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Students' Mental Models of Chemical Reactions

A thesis

submitted in fulfilment

of the requirements for the Degree

of

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at

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by

DENIS ANDREW D. LAJIUM



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Abstract

Previous research on topics such as atomic structure and chemical bonding indicates that students' mental models are often inconsistent with the scientific models, which may impede learning of advanced concepts. International research suggests that model-based teaching and learning in science education shows promise in overcoming student misconceptions, but research about modelling for chemical reactions is sparse. In an attempt to redress this schism, this study took the form of an inquiry into a cross-age study of 67 students drawn from secondary schools and universities, to investigate their mental models of chemical reactions. This naturalistic qualitative inquiry was based within an interpretive paradigm and constructivist epistemology, in which data were generated from interviews with the participants. The data for this inquiry were derived from semi-structured interviews, incorporating the Interview-About-Instances (I.A.I) technique to probe students' mental models of chemical reactions for various chemical phenomena.

Thematic analysis of the students' discourse of their mental models revealed different types of mental models; named Model A, B, and C. Each of the mental models was characterised based on features of energy change and the process of chemical reactions at the submicro level. Model A was considered as an initial mental model, which was based on students' experience with changes of matter in their daily life. This model was also attributed with the notion of agent driven chemical change as its core characteristic. Basically, Model A explained most of the properties of chemical reactions, including the rate, spontaneity and reversibility of reactions. Although, it can be considered a 'causality model,' it seemed essential for young students in making sense of the chemical phenomena that surround them. On the other hand, Model B was based on either the attributes related to kinetic theory of particles or attributes related to chemical bonding but this type of mental models seemed to share some characteristics of Model A. However, Model C was likely to incorporate the attributes related to both kinetic theory of particles and chemical bonding as core ideas used in explaining chemical reactions. Students' preference towards a

given model in their mental models is consistent with previous studies. This preference is probably because of their early exposure to the kinetic theory, and it is simplistic but powerful in explaining the nature of chemical phenomena. Nonetheless, the model of chemical bonding was considered an 'enabling' model for understanding of the chemical phenomena in terms of rearrangement of atoms and as an affordance to make sense of energy change.

Students' mental models were also compared according to their level of education. Generally, most senior university students were found to hold Model C. While junior university and Form 6 students' mental models were mostly Model B, and all secondary school students' mental models were Model A. It seemed then that the more exposed the students are to formal education in chemistry, the more consistent their mental model become with the scientific view. Although students' mental models were categorised in such a manner, all of the mental models shared common attributes, such as the role of reacting agents in reaction spontaneity, energy as a part of reactions, and irreversibility presumptions. This finding indicates that students' initial mental models were not 'erased' but rather coexisted with the advanced mental models, which were developed through formal education. This relationship is similar to how science operates, where superseded models co-exist with more sophisticated models and are still used for practical purposes although scientists are aware of an old model's limitations and discrepancies.

A general conclusion that can be drawn from this study is that, students' mental models were found to be lacking in attributes that relate to scientific ideas such as particle model, particle collisions, activation energy, and entropy, despite being introduced with these ideas in their formal learning. Therefore, it is recommended that students should be engaged in developing their mental models that enables them to link between macro and submicro levels, through modelling approach of instruction that emphasises the understanding, application, and construction of models.

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Denis Lajium
Hamilton, New Zealand

Dedication

To my beloved family, Anne, Ira, and Ian,
to my mother Helen Lo Nyet Yin, and late father David Lajium for their
unconditional love and sacrifices.

*Kotouhadan kou ngavi. Au zou koponingadan tohuod diozu, nga Kinohoingan
dati.*

(Thank you to all. I may not be able to repay your kindness but God will.)

Publications Arising from this Thesis

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If you understand inflation, a mathematical proof, the way a computer works, DNA or a divorce, then you have a mental representation that serves as a model of an entity in much the same way as, say, a clock functions as a model of the earth's rotation.

Johnson-Laird (1983, p. 2)

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Chapter 1 Introduction

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This chapter provides an introduction to the thesis. It begins with a narrative about the background that prompted the inquiry. This is followed by the purpose, nature, and underlying assumptions of the study. The chapter also provides an account of science education in Malaysia, which is the context for the study and justification for the inquiry. It concludes with a discussion of the rationale and significance of this research study.

