed.

If suitable to you, I would like to interview you in a private space in your school, and would arrange to conduct this interview at a time convenient to you (as also allowed by your principal). Alternatively, I can arrange a different interview space of mutual convenience and comfort. Data collected during the interviews may be used in writing thesis, reports, and publications or in presentations. I will not use your name or identity in any publications or presentations but any data used in the reports will use pseudonyms. I will make sure that I store all the information that I gather securely. You can decline to be involved in the research, and can withdraw any or all comments made in the interview at any time up to two weeks after receiving the interview transcription. If you withdraw, I will securely destroy any data gathered from you.

I would appreciate if you would agree to be involved with this research project. If you need any more details about the study, or issues arise for you during the study, please contact Nelson Cyril (nc70@waikato.ac.nz, Phone: 012-2636017). If you have a concern about the project that you wish to discuss with someone else, please contact Professor Richard Coll (email: rcoll@waikato.ac.nz, Phone: 07 838 4100) or Dr. Chris Eames (email: c.eames@waikato.ac.nz, Phone: 078384357) at the University of Waikato.

If you agree to participate in the study, please read and sign the attached participant informed consent form and return it to me. Please also call me at the above number for me to collect the research information form from you and to arrange a time and place for the interview.

Thank you very much for your support.

Yours sincerely ,
Nelson Cyril

APPENDIX D8 Student Information Form

Research Information Form – Student Participant

I have read the attached letter of information.

Research
I give my/our agreement to be interviewed for this study. I understand that:

1. My participation in the project is voluntary.
2. I have the right to withdraw any or all of the information I have provided at any time up to two weeks after receiving a transcription of my/our interview.
3. Data may be collected from me in the ways specified in the accompanying letter. This data will be kept confidential and securely stored.
4. Data obtained from me during the research project may be used in the writing of the thesis, reports or published papers and making presentations about the project. This data will be reported without use of my name or identity. Any self-identifying statement will be excluded.

I can direct any questions/concerns to the study, Nelson Cyril, at the Rawang Batu 16, Secondary School or University of Waikato (email: nc70@waikato.ac.nz, Phone: 012-2636017).

For any unresolved issues I can contact Professor Richard Coll (email: rcoll@waikato.ac.nz, Phone: 078384100) or Dr. Chris Eames (email: c.eames@waikato.ac.nz, Phone:078384357) at the University of Waikato in New Zealand.

Student name(s):___________________

Signed:__________________________________

Date:____________________________________

APPENDIX D9 Copy of Participants Consent Form

Consent Form Copy for Students and Teachers

University of Waikato
Centre for Science and Technology Educational Research
Information Record Form

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

PARTICIPANT'S COPY

Research Project:

Researcher:

I have received information about this research project or the researcher has explained the study to me. I have had the chance to ask any questions and discuss my participation with other people. Any questions have been answered to my satisfaction.

I agree to participate in this research project and I understand that I may withdraw at any time.

Participant's name:___________________________ Signature:___________ Date:___________

APPENDIX D10 Ethics Approval

Ethics Approval From the University of Waikato

Dr Chris Eames

Centre for Science and Technology Education Research
School of Science & Engineering
Te Pūtaiao me te Mātauranga Pūkaha
The University of Waikato
Private Bag 3105
Hamilton, New Zealand

Telephone 64-7-838 4357
Facsimile 64-7-838 4272
Email c.eames@waikato.ac.nz

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

To:	Nelson Cyril
Date:	3 August 2012
From:	Dr Chris Eames
Subject:	Ethics Sub-committee Report on Ethics Proposal

The Faculty of Science and Engineering Human Research ethics sub-committee has considered your proposal An Investigation of Malaysian Secondary School Students' Mental Models of Acid Base Chemistry

The proposal as attached is approved. If you wish to vary the terms of the approved application in any way, please contact me to request an amendment.

Good luck with your research!

Signed ....

APPENDIX E. Interview Protocols

APPENDIX E1 Form 2 Student Interview Protocol

Student F2 Interview Protocol

- Introduction
    - Presentation: About the interviewer and the research project
    - Questions from interviewee; regarding the interview procedure

- Briefing

    - Do you like to study science?
    - Favourite topic in science
        - Why is it your favourite?
    - Are there other topics you do not like to teach?
        - Why do you dislike them?

- Main Phase

    - I would like to talk about acids and bases. What comes to your mind when you think about acids and bases?
    - What are an acid and an alkali?
    - Can you please tell me what the properties of acids and alkalis are?
    - **Introduce Question 1 card**
    - Do you agree with all the statements in Question Card 1? Please explain your reason?
    - **Introduce Question 2 card**
    - Please tick an item with either acids/bases/other. Please explain in comment column
    - **We put an acid and a base in contact. Say briefly what takes place in Question 3 card?**
    - Can you please tell me every day uses of acids and bases in your daily lives? Please give examples
    - Introduce **Question Card 4 (uses)**. Please explain.

- Debriefing
    - I have no further questions
    - Discuss some points from the interview

Question Card 1

a. Acids are corrosive
b. Alkalis tastes bitter
c. Acids are harmful
d. Fruits are alkali
e. Alkalis are slippery
f. Acids produce bubbles
g. Alkalis turn blue litmus paper to red

Do you agree with the statements above? Can you please tell me what you think?

a.

b.

c.

d.

e.

f.

g.

Question Card 2

No	Item	Acid	Alkali	Other (specify)	pH			Reason
1	Milk				1-6	7	8-14	
2	Vinegar				1-6	7	8-14	
3	Lemon Juice				1-6	7	8-14	
4	Soap				1-6	7	8-14	
5	Floor cleaner				1-6	7	8-14	
6	Baking soda solution				1-6	7	8-14	
7	Soda drinks				1-6	7	8-14	
8	Water				1-6	7	8-14	
9	Sodium Hydroxide				1-6	7	8-14	
10	Hydrochloric acid				1-6	7	8-14	

For each item please tick acid,base or other and which of the three pH range categories

Question Card 3

What do you think takes place when an acid and an alkali are put together?

Can you please write or draw what you think?

Question Card 4

How do you reduce the acidity of an acidic soil?

Can you please tell me what you think?

APPENDIX E2 Form 4 Student Interview Protocol

Student F4 Interview protocol

Introduction

- Presentation: About the interviewer and the research project
- Questions from interviewee; regarding the interview procedure
- Briefing
- Do you like to study chemistry?
- Favourite topic in science
    - Why is it your favourite?
- Are there other topics you do not like to teach?
    - Why do you dislike them?

- Main Phase
    - I would like to talk about acids and bases. What comes to your mind when you think about acids and bases?
    - What are an acid and a base? What is an alkali?
    - Can you please tell me what the properties of acids and alkalis are?
    - **Introduce Question 1 card**
    - Do you agree with all the statements in Question 1 Card? Please explain your reason?
    - **Introduce Question 2 card**
    - Please tick an item with either acids/bases/other. Please <u>explain</u> in comment column
    - **We put an acid and a base in contact. Say briefly what takes place in Question 3 card?**
    - Let us take an example of this process. Introduce **Question Card 4** (HCl & NaOH) and ask "Can you please tell me what you think".
    - Introduce **Question Card 5** (HCl and NaOH graph)and ask "Can you please tell me what you think"
    - Can you please tell me every day uses of acids and bases in your daily lives? Please give examples.
    - Introduce **Question Card 6** (soil)and ask "Can you please tell me what you think"
    - Can you tell me the meaning of <u>strong acid, strong base, weak acid, and weak base</u>?
    - **Introduced Question Card 7 card (strong acid) and ask** "Please choose the strongest or stronger acid"
- Debriefing
    - I have no further questions
    - Discuss some points from the interview

Question Card 1

a. Acids are corrosive
b. Bases tastes bitter
c. Acids are harmful
d. Fruits are basic
e. Bases are slippery
f. Acids produce bubbles
g. Bases turn blue litmus paper to red

Do you agree with the statements above? Can you please tell me what you think?

a.

b.

c.

d.

e.

f.

g.

Question Card 2

No	Item	Acid	Base	Other (specify)	pH			Reason
1	Milk				1-6	7	8-14	
2	Vinegar				1-6	7	8-14	
3	Lemon Juice				1-6	7	8-14	
4	Soap				1-6	7	8-14	
5	Floor cleaner				1-6	7	8-14	
6	Baking soda solution				1-6	7	8-14	
7	Soda drinks				1-6	7	8-14	
8	Water				1-6	7	8-14	
9	NaOH				1-6	7	8-14	
10	NH_3				1-6	7	8-14	
11	HCl				1-6	7	8-14	

For each item please tick acid, base or other and which of the three pH range categories

Question Card 3

Can you please tell me what you think takes place when an acid and a base are put together?

Can you please write or draw what you think.

Question Card 4

If I mix an aqueous solution of sodium hydroxide (NaOH) with an aqueous solution of hydrochloric acid (HCl) in equal volume and concentration, do you think the concentration of hydrogen ions (H^+) be same, higher or lower than the concentration of hydroxyl ions (OH^-) in the resulting solution?

Can you please tell me what you think?

Question Card 5

$$NaOH(aq) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

Can you please draw for me what do you think will happen to the pH if 0.10M sodium hydroxide (NaOH) is gradually added to 10.0 mL of 0.10M hydrochloric acid (HCl)?

Question Card 6

How do you reduce the acidity of an acidic soil?

Can you please tell me what you think?

Question Card 7

a. Please choose what you think is the strongest acid solution from the three options below.

i. 0.4 mol L^{-1} HCl(aq) ii. 0.04 mol L^{-1} HCl(aq)

iii. 0.004 mol L^{-1} HCl(aq)

b. Please choose what you think is the stronger acid from the two options below.

i. 0.04 mol L^{-1} HCl(aq) ii. 0.4 mol L^{-1} CH_3COOH(aq)

c. Please choose what you think is the stronger acid from the two options below.

i. 0.004 mol L^{-1} H_2SO_4(aq) ii. 0.004 mol L^{-1} H_3PO_4(aq)

Note: HCl is hydrochloric acid CH_3COOH is ethanoic acid

H_2SO_4 is sulfuric acid H_3PO_4 is phosphoric acid

Can you please tell me what you think?

a.

b.

c.

APPENDIX E3 Form 6 Student Interview Protocol

Student F6 Interview protocol

- Introduction
  - Presentation: About the interviewer and the research project
  - Questions from interviewee; regarding the interview procedure

- Briefing

  - Do you like to study chemistry?
  - Favourite topic in chemistry
    - Why is it your favourite?
  - Are there other topics you do not like to learn?
    - Why do you dislike them?

- Main Phase

  - I would like to talk about acids and bases. What comes to your mind when you think about acids and bases?
  - What are an acid and a base? What is an alkali?
  - Can you please tell me what the properties of acids and alkalis are?
  - **Introduce Question 1 card (properties)**
  - Do you agree with all the statements in Question 1 Card? Please <u>explain</u> your reason?
  - **Introduce Question 2 card (table)**
  - Please tick an item with either acids/bases/other. Please <u>explain</u> in the comment column
  - We put an acid and a base in contact. Write or draw what **takes place in Question 3 card (acid and base together)?**
  - Let us take an example of this process. **Introduce Question Card 4** (HCl & NaOH) and ask "Can you please tell me what you think".
  - Can you please tell me every day uses of acids and bases in your daily lives? Please give examples.
  - **Introduce Question Card 5** (soil)and ask "Can you please tell me what you think"
  - **Introduce Question 6 card** (3 equations) and ask "Please identify in each of them an acid and a base? <u>Please explain.</u>

- **Introduced Question 7 card** (explanation of 3 models) and ask "What do you think takes place?"
- What do you think a strong acid or base is?
- **Introduced Question 8 card** (strong acid) and ask "Please choose the strongest or stronger acid"
- What do you think Acid-base Equilibrium means**?**
- **Introduce Question 9 card** (equilibrium statement) and ask "Do you agree with all the statements? Please explain.
- **Introduce Question 10 card** (application). Can you please tell me what you think?
- Can you please tell me what a buffer solution is?
- **Introduce Question 11 card** (statement) and ask "Do you agree with all the statements? Please explain.

- Debriefing
  - I have no further questions
  - Discuss some points from the interview

Question Card 1

a. Acids are corrosive
b. Bases tastes bitter
c. Acids are harmful
d. Fruits are basic
e. Bases are slippery
f. Acids produce bubbles
g. Bases turn blue litmus paper to red

Do you agree with the statements above? Can you please tell me what you think?

a.

b.

c.

d.

e.

f.

g.

Question Card 2

No	Item	Acid	Base	Other (specify)	pH			Reason
1	Milk				1-6	7	8-14	
2	Vinegar				1-6	7	8-14	
3	Lemon Juice				1-6	7	8-14	
4	Soap				1-6	7	8-14	
5	Floor cleaner				1-6	7	8-14	
6	Baking soda solution				1-6	7	8-14	
7	Soda drinks				1-6	7	8-14	
8	Water				1-6	7	8-14	
9	NaOH				1-6	7	8-14	
10	HCl				1-6	7	8-14	
11	NH_3				1-6	7	8-14	
12	CO_2				1-6	7	8-14	
13	CH_3COO^-				1-6	7	8-14	

For each item please tick acid, base or other and which of the three pH range categories

Question Card 3

Can you please tell me what you think takes place when an acid and a base are put together?

Question Card 4

If I mix an aqueous solution of sodium hydroxide (NaOH) with an aqueous solution of hydrochloric acid (HCl) in equal volume and concentration, do you think the concentration of hydrogen ions (H^+) be same, higher or lower than the concentration of hydroxyl ions (OH^-) in the resulting solution?

Can you please tell me what you think?

Question Card 5

How do you reduce the acidity of an acidic soil?

Can you please tell me what you think?

Question Card 6

1. $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O\ (aq)$
2. $NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$
3. $BH_3(g) + NH_3(g) \rightarrow H_3B\ NH_3(s)$

Can you please tell me what species are acids and bases in each of the equation?

1.

2.

3.

Question Card 7a

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$$

Can you please draw for me what do you think will happen to the pH if 0.10M sodium hydroxide (NaOH) is gradually added to 10.0 mL of 0.10M hydrochloric acid (HCl)?

Question Card 7b.

$$NaOH(aq) + CH_3COOH(aq) \rightleftharpoons CH_3COONa(aq) + H_2O(l)$$

Can you please draw for me what do you think will happen to the pH if 0.10M sodium hydroxide (NaOH) is gradually added to 10.0 mL of 0.10M ethanoic acid (CH_3COOH)?

Question Card 7c

$BH_3(g) + NH_3(g) \rightarrow H_3B\ NH_3(s)$

Can you please tell me what you think will happen when BH_3 is added to NH_3?

Question Card 8

a. Please choose what you think is the strongest acid solution from the three options below.

i. 0.4 mol L^{-1} HCl(aq) ii. 0.04 mol L^{-1} HCl(aq)
iii. 0.004 mol L^{-1} HCl(aq)

b. Please choose what you think is the stronger acid from the two options below.

i. 0.04 mol L^{-1} HCl(aq) ii. 0.4 mol L^{-1} CH_3COOH(aq)

c. Please choose what you think is the stronger acid from the two options below.

i. 0.004 mol L^{-1} H_2SO_4(aq) ii. 0.004 mol L^{-1} H_3PO_4(aq)

Note: HCl is hydrochloric acid CH_3COOH is ethanoic acid
H_2SO_4 is sulfuric acid H_3PO_4 is phosphoric acid

Can you please tell me what you think?

a.

b.

c.

Question Card 9

a. If a solution of sodium ethanoate (CH_3COONa) is gradually added to an ethanoic acid (CH_3COOH) solution, the pH decreases.
b. If a solution of sodium hydroxide (NaOH) is gradually added to an ethanoic acid (CH_3COOH) solution there are only hydroxyl ions (OH^-) in the solution.

Do you agree with the statements above? Can you please tell me what you think?

a.

b.

Question Card 10

I mix aqueous solution of NaOH (sodium hydroxide) with an aqueous solution of CH_3COOH (ethanoic acid) in equal volume and concentration, do you think the concentration of $[H_3O^+]$ be same, higher or lower than the concentration of $[OH^-]$ ions in the resulting solution?

Can you please tell me what you think?

Question Card 11

a. A buffer is only formed by the combination of a weak acid and its salt.
b. A buffer can be formed by a combination of an acid and its conjugate base.
c. A buffer can be formed by a combination of hydrochloric acid (HCl) and sodium chloride (NaCl).