1.1 Background of the Inquiry

Humans have sought knowledge concerning chemical reactions, perhaps since their existence. For example, we can argue that Palaeolithic humans learned chemistry when they discovered and mastered the use of fire in their daily life activities (Cobb & Goldwhite, 1995). Even if one fails to accept that early humans were ‘chemists,’ from prehistoric times humans have acquired knowledge about manipulating substances for their survival in activities such as pottery, development of antiseptics, preservation, painting, and, unfortunately, for weaponry. Despite this long period of experience with chemical changes, detailed understanding of chemical reactions largely remained a mystery until the 20th century, when scientists came to view the nature of matter in terms of particles (Leicester, 1965).

Learning science, particularly chemistry, is more than just developing a model for atoms, and the literature suggests that students struggle to understand many

scientific concepts resulting in much research by science educators to help students learn (Duit, 2009; Vosniadou, 2012). This difficulty in learning science is echoed in my own experiences when introducing organic synthesis to my university students; I soon realised that there were two issues I faced. Firstly, it seemed that many of my students were unable to relate the fundamental ideas learnt in thermodynamics and kinetics from previous chemistry courses, including during university study and pre-university, to organic synthesis. When I mentioned terms like thermodynamics and kinetics (which are essential for the understanding of organic synthesis), they seemed confused and were not able to draw upon this prior knowledge, for example, to predict the major product in an organic synthesis reaction. Some asked, “why is the more stable product produced in lesser quantities than the other products?” while others queried, “are nucleophiles not the same as a base?” Second, when trying to answer such questions, I realised that although I have been teaching chemistry since the beginning of my career as a lecturer, I myself did not actually fully understand why chemical reactions occur (I have since resolved this through reading, and teaching an organic synthesis course!). These questions, along with my reflection on my teaching, suggested that my students and I somehow ‘got through’ our chemistry education (often with good grades!), even though we did not fully understand that thermodynamics and kinetics are actually the fundamental theories used in explaining chemical phenomena and understanding the real world of chemicals that surrounds us.

Such issues are well known in the chemical education literature, which suggests that my identification of my students’ misunderstandings is something of the ‘tip of the iceberg.’ Research in science education indicates that students’ understanding about natural phenomena is frequently inconsistent with what the scientific community understands and the intended learning outcomes of chemistry programmes. Such ideas are now referred as alternative conceptions¹.

¹ Students’ non-scientific ideas which are termed as alternative conceptions viewed differently from misconceptions because misconceptions are ideas that are totally inconsistent with the scientific conceptions (Abimbola, 1988).

There are a variety of other terms also used to refer to these non-scientific ideas such as alternative frameworks, naïve conceptions, pre-conceptions, or children's science (Gilbert & Watts, 1983). Students may have developed these ideas about the world surrounding them through their experiences when they observe and interact with the everyday natural phenomena, or through their daily interaction with their social milieu (Chin, 2001). These ideas help them to make sense, infer, and predict about objects, events, or conditions such as animals, light, fires, heat, and movement (Driver, 1981, 1989).

There is now a vast number of studies reporting various approaches to addressing students' alternative conceptions in chemistry, summarised in substantive reviews such as those by Barke, Al Hazari, and Yitbarek (2009), Barker (2000), Wandersee, Mintzes, and Novak (1994), and Driver, Squires, Rushworth, and Wood-Robinson (1994). With regards to chemical reactions, examination of these resources indicates that this is an area containing some of the most difficult concepts in chemistry. The following are examples of students' shortcomings with regards to understanding chemical reactions: unable to differentiate between chemical reactions and physical changes (Ahtee & Varjola, 1998; Eilks, Moellering, & Valanides, 2007; Glassman, 1967; Hesse & Anderson, 1992; Stavridou & Solomonidou, 1989); fail to recognise the conservation of mass in chemical reactions (Agung & Schwartz, 2007; Barker & Millar, 1999); and struggle when explaining chemical reactions seeing them as transmutation processes rather than as reorganisation of atoms (Andersson, 1990; Merino & Sanmarti, 2008). Despite the vast literature on students' understanding or rather the lack of understanding of chemical reaction concepts, the literature is still lacking insight into students' understanding of advanced topics related to chemical reactions, such as chemical kinetics and thermodynamics. This dearth of research may be due to the limited number of studies conducted on students studying at an advanced level (e.g., senior high school or university) during which such concepts are taught, and may impede further improvement of chemistry teaching and learning, especially in higher education. Therefore, teachers need to be informed about students' core ideas in these topics in order for teachers to

“use these ideas as starting points and address them more effectively” (Chin, 2001, p. 73). Furthermore, informing teachers about students’ initial ideas is noteworthy because teachers are often found to misunderstand the nature of these pre-existing ideas, underestimating their resilience, and considering that these ideas can be dispelled just with additional information (Gomez-Zwiep, 2008).