Do you agree with the statements above? Can you please tell me what you think?

a.

b.

c.

APPENDIX E4 Teacher Interview Protocol

Teacher F2, F4, and F6 Interview protocol

- Introduction
  - Presentation: About the interviewer and the research project
  - Questions from interviewee; regarding the interview procedure

- Briefing

  - How many years of teaching experience and schools have you taught?
  - Favourite domain in chemistry/ science
    - Why is it your favourite?
    - How do you teach it?
    - What do students think about it?
  - Are there other domains you do not like to teach?
    - Why do you dislike them?
    - Are there any differences in the way you teach them compared the one above?

- Main Phase

  - I would like to talk about acids and bases. What comes to your mind when you think about acids and bases?
  - Do you think teaching acids and bases are difficult? Why?
  - What are an acid and a base? What is an alkali?
  - Can you please tell me what the properties of acids and alkalis are?
  - **Introduce Question 1 card (properties)**
  - Do you agree with all the statements in Question 1 Card? Please explain your reason?
  - **Introduce Question 2 card (table)**
  - Please tick an item with either acids/bases/other. Please explain in the comment column
  - **We put an acid and a base in contact. Write or draw what takes place in Question 3 card (acid and base together)?**
  - Do you think there is an equation representing the reaction between an acid and a base?
  - What is the name of this equation?
  - Please explain this equation.
  - Why do you think the equation is called the name you mentioned?
  - What is neutral here?
  - Let us take an example of this process. Introduce **Question Card 4** (HCl & NaOH) and ask “Can you please tell me what you think”.
  - Can you please tell me every day uses of acids and bases in your daily lives? Please give examples.

- **Introduce Question Card 5** (soil)and ask "Can you please tell me what you think"
- **Introduce Question 6 card** (3 equations) and ask "Please identify in each of them an acid and a base? Please explain.
- **Introduce Question 7 card (**explanation of 3 models) and their probing questions.
- How do you explain concept of a strong acid, strong base, weak acid, and weak base?
- **Introduce Question 8 card** (strong acid) and ask "Please choose the strongest or stronger acid"
- How do you explain the concept of Equilibrium in classroom?
- **Introduce Question 9 card** (equilibrium statement) and ask "Do you agree with all the statements? Please explain.
- **Introduce Question 10 card** (application). Can you please tell me what you think?
- How do you explain What is a Buffer solution in classroom?
- **Introduce Question 11 card (**statement) and ask "Do you agree with all the statements? Please explain.

- Debriefing
  - I have no further questions
  - Discuss some points from the interview

Question Card 1

a. Acids are corrosive
b. Bases tastes bitter
c. Acids are harmful
d. Fruits are basic
e. Bases are slippery
f. Acids produce bubbles
g. Bases turn blue litmus paper to red

Do you agree with the statements above? Can you please tell me what you think?

a.

b.

c.

d.

e.

f.

g.

Question Card 2

No	Item	Acid	Base	Other (specify)	pH			Reason
1	Milk				1-6	7	8-14	
2	Vinegar				1-6	7	8-14	
3	Lemon Juice				1-6	7	8-14	
4	Soap				1-6	7	8-14	
5	Floor cleaner				1-6	7	8-14	
6	Baking soda solution				1-6	7	8-14	
7	Soda drinks				1-6	7	8-14	
8	Water				1-6	7	8-14	
9	NaOH				1-6	7	8-14	
10	HCl				1-6	7	8-14	
11	NH_3				1-6	7	8-14	
12	CO_2				1-6	7	8-14	
13	CH_3COO^-				1-6	7	8-14	

For each item please tick acid, base or other and which of the three pH range categories

Question Card 3

Can you please tell me what you think takes place when an acid and a base are put together?

Question Card 4

If I mix an aqueous solution of sodium hydroxide (NaOH) with an aqueous solution of hydrochloric acid (HCl) in equal volume and concentration, do you think the concentration of hydrogen ions (H^+) be same, higher or lower than the concentration of hydroxyl ions (OH^-) in the resulting solution?

Can you please tell me what you think?

Question Card 5

How do you reduce the acidity of an acidic soil?

Can you please tell me what you think?

Question Card 6

1. $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O\ (aq)$
2. $NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$
3. $BH_3(g) + NH_3(g) \rightarrow H_3B\ NH_3(s)$

Can you please tell me what species are acids and bases in each of the equation?

1.

2.

3.

Question Card 7a

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$$

Can you please draw for me what do you think will happen to the pH if 0.10M sodium hydroxide (NaOH) is gradually added to 10.0 mL of 0.10M hydrochloric acid (HCl)?

Question Card 7b.

$NaOH(aq) + CH_3COOH(aq) \rightleftharpoons CH_3COONa(aq) + H_2O(l)$

Can you please draw for me what do you think will happen to the pH if 0.10M sodium hydroxide (NaOH) is gradually added to 10.0 mL of 0.10M ethanoic acid (CH_3COOH)?

Question Card 7c

$$BH_3(g) + NH_3(g) \rightarrow H_3B\ NH_3(s)$$

Can you please tell me what you think will happen when BH_3 is added to NH_3?

Question Card 8

a. Please choose what you think is the strongest acid solution from the three options below.
   i. 0.4 mol L^{-1} HCl(aq) ii. 0.04 mol L^{-1} HCl(aq)
   iii. 0.004 mol L^{-1} HCl(aq)

b. Please choose what you think is the stronger acid from the two options below.
   i. 0.04 mol L^{-1} HCl(aq) ii. 0.4 mol L^{-1} CH_3COOH(aq)

c. Please choose what you think is the stronger acid from the two options below.
   i. 0.004 mol L^{-1} H_2SO_4(aq) ii. 0.004 mol L^{-1} H_3PO_4(aq)

Note: HCl is hydrochloric acid CH_3COOH is ethanoic acid
H_2SO_4 is sulfuric acid H_3PO_4 is phosphoric acid

Can you please tell me what you think?

a.

b.

c.

Question Card 9

a. If a solution of sodium ethanoate (CH_3COONa) is gradually added to an ethanoic acid (CH_3COOH) solution, the pH decreases.
b. If a solution of sodium hydroxide (NaOH) is gradually added to an ethanoic acid (CH_3COOH) solution there are only hydroxyl ions (OH^-) in the solution.

Do you agree with the statements above? Can you please tell me what you think?

a.

b.

Question Card 10

I mix aqueous solution of NaOH (sodium hydroxide) with an aqueous solution of CH_3COOH (ethanoic acid) in equal volume and concentration, do you think the concentration of [H_3O^+] be same, higher or lower than the concentration of [OH^-] ions in the resulting solution?

Can you please tell me what you think?

Question Card 11

a. A buffer is only formed by the combination of a weak acid and its salt.
b. A buffer can be formed by a combination of an acid and its conjugate base.
c. A buffer can be formed by a combination of hydrochloric acid (HCl) and sodium chloride (NaCl).

Do you agree with the statements above? Can you please tell me what you think?

a.

b.

c.

APPENDIX F

Students' stages of mental model for six selected acid-base chemistry concepts

Selected Acid-base Chemistry: Macroscopic Properties

Attribute: Senses

Student	Responses for Question Card 1	Mental Models
SF2a	Yes it will corrosive our skin/organs Acid tastes sour Some fruits are sour which are acids Yes when they are corrosive	1c
SF2b	Yes I agree. Because acids can break our hands. But some of the family will use some corrosive solution to clean white shirts and floor Yes. It tastes bitter. Its pH value is more than 7. It can be example like toothpaste	1c
SF2c	Acid tastes sour (Lemon) is acid and acid tastes sour Yes because the shampoo it produce the bubbles	1c
SF2d	Yes example like shampoo, if we taste that, it will taste bitter. Yes because it can corrosive our hand (orange) is acidic because they taste sour Like soap is slippery Yes fizzy drinks will produce bubbles	1c
SF2e	Acid tastes sour Yes (base is slippery) has substances like soaps in them Yes soap produce bubbles	1c
SF2f	(acid is)Sour (body) It can corrode Lemon because it tastes sour Soap can produce bubbles	1c
SF2g	(acid is) Sour Because the taste (of fruit) is a little sour Soap (produce bubbles)	1c
SF2h	Acid tastes sour like lime juice when we drink it and it taste so sour No not all of them. Like orange taste sour but not all of them taste sour Yes our shower soap when we rub it or when we terlupa nak basuh benda tu (forgot to clean it) kita akan terpijak dan terjatuh (if we step on it we may fall) When we rub <u>soap</u> to our body it produce bubbles	1c
SF4a	Yes like bitter gourd is a base because it tastes bitter Because lemon is acidic so not all fruits are basic Yes (bases produce bubbles)because when we take a bath soap produces bubbles	1c
SF4b	Yes. They be more reactive to human skin	1c

Student	Responses for Question Card 1	Mental Models
SF4c	Yes, I agree because it can cause scald to the skin No, because some fruits are acidic and some are basic. A certain fruit taste sour	1c
SF4d	Because I use soap and if they are corrosive I could not use it on our body	1c
SF4e	Base is a substance which produce hydroxide ion when reacting with water Alkali has 8 to 13 pH value alkali. It is not corrosive example soap An acid tastes sour example vinegar	1c
SF4f	Acid tastes sour Acid like hydrochloric acid can corrode something but like citric acid we can produce many products Yes like just now I said that shampoo is slippery like soap when we touch it so it is slippery	1c
SF4g	Yes. If we pour acid on the hand it irritates the skin Yes because soap is a base and it is slippery	1c
SF4h	Yes because if you take an example like soap its bitter If like sodium hydroxide then it is dilute I think it is not slippery but if it is a soap or toothpaste then it will be slippery	1c
SF6a	I think it taste bitter but I never try because we learn from book I do not think fruits are basic because lime or orange are acidic because it tastes sour	1c
SF6b	Yes if strong acids corrode our skin so it is harmful but we can touch for weak acid The sour type maybe acidic like passion fruit papaya may be a base No when do the experiment strong hydrochloric acid when open the bottle there will be fumes but no bubbles.	1c
SF6c	Yes when acid react with object will produce fumes	1c
SF6d	Yes accidentally (base) and it tastes bitter Sodium hydroxide not slippery because we do the experiment I touched sodium hydroxide and I do not feel it is slippery.	1c
SF6e	No because strong acid will be corrosive but weak acid are not as corrosive as strong acid (acid) tastes sour	1c
SF6f	Acid tastes sour Yes because it is corrosive and it has side effects such as skin diseases	1c
SF6g	Yes because we have bitter taste when we taste soap and shampoo Sometimes apples taste sour I think so because soap and shampoo is slippery Hydrochloric acid because when I accidentally poured hydrochloric acid on the table it actually produces bubbles	1c
SF6h	(acid) tastes sour Harmful is when we touch the acid our skin will get burn Some fruits taste sweet and sour like lemon are acids	1c

Selected Acid-base Chemistry: Macroscopic Properties

Attribute: Source Reference

Student	Responses for Question Card 1	Mental Models
SF2c	Yes I know this in the book	1a
SF2d	I read from the book	1a
SF2g	No teacher told me not to touch because it is corrosive	1a
SF6a	I think it taste bitter but I never try because we learn from book	1a
SF6b	Yes because learn before pH less than 7 and teacher said not to touch strong acid because they are corrosive and they can corrode our skin	1a
SF6e	Yes but I just follow what is written in the books Yes because I just exactly write what is in the book(base is slippery)	1a
SF6h	I am not sure if base taste bitter but I read from book and it write there base taste bitter I am not sure because I read from book (bases are slippery)	1a

Selected Acid-base Chemistry: Macroscopic Properties

Attribute: pH value

Student	Responses for Question Card 1	Mental Models
SF2b	Yes. It tastes bitter. Its pH value is more than 7. It can be example like toothpaste Yes if the pH value is less than lesser than 7, it will be harmful	1a
SF4b	Yes. They be more reactive to human skin. As the pH value decreases, acids are stronger and more corrosive	1a
SF4e	Base is a substance which produce hydroxide ion when reacting with water. Alkali has 8 to 13 pH value alkali. It is not corrosive example soap	1a
SF4f	No acid is with lower pH example pH 1	1a
SF4h	Yes because it is an acid of very low pH like sulfuric acid, it will be corrosive.	1a
SF6b	Yes because learn before pH less than 7 and teacher said not to touch strong acid because they are corrosive and they can corrode our skin	1a
SF6c	Yes especially when low pH like pH 0 to 2 it can cause an organism to death, destroy cell	1a
SF6e	Some acids with high pH can be used in everyday life like weak acid like vinegar so I don't think acids are harmful	1a
SF6f	Bases with pH 13 are corrosive	1a
SF6g	Maybe as the pH go higher	1a
SF6h	Acids are corrosive when pH is very low. If the pH is 1 means it is very acidic and corrosive	1a

Selected Acid-base Chemistry: Macroscopic Properties

Attribute: Physical strength

Student	**Responses for Question Card 1**	**Mental Models**
SF2h	Acid can make us hurt but alkali I don't think it can hurt us	1b
SF4a	No if it is weak acid it is not harmful but strong acids are harmful	1b
SF4b	Yes. Because they are corrosive so they are harmful	1b
SF4c	Yes, I agree because it can cause scald to the skin	1b
SF4e	Yes because it can corrode a building if it has high concentration of hydrogen ions	1e

Selected Acid-base Chemistry: Macroscopic Properties

Attribute: Scientific test

Student	**Responses for Question Card 1**	**Mental Models**
SF2a	Alkali changes from red litmus paper to blue	1c
SF2b	Acid turns blue litmus paper to red. Oh alkali turns red litmus paper to blue	1c
SF2c	No it turns red litmus paper to blue	1c
SF2d	Turn red litmus paper to blue	1c
SF2e	No alkali change litmus paper to blue and an acid change blue litmus paper to red	1c
SF2f	Acids turns blue litmus paper to red	1c
SF2g	For acid blue litmus paper turn to red	1c
SF2h	No, alkali turn red litmus paper to blue while acid turns blue litmus paper to red	1c
SF4a	No I disagree bases turns red litmus paper to blue and acids turns blue	1c
SF4b	No. Acids turns blue litmus paper to red	1c
SF4c	Not agree, because base is bitter and bitter will change the red to blue not blue to red it has higher pH value it must turn red litmus paper to blue	1c
SF4d	Absolutely no, acids are the one which will turn blue litmus paper to red Yes some of the experiments we did in school produce bubbles so I think acids produce bubbles	1c
SF4e	No, base turns red litmus paper to blue	1c
SF4f	Acid turns blue litmus paper to red	1c
SF4g	No because bases turns red litmus paper to blue	1c
SF4h	Acids will turn blue litmus paper to red	1c
SF6a	No bases turns red litmus paper to red	1c
SF6b	Bases turns red litmus paper to blue and an acid turns blue litmus paper to red	1c
SF6c	No acid turn blue litmus paper to red and a base turns litmus paper from red to blue	1c

SF6d	Acids turns blue litmus paper to red Sodium hydroxide not slippery because we do the experiment I touched sodium hydroxide and I do not feel it is slippery.	1c
SF6e	No bases turn red litmus paper to blue and do not change blue litmus paper to red.	1c
SF6f	No because acids turns blue litmus paper to red	1c
SF6g	(acid) Red to blue	1b
SF6h	I am sure it is wrong No bases turn red litmus paper to blue	1c

Selected Acid-base Chemistry: Macroscopic Properties

Attribute: Reactions

Student	Responses for Question Card 1	Mental Models
SF6c	Yes when acid react with object will produce fumes	1b
SF4h	Not harmful like a bee when stung us we can apply an alkali	1e
SF6a	I do not think only acids produce bubbles but any solution when heated will produce bubbles. If you want to produce bubbles for example, like Na metal which is very active when in contact with water confirm will also get the bubbles	1a
SF6d	No because it can be used to neutralise a base.	1e
SF6e	Yes during reaction with something which gives out hydrogen gas especially in electrolysis. During reaction hydrochloric acid in the beaker will release the hydrogen gas which will be bubbles	1d

Selected Acid-base Chemistry: Macroscopic Properties

Attribute: Submicroscopic

Student	Responses for Question Card 1	Mental Models
SF4b	Yes. They ionizes in water to produce H^+ ions/hydrogen gas which is a type of bubble	1d
SF4e	Yes because it can corrode a building if it has high concentration of hydrogen ions For example, sulfuric acid can corrode because it is a diprotic acid but if hydrochloric acid maybe cause a little corrode because it contains less hydrogen ions than sulfuric acid Yes because it produce hydrogen ions in water which will produce hydrogen gas. Yes also because there is hydroxide ions so it will produce oxygen gas	1c
SF4f	Base produce hydroxide ions Yes like hydrochloric acid when it dissolve in water produce hydrogen gas then the hydrogen gas forms the bubbles	1d
SF6b	I think weak acid which partially dissociate will not be corrosive and we can touch them	1d
SF6c	A base react with water will produce hydroxide ions and that produces the bubbles	1d
SF6d	The hydrogen ions turns into hydrogen and release bubbles	1d

Selected Acid-base Chemistry: Macroscopic Properties

Attribute: Use of acids or bases

Student	Responses for Question Card 1	Mental Models
SF2d	Alkali, because example milk of magnesia for stomach pains	1e
SF6f	Base because as I know normally use for gastric pain. The reason we get gastric is because it is acidic right so when we drink milk which is a base it neutralises the acid and pain is reduced	1e

Selected Acid-base Chemistry: Macroscopic Properties

Attribute: Unsure

Student	Responses for Question Card 1	Mental Models
SF2a	No but do no why (acids are corrosive)	1a
SF2c	Yes but not sure why (acids are corrosive)	1a
SF4g	I am not sure (acids produce bubbles)	1a
SF6b	I don't know (bases are slippery) I don't know (acid is harmful)	1a
SF6f	Not sure (acids produce bubbles)	1a
SF6h	Not sure (acids produce bubbles)	1a

Selected Acid-base Chemistry: Neutralisation

Attribute: Product Formation

Student	Responses for "What do you think takes place when an acid and an alkali are put together"	Mental Models
SF2a	Salt and water produced	2c
SF2b	Acid + Alkaline →salt and water and student drew a picture	2c
SF2c	Will produce salt and water … salt is alkali	2c
SF2d	When an acid and an alkali are put together, it will form neutral … salt is acid	2a
SF2e	Merge the first part of acid that is aci and the second part of alkali called kali so acikali	2a
SF2f	(Neutralisation) It is tasteless because acid is a harmful substance and add with alkali will turn to normal … salt is acid because of salty water	2a
SF2g	(the name of something neutral formed)……Don't know	2a
SF2h	When we put an alkali and an acid together it can produce salt which I don't remember what is its scientific name.	2c
SF4a	Neutralisation is a process where acid combine with base would produce salt and water	2c
SF4b	They produce water which is neutral and if HCl is reacted with NaOH it will produce water and NaCl	2c
SF4d	…the reaction will produce salt and water the solution produce will cause no change in the litmus paper	2c
SF4e	Acid and base when put together will produce salt and water	2c
SF4f	When an acid and a base are reactants and it produce salt and water HCl is an acid, KOH is a base, KCl is a salt and H_2O water	2c
SF4g	Hydrochloric acid when added with sodium hydroxide will produce sodium chloride and water	2c
SF4h	Neutralisation will take place and it will produce salt and water	2c
SF6a	Neutralisation process happens produce salt and water	2c
SF6b	Acid + Alkali →salt + water	2c
SF6c	Form salt and water $2NaOH + 2HCl \rightarrow 2NaCl + 2H_2O$. It neutralise, water is neutral with pH value 7.0. Form salt, some are undissolved salt, some can be dissolved	2c
SF6d	I use HCl as an acid and NaOH as a base. When they put together they will react and form the salt which is sodium chloride and water	2c
SF6e	Student writes neutralisation occurs heat energy will be released out and the reacting solution which contains acids and bases will become warmer than the initial solution when reaction took place. Acid and base reacts together, will give out salt and water. Salt can be acidic, alkali or neutral depends on the concentration of the acid and bases used. Salt can also be insoluble salt and soluble salt. Acid and base forms salt and water	2c
SF6f	When acids and base are put together, they become a neutral solution. … The reaction produce salt and water	2c

SF6g	When an acid and a base react they could produce salt and water	2c
SF6h	Because the same amount and concentration of acid. When they react produce water and salt	2c

Selected Acid-base Chemistry: Neutralisation

Attribute: Reactants

Student	**Responses for "How do you reduce the acidity of an acidic soil?"**	**Mental Models**
SF2a	Use lime to reduce acidity	2c
SF2f	Pour water in the acidic soil water will flow with the acid into the funnel. The acidic water is collected in the beaker to make the soil neutral	2b
SF2g	Add some alkali solution	2c
SF2h	We can put some alkali substance (calcium carbonate)	2c
SF4a	Calcium carbonate is an alkali substance so when it is mixed in the soil it will neutralise the acidic soil and reduce the acidity	2c
SF4b	Add alkaline fertilizer	2c
SF4d	Use an alkaline fertilizer	2c
SF4e	When we add alkaline water the acid and the alkali will form neutral salt and water. So when this happens, alkaline in the acidic solution will be reduced	2c
SF4f	Add a base (calcium hydroxide)	2c
SF4g	Add ammonia	2c
SF4h	Pour water into the slaked lime and put it on the soil and mix it	2c
SF6a	Adding something alkali like nitrogen and mix with other chemicals	2c
SF6b	Adding some weak base to the acidic soil	2c
SF6c	Use ammonia as a weak alkali to reduce the acidity and not harmful to soil	2c
SF6d	Pour some basic substance on it such as calcium hydroxide	2c
SF6f	When you add something base and you add water maybe it will neutralise. Just mix the soil	2c
SF6g	Basically we use the basic fertilizer to neutralise the acidic soil	2c
SF6h	Adding base into the soil	2c

Selected Acid-base Chemistry: Neutralisation

Attribute: Senses

Student	Responses for "What do you think takes place when an acid and an alkali are put together"	Mental Models
SF2f	(salt is acid)Because it tastes salty	2d
SF4a	Because when acid is something that is sour and alkali is something that is a bitter so when they combine they form a tasteless substance which is neutral	2d

Selected Acid-base Chemistry: Neutralisation

Attribute: neutralisation

Student	Responses for "What do you think takes place when an acid and an alkali are put together"	Mental Models
SF4c	If acid and base we combine together it will be neutral like if we are stung by a bee we take bitter particles to neutral the toxic.	2c
SF4h	The acid is neutralised by the base and the base is neutralised by the acid to form a neutral thing	2c

Selected Acid-base Chemistry: Neutralisation

Attribute: Properties change

Student	Responses for "What do you think takes place when an acid and an alkali are put together"	Mental Models
SF2a	Because its combine acid and alkali and change the properties	2b
SF4d	Neutralisation will take place, the solution will be neutral after chemical reaction. The solution will not show any acidic or basic properties, the solution is harmless, example $NaOH + HCl \rightarrow NaCl + H_2O$, the reaction will produce salt and water the solution produce will cause no change in the litmus paper	2b
SF4e	It means there are no more hydrogen and hydroxide ions to show the properties of acid or alkali in NaCl	2b
SF4f	Do not exist (acid and basic properties)	2b

Selected Acid-base Chemistry: Neutralisation

Attribute: Submicroscopic

Student	Responses for "What do you think takes place when an acid and an alkali are put together"	Mental Models
SF4e	Because hydrogen ion and hydroxide ion has reacted to form water	2c
SF4h	The hydrogen ions and the hydroxide ions comes together and neutralise each other then it becomes water	2c
SF6a	Neutralise. Ion like react with another ion like hydrogen ions with hydroxyl ions producing water. Use indicator to identify acid and a base. Pink change to colourless reach the neutral point	2c
Student	**Responses for "How do you reduce the acidity of an acidic soil?"**	**Mental Models**
SF6e	We can use something alkali to neutralise the acid in the soil, for example, some bases which have the same concentration of OH^- as the concentration of H^+ of nitric acid	2c

Selected Acid-base Chemistry: Neutralisation

Attribute: Heat

Student	Responses for "What do you think takes place when an acid and an alkali are put together"	Mental Models
SF6e	Student writes neutralisation occurs heat energy will be released out and the reacting solution which contains acids and bases will become warmer than the initial solution when reaction took place. Acid and base reacts together, will give out salt and water. Salt can be acidic, alkali or neutral depends on the concentration of the acid and bases used. Salt can also be insoluble salt and soluble salt. Acid and base forms salt and water	2a

Selected Acid-base Chemistry: Neutralisation

Attribute: Experiment

Student	Responses for "What do you think takes place when an acid and an alkali are put together"	Mental Models
SF2b	Acid 50mL and alkaline 50mL and then produce salt and water for 100mL	2c
SF2e	Squeeze the liquids of acidic substance such as lemon and put in a container. The acid from the lemon goes into the container then squeeze the bitter gourd the liquid goes into the container that is filled with acidic liquids and merge together to form a new substance named acikalic	2b
SF2g	Put the universal indicator under the burette then in the burette pun some acidic solution. acidic or alkali I forgot. Just add a few drops and the universal indicator turns to green colour after a few drops of acidic solution is added into the universal indicator solution	2c
SF4b	Concentration of NaOH and concentration of HCl both $1 moldm^{-3}$ then they are put into a beaker and reacted and will produce sodium chloride	2c
SF4d	I think there is another solution involved but I forget. When NaOH is poured into the conical flask the solution will produce some kind of coloured solution and we put HCl slowly until the solution change its colour to show that it become neutral	2c
SF6f	When acids and base are put together, they become a neutral solution. This method is normally carried out as titration. An acid is pour into burette and bases are pour into conical flask. Acid is dropped into base in the conical flask. An indicator is put into the conical flask which is pink in colour. When the pink colour base changes into colourless, it is known as the end point. End point is the stage where acid and base becomes neutralised	2c
SF6g	Acid would be in the burette, beaker would be alkali just titrate it until temperature change…I can't remember. (laughing)	2c

Selected Acid-base Chemistry: Neutralisation

Attribute: pH value

Student	Responses for "What do you think takes place when an acid and an alkali are put together"	Mental Models
SF2a	pH 7 (is the pH of neutralisation)	2a
SF2b	pH is 7 (because water is neutral)	2a
SF2c	pH 7 (is pH of neutralisation)	2a
SF2f	pH 7 is tasteless so it neutralise	2a
SF2g	pH 7 means its neutral	2a
SF4a	pH of acid is 1 to 6 and for a base is 8 to 14 when combine together it will neutralise and becomes 7	2a
SF4c	pH value for neutral is 7 so when we combine acid and base it will taste neutral so pH is 7 so the pH value will be constant we It is neutral, the pH value is 7.	2a
SF6a	Yes because it neutralise you must get the pH 7 (always)	2a
SF6b	Yes all (acids and bases react)will give a pH 7	2a
SF6d	Because sometimes the concentration of acid is higher than base so the product will not produce exactly pH of 7.	2a

Selected Acid-base Chemistry: Neutralisation

Attribute: Equation

Student	Responses for "What do you think takes place when an acid and an alkali are put together"	Mental Models
SF2a	acid + alkali → salt and water	2c
SF2b	Acid + Alkaline →salt + water	2c
SF2d	Acid + Alkali →salt + water	2c
SF2f	Acid + alkali= salt + water	2b
SF4d	$NaOH + HCl \rightarrow NaCl + H_2O$	2c
SF4e	$HCl + NaOH \rightarrow NaCl + H_2O$	2c
SF4f	$HCl + KOH \rightarrow KCl + H_2O$	2c
SF4g	$HCl + NaOH \rightarrow NaCl + H_2O$	2c
SF4h	$NaOH + HCl \rightarrow NaCl + H_2O$	2c
SF6a	$MH+NOH \rightarrow MN + H_2O$	2c
SF6b	Acid + Alkali →salt + water	2c
SF6c	Form salt and water $2NaOH + 2HCl \rightarrow 2NaCl + 2H_2O$. It neutralise, water is neutral with pH value 7.0. Form salt, some are undissolved salt, some can be dissolved	2c
SF6f	Acid + base → salt and water	2c

Selected Acid-base Chemistry: Neutralisation

Attribute: Physical mixing

Student	Responses for "How do you reduce the acidity of an acidic soil?"	Mental Models
SF2d	Put alkali soil to neutralise the soil	2a

Selected Acid-base Chemistry: Neutralisation

Attribute: Unsure

Student	Responses for "How do you reduce the acidity of an acidic soil?"	Mental Models
SF2b	Do not know	2a
SF2c	Not sure	2a
SF2e	Do not know	2a

Selected Acid-base Chemistry: Acid-Strength

Attribute: Concentration of ions

Student	Responses for question "What do you think strong acid, weak acid, strong base, and weak base means"	Mental Models
SF4a	More concentration of hydrogen ions will be strong acid and strong bases are substance that contains more hydroxyl ions than weak base.	2b
Student	**Responses for question "Please choose what you think is the stronger acid from the two options below. i. 0.004M $H_2SO4(aq)$ ii. 0.004M $H_3PO_4(aq)$"**	**Mental models**
SF4a	I think it is phosphoric acid because it is a triprotic acid which has three hydrogen ions while H_2SO_4 has only two hydrogen which means it has lower concentration of hydrogen ions than phosphoric acid	2b
SF4b	0.004M H_3PO_4 is a triprotic acid so it ionizes in water to produce high concentration of hydrogen ions	2b
SF4d	0.004M H_3PO_4 is stronger acid as it has higher hydrogen ions so it is more acidic	2b
SF4g	I think less number of hydrogen ions will be stronger	2b
SF4h	For every molecule of fosforic acid there will be three hydrogen ions ionize so H_3PO_4 is a stronger acid than sulfuric acid which is a diprotic acid that will produce two mole of hydrogen ions	2b
SF6b	Both the acids are strong acids but 0.004M H_3PO_4 is stronger because produce more hydrogen ions	2b
SF6e	H_2SO_4 is a diprotic acid, so it is stronger than the triprotic acid which is H_3PO_4.The less hydrogen in the structure so the concentration be high and the more hydrogen in the structure the concentration of H^+ is less.	2b

Selected Acid-base Chemistry: Acid-Strength

Attribute: Degree of dissociation

Student	Responses for question "What do you think strong acid, weak acid, strong base, and weak base means"	Mental Models
SF4b	Strong acid ionizes completely in water to produce hydrogen ions	2c
SF4c	Strong acid is the acid that fully dissociate in water to produce hydrogen from the solution , weak acid partially dissociate the hydrogen in water, weak base partially dissociate the hydroxide in water, and strong base fully dissociate the hydroxide from water	2c
SF4d	Weak base can ionize hydroxyl ions partially in the water, strong base can ionize hydroxyl ions completely in water , strong acid can ionize hydrogen ions completely, weak acids is an acid that can ionize hydrogen ion partially in the water	2c
SF4e	Strong acid is an acid which produce hydrogen ions completely when reacting with water. Weak acid is a substance that produces hydrogen ions partially in water. Strong alkali is a substance which produces high concentration of hydroxide ions in water. Weak alkali is a substance that produce low concentration of hydroxide ions when in water	2c
SF4g	Ionize completely to produce hydroxide ions	2c
SF4h	Strong acid will have a corrosive property as well as a strong base while weak acid and a weak base they have less corrosive properties. Then when I learn the strong acid will ionize completely while weak acid and weak base will ionize partially the others exist as molecule	2c
SF6a	Strong acid is an acid that completely ionizes in water to produce H^+ ions and weak base is a base that ionizes partially in water to produce lower amount of OH^-. Strong base ionize completely in water to produce OH^- ions and weak acid is an acid that ionizes partially to produce low concentration of H^+ ions	2c
SF6b	Strong is fully dissociated and weak is partially dissociate	2c
SF6c	Strong acid, fully dissociate in water	2c
SF6d	Strong acid ionize completely in water	2c
SF6e	Strong acid can ionize in water to form higher concentration of H^+ ions than others	2c
SF6f	Strong acid has more hydrogen and easy to dissociate in water and a weak quite difficult to dissociate. A strong base is easy to dissociate to produce hydroxide ions and a weak base difficult to dissociate to produce hydroxyl ions	2c
SF6h	Strong acid is an acid that completely ionizes in water to produce H^+ ions and weak base is a base that ionizes partially in water to produce lower amount of OH^- .Strong base ionize completely in water to produce OH^- ions and weak acid is an acid that ionizes partially to produce low concentration of H^+ ions.	2c