Although studies informing us about students’ understanding and difficulties in learning science are undeniably important (Mulford & Robinson, 2002; Settlage & “Dee” Goldston, 2007), efforts that merely produce further lists of students’ understanding (or otherwise) of chemistry concepts, are not likely to make teaching or learning chemistry any easier; arguably they make it more difficult (Talanquer, 2006). In fact, alternative conceptions are not isolated ideas and identification of individual alternative conceptions may not be easy because of the integrated nature of conceptual structures (Pringle, 2006). Indeed, the “weakness in the range of alternative conceptions research is that the focus in most of the studies is on isolated concepts of science, rather than on the contexts and processes of conceptualisation and nominalisation that led to their invention in science” (Fensham, 2001, p. 30). Therefore, this argument implies that every single alternative concept of an isolated concept of science may require specific remedial intervention, which may compel teachers to disregard the issues of alternative conceptions.

Borges and Gilbert (1999, p. 99) observed that “if science education is to provide more than simple knowledge of science content, that is, of specific facts and laws of science, then it must elicit how students acquire and use mental models to think of the physical world and how these models evolve with age.” Mental models¹ are not a mere substitution for the term of alternative conception (Franco et al., 1999), although both are forms of representation of the world. An alternative conception can be considered as a ‘piece of knowledge’ (diSessa, 1988), a specific representation of particular instances (Stefani & Tsaparlis,

¹ Mental models will be further explored in-depth in Section 2.2 on page 35.

2009). On the other hand, mental models are global and dynamic constructs, integrating various elements, which “may be understood as fully implemented representations of objects, states, or events” (Rickheit & Sichelschmidt, 1999, p. 26) and serve as mental simulations that accomplish cognitive tasks such as understanding, reasoning, prediction, and problem solving (Johnson-Laird, 1983; Norman, 1983). For this reason, Franco et al. (1999) argued that studies of students’ mental models may offer a better understanding of students’ alternative conceptions.

It appears therefore that, with the concept of mental models, science educators are attempting to overcome some limitations of the Alternative Conceptions Movement (ACM), such as: the frequently context specific character of alternative conceptions; the difficulty of the ACM in developing overall interpretations for domain-specific alternative conceptions; the difficulty in offering theoretically dense approaches to an understanding of such educational phenomena. (Franco et al., 1999, p. 277)

Students’ mental models that are reported in the literature are inconsistent with the actual scientific or teaching models, and are not only considered flawed or found to contain some misconceptions (Coll & Treagust, 2003a, 2003b; Vosniadou & Brewer, 1992), but are also usually simplistic (Coll, 2008; Coll & Treagust, 2001, 2003a). Although it is common that simplistic mental models are *preferred* by students, it seems from a number of cross-sectional and longitudinal studies that students’ mental models improve and advance with formal science instruction (Borges & Gilbert, 1999; Coll & Treagust, 2001, 2003b; Hubber, 2006).

Hence, the study reported in this thesis seeks to add to the body of literature, by providing in-depth insights into students’ understanding of chemical reactions as expressed through their mental models. In this thesis, the nature of students’ mental models from a variety of educational levels are examined to identify and consider their conceptions of chemical reactions, conservation of mass, the process of chemical reactions, energy change, spontaneity, and reversibility. This thesis then has the potential to provide a better understanding of students’ difficulties in learning chemistry.

1.2 Purpose and Nature of the Inquiry

The purpose of this inquiry is to explore the nature of students' mental models of chemical reactions across various educational levels, with a view to identify any impediments to the learning of this science, and to provide some guidance for better teaching approaches. To guide the inquiry, the following research questions are addressed:

1. What are the attributes of students' mental models of chemical reactions?
2. Do students' mental models of chemical reactions differ and in what way?
3. How do students' mental models of chemical reactions differ at different levels of education?