Student	Responses for question "Please choose what you think is the strongest acid solution from the three options below. i. 0.4M HCl(aq) ii. 0.04M HCl(aq) iii. 0.004M HCl(aq)"	Mental Model
SF6b	All three are strong acid will fully dissociate and the question has different concentration. Although they have different concentration, but the three are hydrochloric acid which is a strong acid	2c
Student	**Responses for question "Please choose what you think is the stronger acid from the two options below. i. 0.04M HCl(aq) ii. 0.4M CH_3COOH(aq)"**	**Mental model**
SF4b	0.04M HCl because CH_3COOH dissolves partially in water so it is a weak acid	2c
SF4e	No. it is phosphoric acid is a weak acid which when ionize in water will form H_2PO_4 and something else just like CH_3COOH will ionize to become CH_3COO^- and H^+	2c
SF4f	Because ethanoic acid dissolve partially in water and hydrochloric acid dissolve completely in water so hydrochloric acid is a strong acid	2c
SF4h	0.04M HCl because HCl ionize completely in water so it will result in a stronger acid	2c
SF6c	Although the concentration is lower that is 0.04M HCl(aq) because it is a strong acid, fully dissociate in water	2c
SF6d	0.04M HCl because ionize completely in water	2c
SF6f	Yes because HCl is a stronger acid even when the concentration is lower	2c
SF6h	0.04M HCl is a strong acid because I read from the book and ionize completely in water in comparison to CH_3COOH which is a weak acid	2c
Student	**Responses for question "Please choose what you think is the stronger acid from the two options below. i. 0.004M H_2SO_4(aq) ii. 0.004M H_3PO_4(aq)"**	**Mental Model**
SF4c	0.004M H_2SO_4 because the hydrogen from H_2SO_4 is fully dissociated in water and does not form back H_2SO_4 but H_3PO_4 some of the hydrogen will dissociate and some will not dissociate	2c
SF4e	No. it is phosphoric acid is a weak acid which when ionize in water will form H_2PO_4 and something else just like CH_3COOH will ionize to become CH_3COO^- and H^+	2c
SF4f	0.004M H_2SO_4 because it dissolve completely in water	2c
SF6c	0.004MH_2SO_4 (aq) because sulfuric acid is a strong and fully dissociate but the acid, H_3PO_4 is not because presence of PO_4^{3-}	2c

Selected Acid-base Chemistry: Acid-Strength

Attribute: Physical strength based on pH

Student	Responses for question "What do you think strong acid, weak acid, strong base, and weak base means"	Mental Models
SF4f	Strong acid is the acid with lower pH value and weak acid with higher pH value	2a
SF4h	Strong acid will have a lower pH weak acid will have a higher pH	2a
SF6a	Strong acid is pH 1 to 3, strong base about 8 to 12, weak acid 4 to 6, weak base 8 to 9	2a
Student	**Responses for question "Please choose what you think is the stronger acid from the two options below. i. 0.04M HCl(aq) ii. 0.4M CH_3COOH(aq)"**	**Mental Model**
SF6a	0.04MHCl, HCl is a strong acid with pH 1 to 3 while CH_3COOH is pH 4 to 6	2a

Selected Acid-base Chemistry: Acid and Base Strength

Attribute: Physical strength based on properties

Student	Responses for question "What do you think strong acid, weak acid, strong base, and weak base means"	Mental Models
SF4h	Strong acid will have a corrosive property as well as a strong base while weak acid and a weak base they have less corrosive properties. Then when I learn the strong acid will ionize completely while weak acid and weak base will ionize partially the others exist as molecule	2d

Selected Acid-base Chemistry: Acid-Strength

Attribute: Molar concentration

Student	**Responses for question "What do you think strong acid, weak acid, strong base, and weak base means"**	**Mental Models**
SF6g	Strong acid the pH value is less than the weak acid then it is much <u>more concentrated</u>. Weak acid is less concentrated. Same thing goes with strong base is more concentrated than a weak base and the pH value for strong base is higher than for weak base	2a
Student	**Responses for question "Please choose what you think is the strongest acid solution from the three options below. i. 0.4M HCl(aq) ii. 0.04M HCl(aq) iii. 0.004M HCl(aq)"**	**Mental Model**
SF4a	0.4M because it is the molarity of the HCl the highest molarity is the strongest acid	2a
SF4b	0.4M HCl because it has high concentration	2a
SF4c	ai because it has the highest moles of HCl so the pH will be lower from 1 to 2 or 3	2a
SF4d	0.4M HCl is the strongest acid as it has the highest concentration	2a
SF4e	0.4M HCl contains the highest concentration of hydrogen ions in water than the others	2a
SF4f	0.4M HCl because it is highest concentration	2a
SF4g	0.4M HCl because the concentration is the highest	2a
SF4h	0.4 M HCl because it is more concentrated and the hydrogen ions will also exist more	2a
SF6a	I chose 0.4M HCl based on the concentration which shows the strongest. All three are strong acid-based on the pH value but the first one is the strongest	2a
SF6c	0.4M HCl (aq) because the molarity is higher so the concentration is higher	2a
SF6d	The strongest acid is 0.4M HCl because this is the highest concentration	2a
SF6e	0.4M HCl is higher in concentration, so it can ionize in water to form higher concentration of H^+ ions than others	2a
SF6f	0.4M HCl (aq) is the strongest acid solution because it has the highest concentration than the other	2a
SF6g	0.4M HCl is the strongest because it is much more concentrated than the others	2a
Student	**Responses for question "Please choose what you think is the stronger acid from the two options below. i. 0.04M HCl(aq) ii. 0.4M CH_3COOH(aq)"**	**Mental Model**
SF4c	0.4M CH_3COOH is stronger acid as it has higher concentration although it is an organic acid or a weak acid	2a
SF4d	CH_3COOH is more concentrated than HCl so we need to think about the concentration	2a
SF4e	0.04M because HCl is a strong acid while CH_3COOH is a weak acid although the concentration of the ethanoic acid is higher than hydrochloric acid	2a

SF4g	0.4M CH_3COOH because of higher concentration	2a
SF6g	Even though HCl is a stronger acid than ethanoic acid but the concentration is less so 0.4M CH_3COOH is stronger	2a

Selected Acid-base Chemistry: Acid and Base Strength

Attribute: Unsure

Student	**Responses for question "Please choose what you think is the stronger acid from the two options below. i. 0.004M H_2SO_4(aq) ii. 0.004M H_3PO_4(aq)"**	**Mental Models**
SF6a	I remembered H_2SO_4 is a strong acid and H_3PO_4 a weak acid but not sure why	2a
SF6g	I am not sure but I think the lesser the hydrogen number the stronger the acid	2a
SF6h	Because I only know H_2SO_4 is a strong acid and I did not come across H_3PO_4 before so I don't know if H_3PO_4 is a strong acid or not	2a

Selected Acid-base Chemistry: Acid-base Equilibrium

Attribute: Reversible reaction

Student	Responses for "I mix aqueous solution of NaOH (sodium hydroxide) with an aqueous solution of CH_3COOH (ethanoic acid) in equal volume and concentration, do you think the concentration of $[H_3O^+]$ be same, higher or lower than the concentration of $[OH^-]$ ions in the resulting solution?"	Mental Models
SF6a	NaOH is a base CH_3COOH is acid H_2O is neutral and CH_3COONa not sure… I am not sure which ions is higher because this is a reversible reaction when H_2O and CH_3COONa is formed it will reverse back to the CH_3COOH and NaOH. Therefore, I am not sure which concentration is higher than the other. (pH)... not sure of pH because it is a reversible process	3a

Selected Acid-base Chemistry: Acid-base Equilibrium

Attribute: Degree of dissociation

Student	Responses for "I mix aqueous solution of NaOH (sodium hydroxide) with an aqueous solution of CH_3COOH (ethanoic acid) in equal volume and concentration, do you think the concentration of $[H_3O^+]$ be same, higher or lower than the concentration of $[OH^-]$ ions in the resulting solution?"	Mental Models
SF6c	$NaOH + CH_3COOH \rightarrow CH_3COONa + H_2O$ Because at equivalence it neutralise so it has to be 7 The base is fully dissociate so the OH^- ions are more and acid the H^+ ions is less so OH^- will be more than H^+. Because this is neutralisation the equivalence point must have equal hydrogen and hydroxide ions. I am not sure if this equation is correct or not.	3e

Selected Acid-base Chemistry: Acid-base Equilibrium

Attribute: Strong base weak acid

Student	Responses for "I mix aqueous solution of NaOH (sodium hydroxide) with an aqueous solution of CH_3COOH (ethanoic acid) in equal volume and concentration, do you think the concentration of $[H_3O^+]$ be same, higher or lower than the concentration of $[OH^-]$ ions in the resulting solution?"	Mental Model
SF6b	OH^- will be higher than H_3O^+ because NaOH is a strong alkali and can fully dissociate to produce more OH- ions than CH_3COOH which partially dissociate to produce less H^+ ions	3e
SF6e	Hydroxyl ions will be higher concentration than hydronium ions because NaOH is a strong base while CH_3COOH is a weak acid, so NaOH is able to ionize completely in water to give out higher concentration of hydroxyl ions and ethanoic acid ionize partially in water to give low concentration of hydronium. Student writes an equation. ..Yes NaOH is a base, CH_3COOH is an acid, CH_3COONa a base because it produces hydroxyl ions …Higher than pH 7 because it is a reaction between a strong base and a weak acid will have a pH of more than 7.	3e
SF6f	Concentration of H_3O^+ will be lower than concentration of OH^- because strong base reacts with weak acids. … At equivalence point pH is 7	3e
SF6h	I think concentration of OH^- ions is higher than concentration of $[H_3O^+]$ ions in the resulting solution … Sodium hydroxide is a strong base that ionize completely in water to produce OH^- ions and ethanoic acid is a weak acid that ionize partially in water to produce low concentration of H^+ ions	3e

Selected Acid-base Chemistry: Acid-base Equilibrium

Attribute: Quantity of matter

Student	**Responses for "I mix aqueous solution of NaOH (sodium hydroxide) with an aqueous solution of CH_3COOH (ethanoic acid) in equal volume and concentration, do you think the concentration of $[H_3O^+]$ be same, higher or lower than the concentration of $[OH^-]$ ions in the resulting solution?"**	**Mental Models**
SF6d	$NaOH + CH_3COOH \rightleftharpoons CH_3COONa + H_2O$ Yes I think it will be the same because one mole of NaOH react with ethanoic acid to produce salt and water. Therefore, number of hydrogen ions would be the same as the number of hydroxyl ions.	3a
SF6g	They will be the same; because of the concentrations are the same, in both solutions. The equation would be NaOH + CH_3COOH produces CH_3COONa and H_2O … I am not sure if the resulting solution would be an acid or a base or neutral if this is neutralisation process. … do not know the meaning of dissociation and ionization	3a

Selected Acid-base Chemistry: Acid-base Equilibrium

Attribute: Unsure

Student	**Responses for question "What do you think Acid-Base Equilibrium is?"**	**Mental Models**
SF6a	Not sure	3a
SF6b	Not sure	3a
SF6d	I am not sure	3a
SF6f	No idea	3a
SF6g	I am not sure	3a
SF6h	I am not sure	3a
Student	**Responses for "I mix aqueous solution of NaOH (sodium hydroxide) with an aqueous solution of CH_3COOH (ethanoic acid) in equal volume and concentration, do you think the concentration of $[H_3O^+]$ be same, higher or lower than the concentration of $[OH^-]$ ions in the resulting solution?"**	**Mental Model**
SF6a	NaOH is a base CH_3COOH is acid H_2O is neutral and CH_3COONa not sure… I am not sure which ions is higher because this is a reversible reaction when H_2O and CH_3COONa is formed it will reverse back to the CH_3COOH and NaOH. Therefore, I am not sure which concentration is higher than the other. (pH).. not sure of pH because it is a reversible process	3a

Selected Acid-base Chemistry: Buffer

Attribute: Reactant

Student	Responses for "What makes a Buffer solution?"	Mental Model
SF6a	A buffer is a solution that when a small amount of acid or base is added the solution produced is a buffer	3d
SF6b	a buffer is a combination of an acid and a base	3d
SF6h	Buffer is a solution that contains salt and acid but if we add alkali the pH will not change much	3d
Student	**Responses for "A buffer is only formed by the combination of a weak acid and its salt."**	**Mental Model**
SF6b	No buffer is a combination of weak acid and a base not weak acid and a salt	3d
SF6h	I agree because this is what I understand about buffer	3d
Student	**Responses for "A buffer can be formed by a combination of hydrochloric acid (HCl) and sodium chloride (NaCl)"**	**Mental Model**
SF6c	No because buffer is only used in weak acid because HCl is strong acid that have enough full dissociated H^+ ion to react with strong base NaCl OH^- to form salt and water A buffer is formed from a weak acid and a strong alkali like NaCl which fully dissociates to produce OH- ions	3d
SF6e	No, because it must be the combination between an acid and a base, not an acid with salt	3d

Selected Acid-base Chemistry: Buffer

Attribute: Acidity change

Student	Responses for "What makes a Buffer solution?"	Mental Models
SF6c	Buffer is a reaction to either increase or decrease the acidity	3a

Selected Acid-base Chemistry: Buffer

Attribute: Resist pH change

Student	Responses for "What makes a Buffer solution?"	Mental Models
SF6d	Yes something that can resist a pH change.	3a
SF6h	Buffer is a solution that contains salt and acid but if we add alkali the pH will not change much	3a

Selected Acid-base Chemistry: Buffer

Attribute: Improper conjugate ideas

Student	Responses for "A buffer can be formed by a combination of an acid and its conjugate base."	Mental Models
SF6c	Conjugate base is an acid and conjugate acid is a base	3b
SF6a	Yes conjugate base maybe is H^+ acid is HCl	3b
SF6e	No because buffer is form from the combination of conjugate acid and conjugate base. HCl + NaOH forms NaCl and H_2O. HCl is an acid and Cl will be the conjugate base and NaOH is a base and Na will be the conjugate acid. Therefore, conjugate acid reacts with conjugate base to form NaCl which will be the buffer solution	3b

Selected Acid-base Chemistry: Buffer

Attribute: Neutralisation

Student	Responses for "A buffer can be formed by a combination of hydrochloric acid (HCl) and sodium chloride (NaCl)"	Mental Models
SF6a	This reaction will get a neutral pH is 7 but no changes as an acid or base	3d
SF6b	This is a neutralisation process so not a buffer it has only an acid and a salt but no base same like a	3d

Selected Acid-base Chemistry: Buffer

Attribute: Unsure

Student	Responses for "What makes a Buffer solution?"	Mental Models
SF6e	Buffer is buffer is no sorry I cannot remember	3a
SF6f	Not really	3a
SF6g	Cannot remember	3a
Student	**Responses for "A buffer is only formed by the combination of a weak acid and its salt."**	**Mental Model**
SF6a	I am not sure	3a
SF6c	I am not sure	3a
SF6d	I am not sure	3a
SF6e	I am not sure	3a
SF6f	I am not sure	3a
SF6g	I am not sure	3a
Student	**Responses for "A buffer can be formed by a combination of an acid and its conjugate base."**	**Mental Model**
SF6b	Do not know	3a
SF6d	I disagree with the statement. I think there is another way to solve the problem but not sure	3a
SF6f	Do not know	3a
SF6g	Do not know	3a
SF6h	Do not know	3a

Student	**Responses for "A buffer can be formed by a combination of hydrochloric acid (HCl) and sodium chloride (NaCl)"**	**Mental Model**
SF6d	No but not sure how to explain	3a
SF6f	Do not know	3a
SF6g	Do not know	3a
SF6h	Do not know	3a

Selected Acid-base Chemistry: Acid-Base Electron Pair Bonding

Attribute: Strong acid-Weak base reaction

Student	Responses for $BH_3(g)$+ $NH_3(g) \rightarrow H_3B\ NH_3(s)$ (Question Card 7c)	Mental Models
SF6a	This is an equation with strong acid and weak base. If we keep on adding BH_3 sure the pH will go more than 7	3d

Selected Acid-base Chemistry: Acid-Base Electron Pair Bonding

Attribute: Acid-acid reaction

Student	Responses for $BH_3(g)$+ $NH_3(g) \rightarrow H_3B\ NH_3(s)$ (Question Card 7c)	Mental Models
SF6f	No they are (BH_3 and NH_3) are strong acids but I do not know how after reaction they become weak acid	3d
SF6h	All three of them are acids	3d
SF6g	I think both of it as acids because the presence of hydrogen ions	3d

Selected Acid-base Chemistry: Acid-Base Electron Pair Bonding

Attribute: Base-Unknown reaction

Student	Responses for $BH_3(g)$+ $NH_3(g) \rightarrow H_3B\ NH_3(s)$ (Question Card 7c)	Mental Models
SF6b	NH_3 is a base and I think H_3BNH_3 is also a base but not sure about BH_3	3d

Selected Acid-base Chemistry: Acid-Base Electron Pair Bonding

Attribute: Dative Bonding

Student	**Responses for $BH_3(g)$+ $NH_3(g)$ → H_3B $NH_3(s)$ (Question Card 7c)**	**Mental Models**
SF6d	It has a dative bond Kinds of bond it like send a pair of electron to another molecule. …. From BH_3 to NH_3 drawn in the picture and forms the BH_3NH_3 compound …. BH_3 is an acid and NH_3 a base.	3b

Selected Acid-base Chemistry: Acid-Base Electron Pair Bonding

Attribute: Unsure

Student	**Responses for $BH_3(g)$+ $NH_3(g)$ → H_3B $NH_3(s)$ (Question Card 7c)**	**Mental Models**
SF6c	Not sure	3a
SF6e	Not sure	3a

APPENDIX G

Attributes for Question Card 2

The Phenomenological Model

(Students' Responses to Question Card 2: Milk, Vinegar, Lemon Juice, Soap, Floor Cleaner, Baking Soda Solution, soda drinks, water , sodium hydroxide, hydrochloric acid)

Attribute: pH value

Student	Responses (Question Card 2 item)
SF2a	Acid. From knowledge acid pH value is below 7 (vinegar) From knowledge, alkali pH value is more than 7 (floor cleaner) Neutral because pH 7 (water) Acid. From knowledge acid pH value is below 7 (milk) Acid pH value is below than 7 and think it is just an acid (Baking soda) Acid pH value is below than 7 (Soda drinks) Alkali pH value is more than 7 (sodium hydroxide) Acid pH value is below 7 (hydrochloric acid)
SF2h	Water is neutral because it has pH value of 7 (water)
SF4c	Base, it has higher pH value (Milk) Base, pH value is higher because mostly it does not burn the floor so we can use a base (floor cleaner) Acid, and vinegar has a higher pH value and taste is sour (vinegar) Base, it has higher pH value (soap) Acid, because baking soda is a carbonate the pH value is lower (Baking soda)
SF4e	Vinegar is an acid because it taste sour turns blue litmus paper to red and has a pH value of 3 (vinegar)
SF4f	Water is tasteless with pH 7 so neutral (water)
SF6d	Milk is a base because the pH is slightly above 7 (Milk)
SF6g	Acid. Lower pH and it taste sour (Milk) Base. Higher pH value than 7 (floor cleaner) Acid. Lower pH and it taste sour (vinegar) Taste bitter, higher pH value than (soap) Acid because lower pH (Baking soda)

Attribute: Senses

Student	Responses (Question Card 2 item)
SF2a	The taste is sour and acid because the pH value is below 7 (vinegar) The taste is sour and an acid pH value is below 7 (lemon juice) Alkali because bitter and slippery pH value is more than 7 (soap)
SF2b	Acid, because milk taste like sour. If milk put on the table in a long time, it will become more sour (Milk) Acid because lemon juice is taste very sour. It can turn blue litmus paper (lemon juice) Alkali taste bitter. Some of the family use it can make the floor more cleaner (floor cleaner) Neutral because it is tasteless. It does not change any colour between the red litmus paper and blue litmus paper (water) Acid because it taste very sour (vinegar) Alkali because soap is bitter (soap) Alkali. Soda drinks have some salty taste (Soda drinks) It has also taste like sour acid (hydrochloric acid)
SF2c	Acid, because milk tastes sweet but become sour (Milk) Acid, because it tastes sour (vinegar) Acid, because it taste sour (lemon juice) Alkali ,because it feel soapy (floor cleaner) Neutral because tasteless (water) Alkali, feel soapy (soap)
SF2d	Acid, because it tastes sour (vinegar) Acid because tastes sour (lemon juice) Alkali, it is slippery (floor cleaner) Neutral, because tasteless (water) Alkali, it is slippery (soap) An alkali because it is slippery and corrosive (sodium hydroxide) Acid.(it is corrosive) (hydrochloric acid)
SF2e	Acid because fresh milk and magnesia milk has a sour taste (milk) Alkali because bitter taste or something like that (vinegar) Acid because lemon juice has a sour taste (lemon juice) Neutral but I am not sure why it is neutral (floor cleaner)
SF2f	Milk is acid because it tastes sweet (Milk) Vinegar is acid because it tastes sour (vinegar) Lemon juice is acid because it tastes sour (lemon juice) Floor cleaner is an acid because it tastes sour (floor cleaner) Neutral because tasteless (water) Soap is a base because it is bitter (soap) Not alkali or acid but tasteless (Baking soda) Soda is sweet so it is an acid (Soda drinks) It is salty so it is an acid (sodium hydroxide)
SF2g	Acid. Because it taste slightly sour. (Milk) Acid. Because it taste sour (vinegar) Acid. Because it taste sour (lemon juice) Alkali. Because it is similar as soap (floor cleaner) Neutral. Because it is tasteless, colourless, and odourless (water)

SF2h	Alkali because it does not taste sour (milk) Soap can produce bubbles and it is slippery when we step on it so it is alkali (soap) Bila kita minum tekak kita rasa macam sakit (When we drink our throat feels a little pain) so it is an acid (Soda drinks)
SF4a	Milk tastes sweet but sweet is not alkali or acidic.(unsure) (milk) Yes because it tastes sour (vinegar) Yes because it tastes sour (lemon juice) Water is neutral because it is tasteless (water) Soap is a base because it is slippery (soap) Acid. It tastes sour (Soda drinks)
SF4b	Acid because it tastes sour (Milk) Acid. It tastes sour (lemon juice) Base because some are slippery but not all floor cleaner are bases because not all are slippery (floor cleaner) Neutral because it is tasteless (water) Base because it is slippery (soap) Acid because it tastes sour (Baking soda) Acid. It tastes sour (Soda drinks)
SF4c	Milk is a base because the taste is bitter (milk) Neutral …Water is tasteless and water doesn't change any litmus paper colour (water) NH_3 is ammonia which is a gas it is not an acid or a base. Gas we cannot use litmus paper but we can taste the gas sour or bitter (NH_3)
SF4d	An acid because it turn sour when left for a while (Milk) It is an acid because it tastes sour (lemon juice) It is an acid because it taste sour (vinegar) It is a base because it is slippery (soap) A base because it tastes bitter. Baking soda is the one that we used to make cookies and I have tasted it before (Baking soda) It is not sour so it is a base (Soda drinks)
SF4e	Vinegar is an acid because it taste sour turns blue litmus paper to red and has a pH value of 3 (vinegar) Acid because it taste sour (lemon juice) A base because it taste bitter (soap)
SF4f	Neutral because it is tasteless (milk) Acid because it tastes sour (vinegar) It also taste sour so it is an acid (lemon juice) A base because it is slippery (floor cleaner) Water is tasteless with pH 7 so neutral (water) A base because it is slippery (soap) …. because I do not think baking soda solution is sour Baking soda) Acid because it tastes sour (Soda drinks)
SF4g	Tasteless (milk) Acid. Taste sour but I am not sure (vinegar) Taste acidic (lemon juice) Base because it is slippery (floor cleaner) Neutral because tasteless water) Base because it is slippery (soap)

	Acidic because it has a gas (Soda drinks)
SF4h	Acidic because it has a sour taste (vinegar) Acidic because it has a sour taste (lemon juice) I put it as neutral because it is tasteless (water)
SF6a	Milk is an acid because after we drink milk and we do not brush our teeth then we will feel like sour taste so I classify milk as an acid (Milk) It tastes sour ,therefore, an acid (lemon juice) A base because they are slippery (floor cleaner) Water is neutral because no change in colour of litmus (water) Vinegar is acid because it tastes sour (vinegar) A base because they are slippery (soap) Sweet I think is acidic because after we taste sweet and did not brush our teeth it will taste sour (Baking soda)
SF6b	Vinegar is acid because it tastes sour (vinegar) Lemon juice is sour therefore it is an acid (lemon juice) Don't have any taste so neutral (water) I don't think so it is an acid but not sure why (Baking soda)
SF6c	Acid because milk will become sour when it is placed for several days (Milk) Acid because vinegar taste sour (vinegar)
SF6d	Vinegar is an acid because it tastes sour (vinegar) Lemon juice is an acid because it tastes sour (lemon juice) Floor cleaner is a base because it is bitter (floor cleaner) Water is neutral because it is tasteless (water) Soap is a base because it tastes bitter (soap)
SF6e	Acid because it tastes a bit sour and if it is left too long until its expiry date . At that moment it will taste sour. (Milk) Lemon juice is acid because it tastes sour (lemon juice) It is also a base because it is slippery (floor cleaner) Vinegar tastes sour too (vinegar) Soap is a base because it is slippery (soap) Baking soda is acidic because it gives out hydrogen gas and so bread gets larger (Baking soda)
SF6f	Acid because it tastes sour (vinegar) Acid because it tastes sour (lemon juice) Base because it is slippery (floor cleaner) Neutral because it is (water)
SF6g	Neutral but not quite sure because when it turns sour it has the acidic properties when it is normal it has base properties but it does not taste bitter. So I think it is somewhere in between. (Milk) Acid. Sour taste (lemon juice) Taste bitter, higher pH value than 7 (soap)
SF6h	Acid because tastes sour (vinegar) Acid because taste sour (lemon juice) Base because it is slippery (floor cleaner) Base because it is slippery (soap)

Attribute: Uses of acids and bases

Student	Responses (Question Card 2 item)
SF2d	Because if we have stomach pain we drink that (Milk)
SF4a	Shampoo is a base because things that cleans are bases (floor cleaner)
SF4d	An acid because it is used to kill microorganism (floor cleaner)
SF4e	Floor cleaner is a base because kotoran yang di lantai (dirt spots on the floor) shows the properties of acid so when we put an alkaline to wipe it, it will neutralise and become neutral (floor cleaner)
SF4h	Base because it gives a cleaning effect (soap) Base because it gives a cleaning effect (floor cleaner)
SF6c	Base, wash the dirt away (soap) A base, remove oil stain (floor cleaner)
SF6f	Base because as I know normally use for gastric pain. The reason we get gastric is because it is acidic right so when we drink milk which is a base it neutralises the acid and pain is reduced (milk)

Attribute: Scientific test

Studen	Responses (Question Card 2 item)
SF2b	Neutral because it is tasteless. It does not change any colour between the red litmus paper and blue litmus paper (water) Alkali, it can changes colour from red litmus paper to blue (Baking soda) Alkali. It can change colour from red litmus paper to blue but not sure (sodium hydroxide)
SF2e	Alkali because wet soap responds to the litmus paper by changing it to blue (soap) Neutral does not respond to litmus paper (water)
SF2g	Use the litmus paper turn to blue (soap) Acid. Because I have experiment before (Soda drinks)
SF2h	I have done an experiment involve vinegar it turns blue litmus paper to red so it is acidic (vinegar)
SF4b	Acid because it is sour and changes blue litmus paper to red (vinegar) It shows base properties it changes red litmus paper to blue (NH_3)
SF4c	Neutral …Water is tasteless and water doesn't change any litmus paper colour (water)
SF4e	Vinegar is an acid because it taste sour turns blue litmus paper to red and has a pH value of 3 (vinegar) It is tasteless and tasteless is neutral (water)
SF6g	Neutral. Because does not react with litmus paper and then the pH value is 7 (water)

Attribute: Properties of acids and bases

Student	Responses (Question Card 2 item)
SF4d	(Water is neutral) It does not show any acidic or basic properties such as corrosive, sour or bitter (water)
SF4e	A base) No idea but I know it does not show any properties of acid or neutral (milk) Because of the smell it does not show the property of a sour smell then it turns red litmus paper to blue (soap) I think it is a base because it does not show the properties of acid, however, I am not sure (Soda drinks)
SF6b	Soap is a base because if it an acid it will corrode our skin (soap)
SF6c	Sour taste but alkali properties (floor cleaner) Neutral because water is under the specify, neutral (water)
SF6f	Base is slippery and basic properties of alkali are slippery. Normally they use alkali for cleanser (soap)

Attribute: Sub-microscopic

Student	Responses (Question Card 2 item)
SF6e	Water is neutral if it is pure water without any Fluorine ions (water)

Attribute: Neutralisation

Student	Responses (Question Card 2 item)
SF6h	When acid-base combine they form salt and water so I think water is neutral (water)

Attribute: Constituents

Student	Responses (Question Card 2 item)
SF2c	Alkali, because of sodium which is alkali (sodium hydroxide)
SF6c	A soda is a form of a base (Baking soda) Soda drinks are acids because contain carbonic acid (Soda drinks)
SF6d	A base because it contains basic substances. (Baking soda) Soda drinks are acids because it contains acid. (Soda drinks)
SF4h	A base because I always thought that a milk have magnesium and calcium in it so it has to be a base (milk) Yes but because it is carbonated so I think it is a base (Soda drinks)
SF6a	Soda drinks are carbonated drinks and I think there is carbon dioxide so it is acidic (Soda drinks)

Attribute: Physical strength

Student	Responses (Question Card 2 item)
SF2h	Acid because when it is concentrated it can hurt us (sodium hydroxide) Acid because if it is too concentrate it can hurt us (hydrochloric acid)

Attribute: Unsure

Student	Responses (Question Card 2 item)
SF2c	Alkali but not sure (Baking soda) Acid , but not sure (Soda drinks) Acid, because there is acid in hydrochloric acid (unsure) (hydrochloric acid)
SF2e	Neutral but I am not sure why it is neutral (floor cleaner) I am not sure (Baking soda) Alkali but not sure why (Soda drinks) Not sure (sodium hydroxide) Not sure (hydrochloric acid)
SF2f	Acid because the name is acid (unsure) (hydrochloric acid)
SF2g	I don't know (sodium hydroxide) Acid because it has acid in the name (unsure) (hydrochloric acid)
SF2h	I am not so sure about this but I think when use in cake never hurt us or die so it is an alkali (Baking soda)
SF4a	Not sure (Baking soda)
SF4c	Yes because soda is a complete drink with water, soda and other things (Soda drinks)
SF4e	I have no idea (Baking soda)
SF4g	Not sure because I don't think it is an acid because it is baking soda (Baking soda)
SF4h	No but I only guess it tastes bitter (Baking soda)
SF6b	A base but not sure why (floor cleaner)
SF6e	Soda drinks are bases but I am not sure why it is a base (Soda drinks)
SF6f	Not sure (Baking soda)
SF6g	Neutral but not quite sure because when it turns sour it has the acidic properties when it is normal it has base properties but it does not taste bitter. So I think it is somewhere in between (milk) Acid. Because I just got a feeling it is an acid (Soda drinks)
SF6h	Because I don't know .I am really not sure. (milk) I am not sure (Baking soda) No idea (Soda drinks)

The Arrhenius Model

(Students' Responses to Question Card 2: Sodium hydroxide or NaOH and Hydrochloric acid or HCl)

Attribute: pH value

Student	Responses (Question Card 2 item)
SF6c	Alkali because the pH value is 8 to 14 and sodium is alkali (NaOH)
SF6g	Acid because lower pH value (HCl)

Attribute: Scientific test

Student	Responses (Question Card 2 item)
SF4b	Acid because it changes blue litmus paper to red (HCl) Base because changes colourless phenolphthalein to pink (NaOH)
SF6e	Hydrochloric acid is acidic because it is very corrosive in concentrated form and it turns blue litmus paper to red (HCl) NaOH is a base because normally use in titration with hydrochloric acid and it acts as strong base(When NaOH is put in the red litmus paper it will turn blue (NaOH)

Attribute: Senses

Student	Responses (Question Card 2 item)
SF4c	Acid, because when we do experiment HCl may spill on our skin and we feel itchy (HCl) NH_3 is ammonia which is a gas it is not an acid or a base. Gas we cannot use litmus paper but we can taste the gas sour or bitter (NH_3)