The inquiry comprised a cross-age study of 67 students drawn in various levels from secondary schools and a university in Malaysia. This naturalistic qualitative inquiry was based within an interpretive paradigm and constructivist epistemology, in which data were generated from interviews with the participants. The data for this inquiry were derived from semi-structured interviews, incorporating the Interview-About-Instances (I.A.I) technique (White & Gunstone, 1992).

1.3 Science Education in Malaysia

Education in Malaysia is centralised and regulated by the Ministry of Education through several education acts. The most important act is the Education Act 1961, in which education in Malaysia became a nationalised system of education, with a common curriculum and language of instruction. The current educational structure is 6-3-2 (see Figure 1.1), comprising 6 years in primary, 3 years in lower secondary, and 2 years in upper secondary (Ministry of Education Malaysia, 2008).

After completing secondary school, students can either opt for employment or further their education through various ways (see Figure 1.1). Qualified secondary school leavers with the Malaysia Certificate of Education (SPM) can enrol into the matriculation programme, which is a preparatory programme for

undergraduate degrees (e.g., medicine, accountancy, engineering, etc.) offered in the local universities. Students can major either in science or accountancy in this programme. Students may also choose to enrol into Form 6 for preparation for the Malaysia Higher Certificate (STPM)¹ examination as an entrance requirement to undergraduate degrees offered at university.

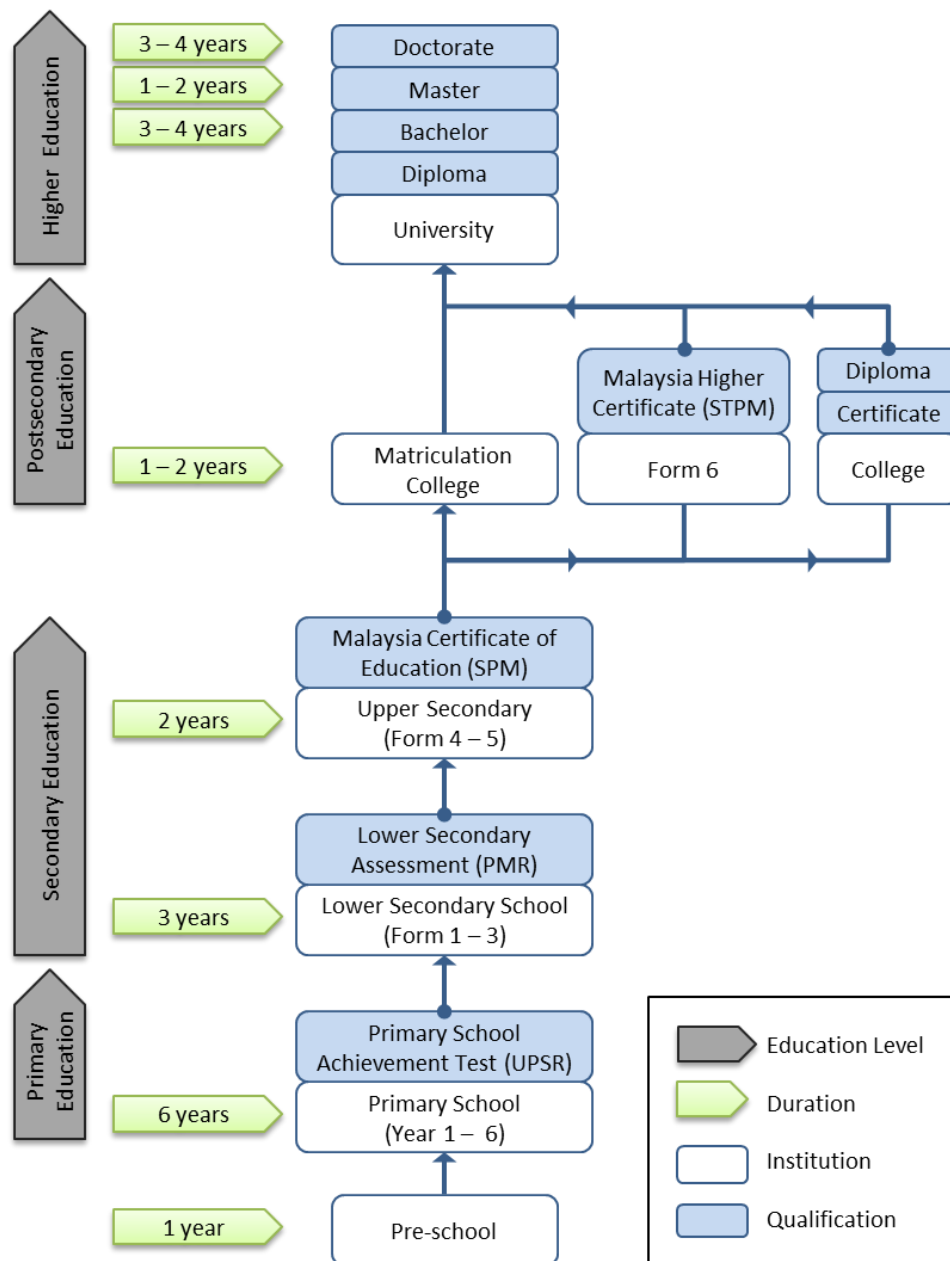


Figure 1.1 Structure of the Education System in Malaysia

¹ Equivalent to the general certificate of secondary education (GCSE) 'A' level certificate and recognised by professional examination bodies worldwide.

Students who are more skills oriented, may enrol in (1) polytechnics colleges for certificate, and diploma level qualifications in engineering, business and hospitality, or (2) community colleges for certificate and diploma qualifications in work based skills such as automotive, information technology, draughtsmanship, and many others. Students who acquired suitable qualifications from such polytechnics and community colleges are then eligible to study for the undergraduate degrees or seek employment.

1.3.1 Development of Science Education in Malaysia

Since the early days of Malaya independence in 1957 and the formation of Malaysia in 1963, science education has been a special feature in the national agenda, which recognises its roles in promoting economic progress and social development. More importantly is science education's role in uniting Malaysian citizens of the newly formed country (Ministry of Education Malaysia, 2003a) by building a science and technology-oriented society (Cahill, 1984). As a consequence, in 1965, science as a subject became compulsory for students in both primary and secondary schools (Tan, 1991). During this era, the first change experienced in science education was the adoption of the Scottish Integrated Science Syllabus and Nuffield O-Level Pure Science Syllabi in the late 1960s and early 1970s (Lewin, 1975; Tan, 1991). This change was motivated by a desire to keep abreast with the western countries' response to the launching of Sputnik by the USSR (Wissehr, Concannon, & Barrow, 2011).

Over time, problems were experienced with the adoption of the British-based curriculum. Hence, a 1979 Cabinet Report recommended a restructure of the entire school curricula to reflect Malaysian identity and background. Science education in Malaysia then experienced a second change with the introduction of the Integrated Curriculum for Primary School (KBSR)¹ in 1983, and the New Integrated Curriculum for Secondary School (KBSM)² in 1989 (Ministry of Education Malaysia, 2003a). These revisions were intended to provide students

¹ Local acronym which stand for *Kurikulum Bersepadu Sekolah Rendah*.

² Local acronym which stand for *Kurikulum Bersepadu Sekolah Menengah*.

with a general education that was balanced in terms of intellectual, psychomotor, emotional, and spiritual development. School science then became known as Science KBSR and Science KBSM. These science curricula provided the framework for science education up until the present, even though a variety of changes have been made in the education policies that followed.

The reform of science education was taken to a new level with the introduction of Vision 2020¹ by the fourth prime minister soon after the implementation of Integrated Curriculum for Secondary School in 1991. He set the challenge for the country to become a developed nation by the year 2020 by creating a scientific and progressive society (Mohamad, 1991). Since 1991, much effort has been put into making improvements to the education in Malaysia, especially in science and mathematics education, which were geared to the realisation of Vision 2020. The role of science and mathematics education as a catalyst for economic development has become more distinct and obvious. The Malaysian government has allocated increasingly large amounts of money for educational development including investment in infrastructure and teacher training, all with the intention of improving science education in every economic development plan over the last 20 years (Hussin, 2004; Ministry of Education Malaysia, 2003a, 2008). As an example, in the 1990s, the Government introduced Information and Communication Technology (ICT) into the education system, supported by investment in the infrastructure, curriculum, and teacher training. This innovation involved projects such as the supply of computer hardware, laboratories, and Internet connections with the intention of providing technological aid in teaching and learning in science and mathematics (Ministry of Education Malaysia, 2006b).