Attribute: Hydrogen hydroxide ions

Student	Responses (Question Card 2 item)
SF4a	It is a base because it contains hydroxide ions when dissolved in water (NaOH) An acid because when dissolve in water produces hydrogen ions in water (HCl)
SF4e	No no NaOH is a base because it shows properties of hydroxide ions (NaOH) It is an acid .It is a strong acid because it ionize hydrogen ion completely in water (HCl)
SF4f	A base because produce hydroxide ions (NaOH)
SF4g	Base because there is presence of hydroxide ions (NaOH) Acid because presence of hydrogen ions (HCl)
SF4h	It is a base because it contains hydroxide ions (NaOH) Acid because it contains hydrogen ions (HCl)
SF6a	NaOH is a base because got OH^- ions (NaOH) This is an acid because got hydrogen ions (HCl)
SF6c	HCl is a strong acid with the presence of H^+ ions (HCl)
SF6d	NaOH is a base because it contains OH^- ions (NaOH) HCl is an acid because it contains hydrogen ions (HCl)
SF6f	Base because it has hydroxyl group that dissociates in water to produce OH^- ions (NaOH) Acid because it dissociates with water to produce H^+ ions (HCl))
SF6g	Base because have higher pH value, presence of OH (NaOH)
SF6h	Base because presence of OH^- (NaOH) Acid because presence of H^+ ions (HCl)

Attribute: Properties of acids or bases

Student	Responses (Question Card 2 item)
SF4g	Base because it is alkali (NH_3)
SF6b	It is a strong alkali so it is a base (NaOH)
SF6c	

Attribute: Source Reference

Student	Responses (Question Card 2 item)
SF6b	Strong acid because knowledge (HCl)

Attribute: Constituent

Student	Responses (Question Card 2 item)
SF4c	Acid, sodium mostly is acidic (NaOH)

Attribute: Reaction

Student	Responses (Question Card 2 item)
SF4f	Acid because it produce hydrogen gas (HCl)

Attribute: Unsure

Student	Responses (Question Card 2 item)
SF4d	I think it is a base but not sure (NaOH) An acid but I am not sure the reason why it is an acid (HCl)

The Brønsted-Lowry Model

Students Responses to Question Card 2: CH_3COO^-

Attribute: Hydrogen ions

Student	Responses (Question Card 2 item)
SF6b	Neutral because it does not have the H^+ ions and it is an ion
SF6d	CH_3COO^- is neutral because ethanoate does not contain H^+ ions
SF6e	Because I think hydrogen ions will be present because of the CH_3
SF6f	Acid because it is a weak acid which produces H+ ions when dissociate in water

Attribute: Carbon or/and oxygen

Student	Responses (Question Card 2 item)
SF6c	I think because of carbon or oxygen that makes it a weak acid
SF6g	Acid because presence of COO^- but not sure

Attribute: Unsure

Student	Responses (Question Card 2 item)
SF6a	I know CH_3COOH is an acid but I am not sure of CH_3COO^-
SF6h	I have no idea

The Lewis Model

Students Responses to Question Card 2: CO_2

Attribute: Scientific Test (lime water test)

Student	Responses (Question Card 2 item)
SF6a	Acidic because it turns lime water to chalky or milky
SF6e	CO_2 is an acidic because it is able to turn lime water to cloudy.
SF6f	Acid because normally it changes lime water cloudy and then litmus paper change to red

Attribute: Source Reference

Student	Responses (Question Card 2 item)
SF6c	An acid because when I read from the book, if there is a high level of $C0_2$ content in blood will cause the blood to become more acidic
SF6d	Not sure but when we study Group 14 stated that carbon dioxide has the acidic characteristics

Attribute: Unsure

Student	Responses (Question Card 2 item)
SF6b	Not sure
SF6g	I am not sure maybe acidic or neutral
SF6h	Other but not sure

APPENDIX H

Attributes for Question Card 2

Student	Students' responses for milk	Students' attributes	Acid-base model
SF2a	Acid. From knowledge acid pH value is below 7	pH	None
SF2b	Acid, because milk taste like sour. If milk put on the table in a long time, it will become more sour	*Senses	Phenomenological
SF2c	Acid, because milk tastes sweet but become sour	*Senses	Phenomenological
SF2d	Alkali, because example milk of magnesia for stomach pains	Use of acids or bases	None
SF2e	Acid because fresh milk and magnesia milk has a sour taste	*Senses	Phenomenological
SF2f	Milk is acid because it tastes sweet	Senses	Phenomenological
SF2g	Acid. Because it taste slightly sour	*Senses	Phenomenological
SF2h	Alkali because it does not taste sour	Senses	Phenomenological
SF4a	Milk tastes sweet but sweet is not alkali or acidic.(unsure)	Senses	Phenomenological
SF4b	Acid because it tastes sour	*Senses	Phenomenological
SF4c	Milk is a base because the taste is bitter	Senses	Phenomenological
SF4d	An acid because it turn sour when left for a while	*Senses	Phenomenological
SF4e	(A base) No idea but I know it does not show any properties of acid or neutral	properties	None
SF4f	Neutral because it is tasteless	Senses	Phenomenological
SF4g	Tasteless	Senses	Phenomenological
SF4h	A base because I always thought that a milk have magnesium and calcium in it so it has to be a base	Constituents	None
SF6a	Milk is an acid because after we drink milk and we do not brush our teeth then we will feel like sour taste so I classify milk as an acid	*Senses	Phenomenological
SF6b	Milk is to be a base because it cannot be an acid	Unsure	None
SF6c	Acid because milk will become sour when it is placed for several days	*Senses	Phenomenological
SF6d	I read somewhere before (Milk is a base because the pH is slightly above 7.)	Source reference	None
SF6e	Acid because it tastes a bit sour and if it is left too long until its expiry date . At that moment it will taste sour	*Senses	Phenomenological

SF6f	Base because as I know normally use for gastric pain. The reason we get gastric is because it is acidic right so when we drink milk which is a base it neutralises the acid and pain is reduced	Use of acids or bases	None
SF6g	Neutral but not quite sure because when it turns sour it has the acidic properties when it is normal it has base properties but it does not taste bitter. So I think it is somewhere in between.	Senses	Phenomenological
SF6h	Because I don't know .I am really not sure..	Unsure	None

Students' attributes aligned with the Phenomenological model

Student	Students' responses for vinegar	Students' attributes	Acid-base model
SF2a	The taste is sour	*Senses	Phenomenological
SF2b	Acid because it taste very sour	*Senses	Phenomenological
SF2c	Acid, because it tastes sour	*Senses	Phenomenological
SF2d	Acid, because it tastes sour	*Senses	Phenomenological
SF2e	Alkali because bitter taste or something like that	Senses	Phenomenological
SF2f	Vinegar is acid because it tastes sour	*Senses	Phenomenological
SF2g	Acid. Because it taste sour	*Senses	Phenomenological
SF2h	I have done an experiment involve vinegar it turns blue litmus paper to red so it is acidic	*Scientific test	Phenomenological
SF4a	Yes because it tastes sour	*Senses	Phenomenological
SF4b	Acid because it is sour and changes blue litmus paper to red	* Scientific test	Phenomenological
SF4c	Acid, and vinegar has a higher pH value and taste is sour	*Senses	Phenomenological
SF4d	It is an acid because it taste sour	*Senses	Phenomenological
SF4e	Vinegar is an acid because it taste sour turns blue litmus paper to red and has a pH value of 3	* Scientific test	Phenomenological
SF4f	Acid because it tastes sour	*Senses	Phenomenological
SF4g	Acid. Taste sour but I am not sure	*Senses	Phenomenological
SF4h	Acidic because it has a sour taste	*Senses	Phenomenological
SF6a	Vinegar is acid because it tastes sour	*Senses	Phenomenological
SF6b	Vinegar is acid because it tastes sour	*Senses	Phenomenological
SF6c	Acid because vinegar taste sour	*Senses	Phenomenological
SF6d	Vinegar is an acid because it tastes sour	*Senses	Phenomenological
SF6e	Vinegar tastes sour too	*Senses	Phenomenological
SF6f	Acid because it tastes sour	*Senses	Phenomenological
SF6g	Acid. It taste sour	*Senses	Phenomenological
SF6h	Acid because tastes sour	*Senses	Phenomenological

* Students' attributes aligned with the Phenomenological model

Student	Students' responses for lemon juice	Types	Acid-base model
SF2a	The taste is sour and an acid pH value is below 7	*Senses	Phenomenological
SF2b	Acid because lemon juice is taste very sour. It can turn blue litmus paper to red	*Senses	Phenomenological
SF2c	Acid, because it taste sour	*Senses	Phenomenological
SF2d	Acid because tastes sour	*Senses	Phenomenological
SF2e	Acid because lemon juice has a sour taste	*Senses	Phenomenological
SF2f	Lemon juice is acid because it tastes sour	*Senses	Phenomenological
SF2g	Acid. Because it taste sour.	*Senses	Phenomenological
SF2h	Obviously taste sour so it is an acid	*Senses	Phenomenological
SF4a	Yes because it tastes sour.	*Senses	Phenomenological
SF4b	Acid. It tastes sour	*Senses	Phenomenological
SF4c	Lemon juice is sour so it is an acid and it has lower pH value	*Senses	Phenomenological
SF4d	It is an acid because it tastes sour	*Senses	Phenomenological
SF4e	Acid because it taste sour	*Senses	Phenomenological
SF4f	It also taste sour so it is an acid	*Senses	Phenomenological
SF4g	Taste acidic	*Senses	Phenomenological
SF4h	Acidic because it has a sour taste	*Senses	Phenomenological
SF6a	It tastes sour therefore an acid	*Senses	Phenomenological
SF6b	Lemon juice is sour, therefore, it is an acid	*Senses	Phenomenological
SF6c	Sour taste but alkali properties	*Senses	Phenomenological
SF6d	Lemon juice is an acid because it tastes sour	*Senses	Phenomenological
SF6e	Lemon juice is acid because it tastes sour	*Senses	Phenomenological
SF6f	Acid because it tastes sour	*Senses	Phenomenological
SF6g	Acid. Sour taste	*Senses	Phenomenological
SF6h	Acid because taste sour	*Senses	Phenomenological

* Students' attributes aligned with the Phenomenological model

Student	Students' responses for soap	Types	Acid-base model
SF2a	Alkali because bitter and slippery pH value is more than 7	*Senses pH	Phenomenological None
SF2b	Alkali because soap is bitter	*Senses	Phenomenological
SF2c	Alkali, feel soapy	*Senses	Phenomenological
SF2d	Alkali, it is slippery	*Senses	Phenomenological
SF2e	Alkali because wet soap responds to the litmus paper by changing it to blue	*Scientific test	Phenomenological
SF2f	Soap is a base because it is bitter	*Senses	Phenomenological
SF2g	Use the litmus paper turn to blue	*Scientific test	Phenomenological
SF2h	Soap can produce bubbles and it is slippery when we step on it so it is alkali	*Senses	Phenomenological
SF4a	Soap is a base because it is slippery	*Senses	Phenomenological
SF4b	Base because it is slippery	*Senses	Phenomenological
SF4c	Base, it has higher pH value	pH value	Arrhenius
SF4d	It is a base because it is slippery	*Senses	Phenomenological
SF4e	A base because it taste bitter	*Senses	Phenomenological
SF4f	A base because it is slippery	*Senses	Phenomenological
SF4g	Base because it is slippery	*Senses	Phenomenological
SF4h	Base because it gives a cleaning effect	Use of acids or bases	None
SF6a	A base because they are slippery	*Senses	Phenomenological
SF6b	Soap is a base because if it an acid it will corrode our skin	Physical strength	None
SF6c	Base, wash the dirt away	*Senses	Phenomenological
SF6d	Soap is a base because it tastes bitter	*Senses	Phenomenological
SF6e	Soap is a base because it is slippery	*Senses	Phenomenological
SF6f	Base is slippery and basic properties of alkali are slippery. Normally they use alkali for cleanser	*Senses Use of acids or bases	Phenomenological
SF6g	Taste bitter, higher pH value than 7	*Senses pH	Phenomenological, None
SF6h	Base because it is slippery	*Senses	Phenomenological

*Students' attributes aligned with the Phenomenological model

Studen t	Students' responses for floor cleaner	Types	Acid-base model
SF2a	From knowledge, alkali pH value is more than 7	pH	None
SF2b	Alkali taste bitter. Some of the family use it can make the floor more cleaner	*Senses	Phenomenological
SF2c	Alkali ,because it feel soapy	*Senses	Phenomenological
SF2d	Alkali, it is slippery	*Senses	Phenomenological
SF2e	Neutral but I am not sure why it is neutral	Unsure	none
SF2f	Floor cleaner is an acid because it tastes sour	Senses	Phenomenological
SF2g	Alkali. Because it is similar as soap	*Senses	Phenomenological
SF2h	Same as soap which can produce bubbles and it is slippery when we step on it so it is alkali	*Senses	Phenomenological
SF4a	Shampoo is a base because things that cleans are bases	Use of acids or bases	None
SF4b	Base because some are slippery but not all floor cleaner are base . because not all are slippery	*Senses	Phenomenological
SF4c	Base, pH value is higher because mostly it does not burn the floor so we can use a base	Use of acids or bases	None
SF4d	An acid because it is used to kill microorganism	Use of acids or bases	None
SF4e	Floor cleaner is a base because kotoran yang di lantai (dirt spots on the floor) shows the properties of acid so when we put an alkaline to wipe it, it will neutralise and become neutral	*Neutralise	Arrhenius
SF4f	A base because it is slippery	*Senses	Phenomenological
SF4g	Base because it is slippery	*Senses	Phenomenological
SF4h	Base because it gives a cleaning effect	Use of acids or bases	None
SF6a	A base because they are slippery	*Senses	Phenomenological
SF6b	A base but not sure why	Unsure	None
SF6c	A base, remove oil stain	Use of acids or bases	None
SF6d	Floor cleaner is a base because it is bitter	*Senses	Phenomenological
SF6e	It is also a base because it is slippery	*Senses	Phenomenological
SF6f	Base because it is slippery	*Senses	Phenomenological
SF6g	Base. Higher pH value than 7	pH value	Arrhenius
SF6h	Base because it is slippery	*Senses	Phenomenological

*Students' attributes aligned with the Phenomenological model or Arrhenius model

Student	Students' responses for baking soda	Types	Acid-base model
SF2a	Acid pH value is below than 7 and think it is just an acid	pH	Arrhenius
SF2b	Alkali, it can changes colour from red litmus paper to blue	*Scientific test	Phenomenological
SF2c	Alkali but not sure	Unsure	None
SF2d	Alkali but not sure	Unsure	None
SF2e	I am not sure	Unsure	None
SF2f	Not alkali or acid but tasteless	Senses	Phenomenological
SF2g	I don't know	Unsure	None
SF2h	I am not so sure about this but I think when use in cake never hurt us or die so it is an alkali	Unsure	None
SF4a	Not sure	Unsure	None
SF4b	Acid because it tastes sour	Senses	Phenomenological
SF4c	Acid, because baking soda is a carbonate the pH value is lower	pH value	Arrhenius
SF4d	A base because it tastes bitter. Baking soda is the one that we used to make cookies and I have tasted it before	*Senses	Phenomenological
SF4e	I have no idea	Unsure	None
SF4f	I have no idea but maybe a base because I do not think baking soda solution is sour	*Senses	Phenomenological
SF4g	Not sure because I don't think it is an acid because it is baking soda	Unsure	None
SF4h	No but I only guess it tastes bitter	Unsure	None
SF6a	Sweet I think is acidic because after we taste sweet and did not brush our teeth it will taste sour	Senses	Phenomenological
SF6b	I don't think so it is an acid but not sure why	Senses	Phenomenological
SF6c	A soda is a form of a base	Constituents	None
SF6d	A base because it contains basic substances.	Constituents	None
SF6e	Baking soda is acidic because it gives out hydrogen gas and so bread gets larger	Senses	Phenomenological
SF6f	Not sure	Unsure	None
SF6g	Acid because lower pH	pH value	Arrhenius
SF6h	I am not sure	Unsure	None