Another important action taken by the government to improve science education in Malaysia, was the implementation of English in the Teaching of Mathematics and Science (ETeMS)² in 2003. The intention here was to “provide

¹ Malaysian developmental aspirations to become a developed country by the year 2020.

² Malaysian government had decided to revoke ETeMS in 2010.

students with early exposure to master these disciplines in English” as a pragmatic response to the “rapid advancements of these disciplines and the predominant availability of references in English” (Ministry of Education Malaysia, 2008, p. 46). To implement this policy, schools were supplied with extensive technological resources such as educational software, laptops, projectors, Internet access, and laboratory apparatuses. However, despite these curriculum reviews and amendments, the content of science and mathematics courses in schools has remained essentially unchanged since it was first introduced into the curriculum in the 80’s.

1.3.2 Science Curriculum in Malaysian Education

Although science education in Malaysia has undergone some revision since the implementation of the Integrated Curriculum for Primary School (KBSR) and Integrated Curriculum for Secondary School (KBSM) reforms, the science curricula remain framed by the National Science Philosophy of Education, which states “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” (Ministry of Education Malaysia, 2006a, p. 4). Based on this philosophy, the Malaysian science curriculum aims to enable students to acquire and integrate scientific knowledge, skills, and values in science and technology for their daily life needs, such as problem solving, decision making, and conservation of the environment.

At the primary and lower secondary levels, core science is compulsory for all students. The curriculum is designed to provide students with basic science knowledge preparing them for upper secondary science. However, at the upper secondary level students are given options either to take secondary core science, or science electives, which includes biology, chemistry, physics and additional science (Ministry of Education Malaysia, 2003b, 2003c). Secondary core science is designed for further development and nurturing of the primary core science, while the science electives offer deeper content of the major areas in science.

Upon completing their learning in secondary schools with the Malaysia Certificate of Education (SPM)¹, students can continue to Form 6, taking chemistry, biology and physics at an advanced level to obtain the Malaysia Higher School Certificate² (STPM³), which is needed to enter university. In addition, another cohort of students is selected to enter matriculation programme, a pre-university programme designed to prepare students for the degree programmes offered in the universities in fields such as industrial chemistry, biotechnology, pharmaceutical, medical science, chemical engineering and many others. However, matriculation students are only required to take chemistry, and biology or physics (Figure 1.2). Both of these qualifications enable students to pursue their education in science disciplines in tertiary education.

¹ Local acronym which stand for *Sijil Pelajaran Malaysia*.

² Equivalent to the UK General Certificate of Secondary Education, GCSE 'A' level.

³ Local acronym which stand for *Sijil Tinggi Pelajaran Malaysia*.

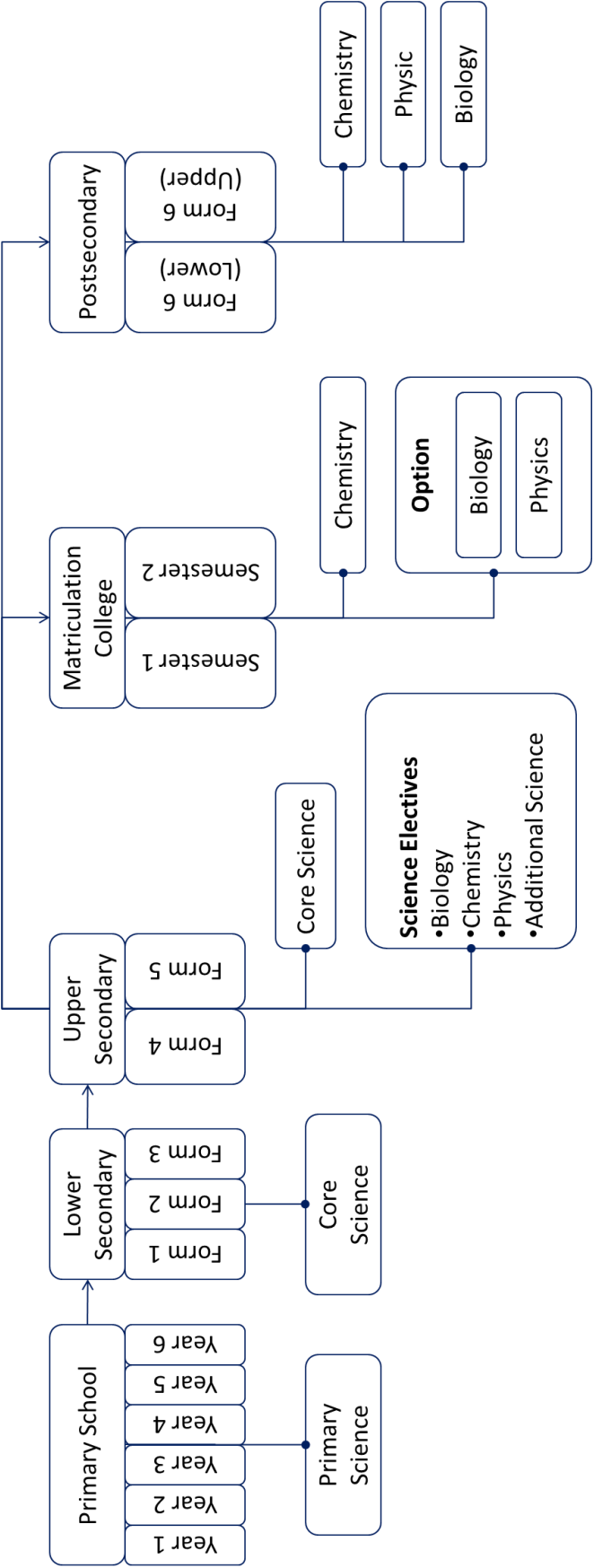


Figure 1.2 Science Education in Malaysia

1.3.3 Chemical Reactions in Malaysian Science Education

Chemistry education can thus be considered a significant component of the Malaysian science curriculum. Although chemistry is not taught as a separate subject in primary and lower secondary school, students are exposed to some chemistry knowledge in their science subjects. The chemistry content that is incorporated in Malaysia science education is summarised in Table 1.1.

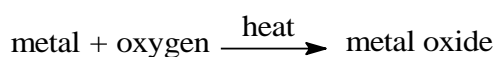
At the primary school level, chemistry is introduced on a phenomenological or macro level by providing opportunities to investigate the physical properties of various materials; this includes the topics of rusting, state of matter, and acids and alkalis¹. In other words, these concepts are introduced as properties of materials rather than as change of material. In the case of the chemical phenomena of rusting, for example,, it is simply introduced that “certain materials can rust” (Ministry of Education Malaysia, 2003b, p. 10), and the terms acid and alkali are used to designate substances with taste and litmus paper test properties. Similarly, state of matter is used to classify materials into solid, liquid, and gas, and to describe their interchanges (Raja Alias, Yassin, Toh, & Johar, 2005). In summary, at the primary school students are not expected to recognise the change of chemical substances, but rather to recognise the properties of chemical substances.

¹ Similarly, the concept of energy, which is also presented in primary school level phenomenologically. At this level, primary school students are expected to understand the uses of energy, types and sources of energy, and transformation of energy. In addition, the phenomena of heat conduction is also introduced (Ministry of Education Malaysia, 2003b).

Table 1.1 Chemistry in Malaysian Science Education

Core Science			Additional Science		Chemistry	
Primary	Lower Secondary	Upper Secondary	Upper Secondary	Upper Secondary	Postsecondary	Matriculation
<ul style="list-style-type: none">• Properties of materials (rusting)• Acid and alkali• Solid, liquid and gas	<ul style="list-style-type: none">• Matter• Variety of resources on earth• The air around us• Water and solution• Land and its resources	<ul style="list-style-type: none">• Matter and substance• Carbon compound	<ul style="list-style-type: none">• Periodic table• Chemical bonding• Mole concept• Chemical reactions• Petrochemicals	<ul style="list-style-type: none">• Introduction to chemistry• Structure of atom• Formula and chemical equation• Periodic table of elements• Chemical bonds• Electrochemistry• Acids, bases and salts• Carbon compounds• Oxidation and reduction reactions• Thermochemistry• Rate of reaction• Manufactured substance in industry• Chemicals for consumers	<ul style="list-style-type: none">• Matter• Electronic structure of atoms• The periodic table• Chemical bonding• Reaction kinetics• Equilibria• Electrochemistry• Thermochemistry and chemical energetics• Period 3 and Group 2• Group 13• Group 14• Group 15• Group 17• An introduction to the chemistry of <i>d</i>-block elements• The chemistry of carbon• Hydrocarbons• Haloalkanes• Hydroxy compounds• Carbonyl compounds• Carboxylic acids• Carboxylic acids derivatives• Amines• Amino acids and proteins• Polymers	<ul style="list-style-type: none">• Matter• State of matter• Atomic structure• Periodic table• Chemical bonding• Chemical equilibrium• Ionic equilibrium• Phase equilibria• Thermochemistry• Electrochemistry• Reaction kinetics• Introduction to organic chemistry• Hydrocarbons• Aromatic compounds• Haloalkanes• Hydroxy compounds• Carbonyl compound• Carboxylic acid and derivatives• Amino acids and proteins• Polymers