*Students' attributes aligned with the Phenomenological model

Student	Students' responses for soda drinks	Types	Acid-base model
SF2a	Acid pH value is below than 7	pH	None
SF2b	Alkali. Soda drinks have some salty taste	Senses	Phenomenological
SF2c	Acid , but not sure	Unsure	None
SF2d	The newspaper stated	Source reference	None
SF2e	Alkali but not sure why	Unsure	None
SF2f	Soda is sweet so it is an acid	Senses	Phenomenological
SF2g	Acid. Because I have experiment before	Scientific test	Phenomenological
SF2h	Bila kita minum tekak kita rasa macam sakit (When we drink our throat feels a little pain) so it is an acid	Physical strength	None
SF4a	Acid. It tastes sour	*Senses	Phenomenological
SF4b	Acid. It tastes sour	*Senses	Phenomenological
SF4c	Yes because soda is a complete drink with water, soda and other things	Unsure	None
SF4d	It is not sour so it is a base	Senses	Phenomenological
SF4e	I think it is a base because it does not show the properties of acid however,I am not sure	Macroscopic properties	None
SF4f	Acid because it tastes sour	*Senses	Phenomenological
SF4g	Acidic because it has a gas	Senses	Phenomenological
SF4h	Yes but because it is carbonated so I think it is a base	Constituents	None
SF6a	Soda drinks are carbonated drinks and I think there is carbon dioxide so it is acidic	Constituents	None
SF6b	Soda drinks are acids because if drink more soda drinks will corrode our teeth. Soda drinks are weak acids	Physical strength	None
SF6c	Soda drinks are acids because contain carbonic acid	Constituents	None
SF6d	Soda drinks are acids because it contains acid.	Constituents	None
SF6e	Soda drinks are bases but I am not sure why it is a base	Unsure	None
SF6f	Acid because got carbon dioxide which is acidic	Constituents	None
SF6g	Acid. Because I just got a feeling it is an acid	Unsure	None
SF6h	No idea	Unsure	None

*Students' attributes aligned with the Phenomenological model

Student	Students' responses for water	Types	Acid-base model
SF2a	Neutral because pH 7	pH value	None
SF2b	Neutral because it is tasteless. It does not change any colour between the red litmus paper and blue litmus paper	*Senses	Phenomenological
SF2c	Neutral because tasteless	*Senses	Phenomenological
SF2d	Neutral, because tasteless	*Senses	Phenomenological
SF2e	Neutral does not respond to litmus paper	*Scientific test	Phenomenological
SF2f	Neutral because tasteless	*Senses	Phenomenological
SF2g	Neutral. Because it is tasteless, colourless, and odourless	*Senses	Phenomenological
SF2h	Water is neutral because it has pH value of 7	pH value	None
SF4a	Water is neutral because it is tasteless	*Senses	Phenomenological
SF4b	Neutral because it is tasteless	*Senses	Phenomenological
SF4c	Neutral …Water is tasteless and water doesn't change any litmus paper colour	*Senses	Phenomenological
SF4d	(Water is neutral) It does not show any acidic or basic properties such as corrosive, sour or bitter	Macroscopic properties	None
SF4e	It is tasteless and tasteless is neutral	*Senses	Phenomenological
SF4f	Water is tasteless with pH 7 so neutral	*Senses	Phenomenological
SF4g	Neutral because tasteless	*Senses	Phenomenological
SF4h	I put it as neutral because it is tasteless	*Senses	Phenomenological
SF6a	Water is neutral because no change in colour of litmus paper	Scientific test	Phenomenological
SF6b	Don't have any taste so neutral	Senses	Phenomenological
SF6c	Neutral because water is under the specify, neutral	Macroscopic properties	Phenomenological
SF6d	Water is neutral because it is tasteless	Senses	Phenomenological
SF6e	Water is neutral if it is pure water without any Fluorine ions	Sub-microscopic	None
SF6f	Neutral because it is tasteless	Senses	Phenomenological
SF6g	Neutral. Because does not react with litmus paper and then the pH value is 7	Scientific test	Phenomenological
SF6h	When acid-base combine they form salt and water so I think water is neutral	Reaction	Arrhenius

Students' attributes aligned with the Phenomenological model or Arrhenius model for Form 2 and Four because the Brønsted-Lowry model is not taught at this two schooling levels

Student	Students' responses for sodium hydroxide (NaOH)	Types	Acid-base model
SF2a	Alkali pH value is more than 7	pH	None
SF2b	Alkali. It can change colour from red litmus paper to blue but not sure	*Scientific test	Phenomenological
SF2c	Alkali, because of sodium which is alkali	Constituent s	None
SF2d	An alkali because it is slippery and corrosive	*Senses	Phenomenological
SF2e	Not sure	Unsure	None
SF2f	It is salty so it is an acid	Senses	Phenomenological
SF2g	Don't know	Unsure	None
SF2h	Acid because when it is concentrated it can hurt us	Physical strength	Phenomenological
SF4a	It is a base because it contains hydroxide ions when dissolved in water	*Hydrogen and hydroxide	Arrhenius
SF4b	Base because changes colourless phenolphthalein to pink	*Scientific test	Phenomenological
SF4c	Acid, sodium mostly is acidic	Constituent s	None
SF4d	I think it is a base but not sure	Unsure	None
SF4e	No no NaOH is a base because it shows properties of hydroxide ions	*Hydrogen and hydroxide	Arrhenius
SF4f	A base because produce hydroxide ions	*Hydrogen and hydroxide	Arrhenius
SF4g	Base because there is presence of hydroxide ions	*Hydrogen and hydroxide	Arrhenius
SF4h	It is a base because it contains hydroxide ions	*Hydrogen and hydroxide	Arrhenius
SF6a	NaOH is a base because got OH- ions	*Hydrogen and hydroxide	Arrhenius
SF6b	It is a strong alkali so it is a base	Properties of acids and bases	Arrhenius
SF6c	Alkali because the pH value is 8 to 14 and sodium is alkali	pH value	None
SF6d	NaOH is a base because it contains OH- ions	*Hydrogen and hydroxide	Arrhenius
SF6e	NaOH is a base because normally use in titration with hydrochloric acid and it acts as strong base(When NaOH is put in the	*Scientific test	Phenomenological

	red litmus paper it will turn blue)		
SF6f	Base because it has hydroxyl group that dissociates in water to produce OH- ions	*Hydrogen and hydroxide	Arrhenius
SF6g	Base because have higher pH value, presence of OH	*Hydrogen and hydroxide	Arrhenius
SF6h	Base because presence of OH-	*Hydrogen and hydroxide	Arrhenius

*Students' attributes aligned with the Phenomenological model or Arrhenius model

Student	Students' responses for hydrochloric acid (HCl)	Types	Acid-base model
SF2a	Acid. Acid pH value is below 7	pH value	None
SF2b	It has also taste like sour acid	*Senses	Phenomenological
SF2c	Acid, because there is acid in hydrochloric acid (unsure)	Unsure	None
SF2d	Acid.(it is corrosive)	Physical strength	None
SF2e	Not sure	Unsure	None
SF2f	Acid because the name is acid (unsure)	Unsure	None
SF2g	Acid because it has acid in the name (unsure)	Unsure	None
SF2h	Acid because if it is too concentrate it can hurt us	Physical strength	None
SF4a	An acid because when dissolve in water produces hydrogen ions in water	*Hydrogen and hydroxide	Arrhenius
SF4b	Acid because it changes blue litmus paper to red	*Scientific test	Phenomenological
SF4c	Acid, because when we do experiment HCl may spill on our skin and we feel itchy	*Senses	Phenomenological
SF4d	An acid but I am not sure the reason why it is an acid	Unsure	None
SF4e	It is an acid .It is a strong acid because it ionize hydrogen ion completely in water	*Hydrogen and hydroxide	Arrhenius
SF4f	Acid because it produce hydrogen gas	Reaction	None
SF4g	Acid because presence of hydrogen ions	*Hydrogen and hydroxide	Arrhenius
SF4h	Acid because it contains hydrogen ions	*Hydrogen and hydroxide	Arrhenius
SF6a	This is an acid because got hydrogen ions	*Hydrogen and hydroxide	Arrhenius
SF6b	Strong acid because knowledge	Source reference	None
SF6c	HCl is a strong acid with the presence of H^+ ions	*Hydrogen and hydroxide	Arrhenius
SF6d	HCl is an acid because it contains hydrogen ions	*Hydrogen and hydroxide	Arrhenius
SF6e	Hydrochloric acid is acidic because it is very corrosive in concentrated form and it turns blue litmus paper to red	*Scientific test	Phenomenological

SF6f	Acid because it dissociates with water to produce H^+ ions	*Hydrogen and hydroxide	Arrhenius
SF6g	Acid because lower pH value	pH value	none
SF6h	Acid because presence of H^+ ions	*Hydrogen and hydroxide	Arrhenius

*Students' attributes aligned with the Phenomenological model or Arrhenius model

Students	Students' responses for ethanoate ions (CH_3COO^-)	Types	Acid-base model
SF6a	I know CH_3COOH is an acid but I am not sure of CH_3COO^-	Unsure	Arrhenius
SF6b	Neutral because it does not have the H+ ions and it is an ion	Hydrogen ions	Arrhenius
SF6c	I think because of carbon or oxygen that makes it a weak acid	Carbon or/and oxygen	None
SF6d	CH_3COO^- is neutral because ethanoate does not contain H^+ ions	Hydrogen ions	Arrhenius
SF6e	(Acid) Because I think hydrogen ions will be present because of the CH_3	Hydrogen ions	Arrhenius
SF6f	Acid because it is a weak acid which produces H^+ when dissociate with water	Hydrogen ions	Arrhenius
SF6g	Acid because presence of COO- but not sure	Carbon or/and oxygen	None
SF6h	Other but not sure	Unsure	None

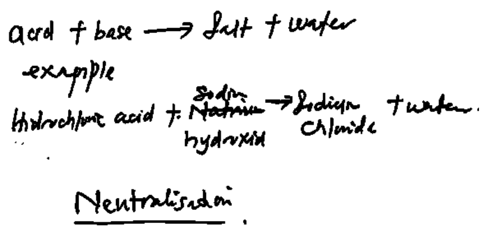
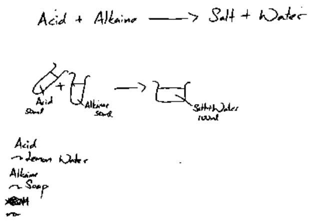
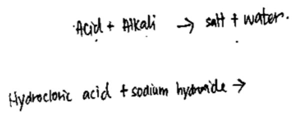
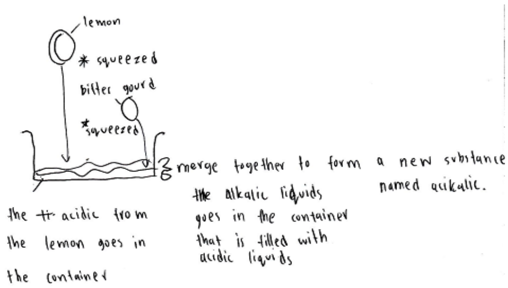
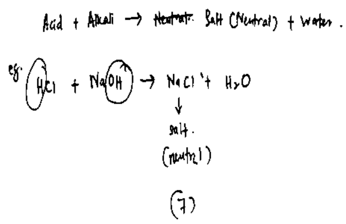
Student	Students' responses for carbon dioxide (CO_2)	Types	Acid-base model
SF6a	Acidic because it turns lime water to chalky or milky	Scientific test	Phenomenological
SF6b	Not sure	Unsure	None
SF6c	An acid because when <u>I read from the book</u>, if there is a high level of $C0_2$ content in blood will cause the blood to become more acidic	Source reference	None
SF6d	It is an acid because it can react with base.	Reaction	Arrhenius
SF6e	CO_2 is an acidic because it is able to turn lime water to cloudy.	Scientific test	Phenomenological
SF6f	Acid because normally it changes lime water cloudy and then litmus paper change to red	Scientific test	Phenomenological
SF6g	Not sure	Unsure	None
SF6h	Other but not sure	Unsure	None

APPENDIX I

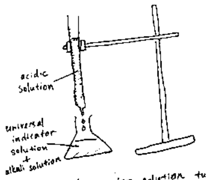
Selected Learning Outcomes of Teachers' and Students' Mental Models for Form 2

Teacher/ Student	**Responses for *identify the properties of acids, and alkalis* learning outcome**
TF2a	Sour taste/ bitter taste, change colour blue litmus paper to red, change colour red litmus paper to blue show the properties only with presence of water pH value 1-6 – acid pH value 8-14 – alkali
SF2a	For acid below pH 7, corrosive, turns lime water chalky, can find out in CO_2
SF2b	I have no idea
SF2d	Acids are corrosive, pH value from 1 to 6 and tastes sour. Alkaline slippery, corrosive , pH value from 8 to 14, tastes bitter
SF2e	Acidic sour in taste, litmus paper turns to red, consists of lemon, orange. Alkali bitter in taste litmus paper turns to blue consists of bitter gourd, toothpaste
TF2b	Not sure because I have forgotten
SF2c	Acid less than pH 7, sour, corrosive, blue litmus paper to change red. Alkali more than pH 7 bitter, soapy, red litmus paper change to blue
SF2f	Acidic sour in taste, litmus paper turns to red, consists of lemon, orange. Alkali bitter in taste litmus paper turns to blue consists at bitter gourd, toothpaste
SF2g	Acid, battery, milk, tomato, carbon dioxide. Alkali, soap, toothpaste, milk of magnesia, bitter gourd, and lime water. Acid is sour and corrosive and alkali taste bitter
SF2h	Acid tastes sour, turn blue litmus paper to red, pH value less than 7. Base taste bitter, turn red litmus paper to blue and pH value more than 7

Teacher/ Student	**Responses for *explain the meaning of Neutralisation learning outcome***
TF2a	(Neutralisation) It is the process to neutralise the acidic properties and basic properties to become neutral. That means acid lost its acidic and alkali lost its alkali properties. …The properties disappear because it has been neutralised …pH form is 7 which is neutral … produce sodium chloride and water which are both neutral
SF2a	Because its (neutralisation) combine acid and alkali and change the properties …pH 7 (is the pH of neutralisation)
SF2b	… pH is 7 because water is neutral Acid 50mL and alkaline 50mL and then produce salt and water for 100mL
SF2d	When an acid and an alkali are put together, it will form neutral water and acidic salt
SF2e	Merge the first part of acid that is aci and the second part of alkali called kali so acikali
TF2b	Acid and alkali produces salt which is neutral and water
SF2c	SF2c : Will produce salt and water Res : What do you call the name of this reaction? SF2c : Neutralisation …pH 7 (is pH of neutralisation)
SF2f	(Neutralisation) It is tasteless because acid is a harmful substance and add with alkali will turn to normal. … the reaction produce a salty water an acid and a neutral water … pH 7 is tasteless so it neutralise … The equation is called Neutralisation
SF2g	SF2g : (an acid and a base) It became neutral Res : Do you know what the name of the something neutral? SF2g : Don’t know ….pH 7 means its neutral
SF2h	when we put an alkali and an acid together it can produce salt …which I don’t remember what is its scientific name. …Yes salt (That is the only substance it produce)

Teacher/ Student	**Responses for *write an equation in words to describe the Neutralisation process* learning outcome**
TF2a	
SF2a	
SF2b	
SF2d	
SF2e	
TF2b	
SF2c	Is there an equation for acid and alkali reaction? Maybe but not sure

<table>
<tr><td>SF2f</td><td>It will neutralize.
acid + alkali = water + salt

Sea + salt = Salty water
water</td></tr>
<tr><td>SF2g</td><td>Is there an equation?
Never learn before.

The universal indicator solution turns to green colour, after a few drops of acidic solution is added in to the universal indicator solution.</td></tr>
<tr><td>SF2h</td><td>If we put acid and alkali together,
it can produce salt.</td></tr>
</table>

Teacher/ Student	Responses for *explain through examples the uses of Neutralisation in daily life* learning outcomes
TF2a	When we are stung by insects which is acid and we use an alkaline cream so that it reduces the acidity. Shampoo we use to neutralise acidic hair.
SF2a	I forget already
SF2b	No
SF2d	Not sure
SF2e	No I have no idea
TF2b	Actually it is a type of milk (milk of magnesia) that we drink to reduce acidity of stomach
SF2c	No idea
SF2f	Alkali is toothpaste acid is the food we eat so alkali cleans our teeth
SF2g	Most of the food are acidic so we use the toothpaste and then it will become neutral
SF2h	No I don't know

Selected Learning Outcomes of Teachers' and Students' Mental Models for Form 4

Teacher/ Student	**Responses for *relating strong or weak acid with degree of dissociation* learning outcome**
TF4a	Strong acid means the acid which ionizes completely to produce higher concentration of hydrogen ions while strong bases ionize completely to produce hydroxyl ions. Weak acids partially ionize to produce hydrogen ions. So comparing strong and weak acid, weak acid has less number of hydrogen ions or less number of hydroxide ions
SF4a	More concentration of hydrogen ions will be strong acid and strong bases are substance that contains more hydroxyl ions than weak base when ionize
SF4b	Strong base ionizes completely in water to produce hydroxyl ions While weak base ionizes partially in water to produce hydroxyl ions
SF4c	Strong acid is the acid that fully dissociate in water to produce hydrogen from the solution , weak acid partially dissociate the hydrogen in water, weak base partially dissociate the hydroxide in water, and strong base fully dissociate the hydroxide from water
SF4d	Weak base can ionize hydroxyl ions partially in the water, strong base can ionize hydroxyl ions completely in water , strong acid can ionize hydrogen ions completely, weak acids is an acid that can ionize hydrogen ion partially in the water
TF4b	Strong base means it can completely ionize in water ,for example, hydrochloric acid can ionize completely in water to produce hydrogen ions. In weak acid just can ionize partially in water
SF4e	Strong acid is an acid which produce hydrogen ions completely when reacting with water. Weak acid is a substance that produces hydrogen ions partially in water. Strong alkali is a substance which produces high concentration of hydroxide ions in water. Weak alkali is a substance that produce low concentration of hydroxide ions when in water
SF4f	Strong acid is the acid with lower pH value and weak acid with higher pH value
SF4g	Strong acid is hydrochloric acid, weak acid is ethanoic acid, strong base is sodium hydroxide and weak base is CH_3COOH
SF4h	Strong acid is an acid that completely ionizes in water to produce H+ ions and weak base is a base that ionizes partially in water to produce lower amount of OH- . Strong base ionize completely in water to produce OH- ions and weak acid is an acid that ionizes partially to produce low concentration of H+ ions

Teacher/ Student	**Responses for *explanation of Neutralisation* learning outcome**
TF4a	Acid and base produce salt and water
SF4a	Neutralisation is a process where acid combine with base would produce salt and water
SF4b	Because acid and base they will neutralise when they combine so an acid and a base react they will neutralise
SF4c	pH value for neutral is 7 so when we combine acid and base it will taste neutral so pH is 7 so the pH value will be constant. It is neutral, the pH value is 7.
SF4d	Neutralisation will take place, the solution will be neutral after chemical reaction. The solution will not show any acidic or basic properties, the solution is harmless, example $NaOH + HCl \rightarrow NaCl + H_2O$, the reaction will produce salt and water the solution produce will cause no change in the litmus paper
TF4b	Teacher writes acid and base produce salt and water. If we add acid and base at the same time salt and water may not be produced. However, if we carry out titration, with a fixed volume of alkali salt and water are produce.
SF4e	Acid + Base when put together will produce salt and water $HCl + NaOH \rightarrow NaCl + H_2O$ Process is neutralisation Result: acid react with a base to form salt and water produces soluble salt that shows the properties of neutral formed a colourless salt
SF4f	When an acid and a base are reactants and it produce salt and water HCl is an acid, KOH is a base, KCl is a salt and H_2O water
SF4g	Hydrochloric acid when added with sodium hydroxide will produce sodium chloride and water
SF4h	Neutralisation will take place and it will produce salt and water. The acid is neutralised by the base and the base is neutralised by the acid to form a neutral thing

Teacher/ Student	Responses for *describing Neutralisation in daily life* learning outcome
TF4a	I am not sure. Building ,for example, corrodes because of acid rain. How do you introduce a base in a building? Base is from calcium carbonate found in cement and therefore neutralises the acid rain and lowers the acidity
SF4a	Bee sting can be acid or alkali we put acid or alkali to neutralise it so that in would not be harmful
SF4b	Bee sting is alkaline so can use acidic like vinegar to reduce the alkali
SF4c	We can use toothpaste to neutralise the bee sting
SF4d	When the bee bites, there will be pain because bee stings have acids. We can use toothpaste and cover it There will be a cold sensation so the pain will be reduced as the acid is reduced or neutralise by the toothpaste
TF4b	I am sorry I could not remember
SF4e	Lantai berhabuk ader properties of acid apabila kita gunakan alkaline dia kan neutralise asid dan alkaline to jadi benda neutral (The floor when dirty will form acids and when we use alkaline it will neutralise acid and be neutral)
SF4f	Like a toothpaste is a base and our mouth will produce the acid so we need to brush our teeth with toothpaste
SF4g	There is a lot but I don't know
SF4h	Like toothpaste in our mouth will be bacteria, bacteria digest the decompose things in our food and will produce acid then the toothpaste would neutralise it so that our tooth will not corrode

Teacher/ Student	**Responses for *describing acid-base titration* learning outcome**
TF4a	pH value of hydrochloric acid will change. The pH value may be from 3 changes to 6
SF4a	I have not done this experiment so I do not know
SF4b	We can test it and see if the salt can dissolve in water
SF4c	Firstly pour HCl into test tube filled with NaOH and test with litmus paper… Pour the mixed solution into a beaker and use pH meter to measure the pH value. And we plot the pH meter in a graph will become value 1
SF4d	My idea put a clipper to hold the litmus paper (in a beaker)
TF4b	The amount of NaOH is 10.0mLbecause the molarity is the same. To carry out this experiment I think we need to use titration. We need to use a burette added with 50.0 mL of acid HCl. Sorry not HCl but NaOH because the volume of hydrochloric acid is already fixed at 10.0 mL. In the conical flask we add 10.0mL of 0.1mol dm^{-3} of HCl and we titrate. When the amount of NaOH is 10.0 mL the solution becomes neutral.
SF4e	Acid which is put in the burette containing 10mL of 0.1mol L^{-1} HCl when reacted with 10mL of 0.1mol L^{-1} of NaOH will form sodium chloride and water in the solution. We want to test the sodium chloride because water is obviously neutral so to separate the sodium chloride we need to use filtration because sodium chloride exist as a solid in a room temperature so when we filtrate the solid will be trapped in the filter paper while water will pass through it to the solution so this sodium chloride be put into a petri dish and will pour some water so that it will be in molten or in aqueous solution so when this happen we try to use a red and blue litmus paper to see if it is acidic or alkali properties when we test it surely it would not change red or blue litmus paper and be neutral
SF4f	Because before we add the sodium hydroxide the contain in the beaker is only hydrochloric acid so it is a smaller value in pH and then when we added sodium hydroxide, the pH value increases and becomes neutral
SF4g	In the test tube we pour NaOH to HCl then use litmus paper to test … I will put litmus paper and check at 30 seconds interval … I think I will put two types of litmus paper but somehow I think this experiment is not suitable. maybe I would use titration but no not titration I am confuse, confuse
SF4h	It is a titration method that you have to put the amount of acid you want in the conical flask then you have to titrate the sodium hydroxide drop by drop into the acid until the indicator turns into another colour and for phenolphthalein it will which will be colourless in acid and neutral solution it will be pinkish also in the alkali solution

Selected Learning Outcomes of Teachers' and Students' Mental Models for Form 6

Teacher/ Student	**Responses for *use of Arrhenius, Brønsted-Lowry, and Lewis models to explain acids and bases* learning outcome**
TF6a	QC6 1. HCl acts as a source of hydrogen ions sodium hydroxide acts a s a source of OH- ions which is Arrhenius theory QC6 2.This second one is the Brønsted- Lowry's concept where NH_3 is a base because it is a proton acceptor while H_2O is a proton donor so it donates a proton acid NH_4^+ is a conjugate acid and OH^- is a conjugate base. This is a Brønsted-Lowry's theory QC6 3.This is Lewis acid and Lewis base where Lewis acid is a lone pair electron acceptor while Lewis base is a lone pair electron donor. Res : What is NH_3? TF6a : NH_3 is a lewis base (lone pair electron donor) Res : What is BH_3? TF6a : Lewis acid (lone pair electron acceptor)
SF6a	QC6 1.HCl has H^+, NaOH has OH^- ,H_2O test with litmus paper and get pH 7 and NaCl not sure QC6 2.NH_3 is a weak bases, H_2O neutral, NH_4^+ not sure and OH^- is bases QC6 3.BH_3 is acidic because got H^+, NH_3 is alkali and NH_3BH_3 neutral
SF6b	QC6 1.HCl is an acid, NaOH a base, H_2O neutral and NaCl not sure. QC6 2.NH_3 alkali, H_2O neutral, NH_4^+ neutral and OH^- alkali QC6 3.BH_3 not sure, NH_3 alkali H_3BNH_3 is alkali
SF6c	QC6 1.HCl is acid NaOH is a base Res : Why are they acid or a base? SF6c : Presence of hydrogen ions in acids and hydroxide ions in a base QC6 2.NH_3 a base, H_2O neutral, NH_4^+ a base, OH^- alkali QC6 3.BH_3 not sure, NH_3 base H_3BNH_3 not sure

SF6d	QC6 1.HCl is acid, NaOH is base NaCl and H_2O are neutral Res : Why do you say HCl is an acid? SF6d : Because it has H^+ ions. Res :How about NaOH SF6d : It has the OH- ions QC6 2. SF6d : NH_3 is accepting proton from H_2O which is an acid that donates proton to NH_3 Res : How about NH_4^+ and OH^-? SF6d : Both of them are neutral I am not sure for this equation. I think BH_3 is an acid because there is another theory which said that donate electron pair is acid but not sure. QC6 3.What do you think about NH_3? SF6d: It is a base because NH_3 is accepting the electron pair, therefore, a base. Res : Where is NH_3 accepting the electron from? SF6d : BH_3
TF6b	QC6 1.HCl is acid NaOH is a base NaCl and H_2O are neutral. According to Arrhenius that any substances that dissociate and forms hydrogen ions are called acids while any substance that dissociates to form hydroxyl ions are called bases. NaCl and H_2O are neutral QC6 2.According to … the second person I forgotten already, this is a species that donates a proton and become a conjugate acid Res : What species donates proton? TF6b: Water donates to the ammonia, so ammonia receive the proton to become a base and the species that donates a proton becomes an acid now ammonium ions donate a proton to become an acid while OH- receives a proton to become water which is a base QC6 3.This receives a pair of electron is an acid? Res : In this question which is an acid or a base? TF6b: BH_3 is an acid; NH_3 is a base H_3BNH_3 is neutral. This is because NH_3 donates a pair of electron to Boron so NH_3 is a base and BH_3 an acid is according to the Lewis a species that donates electron is called a base and species that accepts electron is called an acid.
SF6e	QC6 1.HCl is a strong acid, NaOH is a strong base, NaCl and H_2O is neutral QC6 2.NH_3 is bases because it ionizes in water to produce hydroxyl ions in the equation H_2O is neutral, NH_4^+ are bases and OH^- is alkaline. QC6 3.Not sure
SF6f	QC6 1.HCl is acidic NaOH is a base NaCl is neutral and H2O is neutral QC6 2.NH_3 is acidic, H_2O is neutral, NH_4^+ is acidic OH^- is a base QC6 3.BH_3 is acidic , NH_3 is acidic, H_3BNH_3 is acidic

SF6g	QC6 1.HCl is acid, NaOH is a base, NaCl is a salt and H2O is neutral QC6 2.NH_3 is acidic H_2O is neutral NH_4^+ acidic OH^- is a base QC6 3.Not sure
SF6h	QC6 1.Acid is HCl, Base is NaOH neutral is NaCl and H_2O QC6 2.Acid is NH_3, neutral is H_2O, base is NH_4^+ and OH^- QC6 3.Acid is BH_3 and NH_3 and H_3BNH_3

Teacher/ Student	**Responses for *explain changes in pH during acid-base titration* learning outcome**
TF6a	CH_3COOH dissociates partially in water to produce low concentration of H^+ ions. The pH is quite high but lower than 7. When sodium hydroxide is added the OH^- ions reacts with the H^+ ions causing a gradual increase in pH because the OH^- ions neutralises the H^+ ions in the acid. When more OH^- ions are reacted with hydrogen ions the pH increased gradually. When 10.0mL of sodium hydroxide is added, there is a sharp increase because all the H^+ ions have been neutralised by the OH^- ions. NaOH is a strong base so at the the equivalence point the pH that is more conducive for the base indicating a pH 8 to pH 10 of the final solution.
SF6a	The reason and method is the same as 7a but the reaction maybe reverse because the acid is a weak acid Res : Is there a difference between two signs? SF6a : Yes there is, maybe after reaction it may be back to the like its normal reactants but for the one way arrow it means it would not change back to the original Res : What happens to the pH? SF6a : Initially the pH maybe around 4 to 6 after added the NaOH will increase until pH 7 Res : What happens when you add more NaOH? SF6a : If excess NaOH, will confirm reach above 7
SF6b	What I think is same ethanoic acid is weak acid so maybe the time or the volume use by the NaOH will less compared to the neutralise the hydrochloric acid ethanoic acid is a weak acid so it is near the pH 7 so I think less volume and less time needed to neutralise Res : So is there a change in pH? SF6b : Maybe earlier the pH is 5 or 4 then after neutral when the pink colour turn colourless so they will be 7 and when continue adding will become alkali and the colour will turn pink back
SF6c	Student drew a graph, the graph has two axis, one for the acid and one for the alkaline. SF6c : Sodium hydroxide is a strong base and the CH_3COOH is a weak acid so the neutralisation may be difficult to happen because strong base Res : Do you think the reaction can take place or not? SF6c : I think can but very slow reaction
SF6d	The initial pH is higher because the ethanoic acid is a weak acid then it will neutralise and the pH will also rise. I think the pH will rise faster than the question before because ethanoic acid is a weak acid. Res : How is it that ethanoic acid will make the pH rise faster? SF6d : Because it is a weak acid and when a strong base is added the change will be very big so the change will be faster Res : What will the used volume of NaOH? SF6d : The volume is 10.0mL because the ethanoic acid contains equal amount of hydrogen ions. Res : How do you know that ethanoic acid contains equal amount of hydrogen ions? SF6d : Yes ethanoic acid contains one mole of hydrogen ions and the sodium hydroxide also contains one mole of hydroxide ions. Therefore, the volume is 10.0mL

TF6b	This is a weak acid. So the weak acid concentration….I mean the dissociation of the weak acid is not 100 percent so the hydrogen ions is less so the pH –log concentration so the pH is more than 1 maybe 2 or 3 same thing also so pH increase gradually but not start from 1 but start from 3 and then will change about pH 7 and the end point is around 8 to 10
SF6e	SF6e : The difference is when the 10mL of NaOH is added to HCl the salt formed will be pH 7 while when 10mL of NaOH is added to ethanoic acid, the salt formed is more than pH 7 Res : Why do you think so? SF6e : Strong base react with weak acid will form a salt which is slightly more to alkaline because the concentration of NaOH is high but hydrogen formed by the ethanoic acid is lower. Therefore the hydroxyl ions be more and then it shows base.
SF6f	Acid is poured into the burette and base is in the conical flask. The indicator changes to colourless and neutralise after sufficient amount of acid and base for neutralisation Res : Is there a difference between question Card 7b and 7a? SF6f : Yes acid is weak acid Res : So what difference do you think it will make? SF6f : Weak acid and strong base maybe will make more acid to neutralise Res : Why do you think it will be more acid? SF6f : Because less hydrogen ions produce need more hydrogen to neutralise so more amount CH_3COOH needed to produce water Res : What about the pH? SF6f : pH is 7 Res : Why do you think the pH is 7? SF6f : This is a neutralisation process so the pH is 7 Res : Do you think all neutralisation will have a pH of 7? SF6f : Yes Res : Do you think there is a particular reason that it has to be a pH 7? SF6f : Because it neutralises so it is a pH 7
SF6g	Res : What is the difference between 7a and 7b? SF6g : 7a not reversible Res : Any other differences? SF6g : In 7a we use hydrochloric acid and now is ethanoic acid Res : What is the difference between the two acids? SF6g : Presence of COO^-
SF6h	SF6h : The amount of H^+ ions produced is not equal with the amount of OH^- produced in sodium hydroxide Res : If it is not equal then, what happens? SF6h : The solution cannot be neutralised

Teacher/ Student	**Responses for *define buffer solution* learning outcome**
TF6a	An acid buffer is a mixture made up of a weak acid and its salt which resists slight changes in pH when a small amount of strong acid or alkali is added and vice versa for a base buffer
SF6a	A buffer is a solution that when a small amount of acid or base is added the solution produced is a buffer
SF6b	I learnt before but I forgot but I think a buffer is a combination of an acid and a base
SF6c	Buffer is a reaction to either increase or decrease the acidity
SF6d	Yes something that can resist a pH change
TF6b	Contains a weak acid if it is an acidic buffer solution and its salt. If a basic buffer then contains a weak base and its salt and if there is a strong base added the pH will not change much
SF6e	Buffer is buffer is no sorry I cannot remember
SF6f	Not really
SF6g	Cannot remember
SF6h	Buffer is a solution that contains salt and acid but if we add alkali the pH will not change much