At the lower secondary school, fundamental ideas in chemistry students are introduced to the idea of particles and the kinetic theory of particles. However, these ideas do not make reference to the concepts of atoms or molecules, and are mainly used in the explanation of the change of state of matter (Ministry of Education Malaysia, 2002). Regardless the introduction of particulate and kinetic ideas of particles, the phenomena of chemical reactions, that is introduced at this level of education is still phenomenological¹. Chemical reactions such as combustion, neutralisation, and reactions between metallic and non-metallic elements, decomposition of metal carbonates are represented as in word equations such as follows:



Hence, lower secondary students are expected to be able to identify the substances that involved in chemical reactions and substances formed from the reactions. Therefore, the introduction of chemical reactions at this level would not expect students to understand that there are changes of chemical composition in chemical reactions, but rather a transformation of one substance to another.

In contrast to the lower secondary level, chemistry at the upper secondary school is presented mainly at the particulate and symbolic levels (see also Table 1.1). At this level, students' chemistry foundations are strengthened with the emphasis of the particle theory through the introduction the terms of atoms, ions and molecules, along with the topics around atomic structure, periodicity, chemical bonds, and chemical formulae and equations. Various chemical interactions introduced in this level of education that aim "to provide understanding of chemical reactions which cause chemical changes to substances," and "that matter interacts to produce new substances and causes energy change" (Ministry of Education Malaysia, 2006a, p. 13). These chemical

¹ The treatment of energy in the lower secondary level is similar to that in primary school level (Ministry of Education Malaysia, 2003c).

interactions include the topics of electrochemistry, acids and bases, carbon compounds, and redox reactions (see Table 1.1). Students are also introduced to the idea rate of reaction based on the particle collision theory, which includes the concepts of activation energy and effective collision. Energy¹ change in chemical reactions also covered in the upper secondary school chemistry which includes the concepts of exothermic and endothermic reactions, and highlights the relation between energy and chemical bonding (Lim, Low, Lim, Eng, & Ahmad, 2006). Thus, based on this examination of chemistry curriculum, Malaysian students who have finish their upper secondary education are expected to be able to explain chemical reactions at *submicro*² level based on the particle theory and collision theory, in terms of chemical compositions, reaction kinetics, and energy change.

Chemistry at the postsecondary levels (Form 6 and matriculation programme), which to prepare students for pursuing their studies in the science related fields at university, is further developed and detailed around similar areas as in the upper secondary chemistry, *inter alia*, Maxwell-Boltzman distribution, atomic orbital, valance bond theory, intermolecular forces, electrode potential, and Hess law (Lim & Yip, 2005; Majlis Peperiksaan Malaysia, 2002). The knowledge of chemical reactions is intensified in inorganic chemistry (i.e., chemistry of the main group and third period elements) and organic chemistry (hydrocarbon and functional group chemistry). However, a significant difference in postsecondary level from the upper secondary level is the introduction of chemical equilibrium, which discusses the ideas of dynamic equilibrium and ionic equilibrium. This introduction can be considered a new idea to students whom probably think that all chemical reactions come to a completion. Students' knowledge in chemistry

¹ Other aspects of energy are introduced in Physics subject. However, students taking Chemistry are not required to take the subject Physics, because both of these subjects are elective subjects. This situation is the same at the postsecondary and university level (Ministry of Education Malaysia, 2008).

² The term 'submicro' is based on Gilbert and Treagust (2009) which also used interchangeably with the term 'microscopic' or 'sub-microscopic' in the literature that usually used to refer to entities cannot be seen through optical microscopes (e.g., Jaber & BouJaoude, 2012; Johnstone, 1991). The three levels of chemistry will be discussed briefly in Section 3.2 on page 90.

especially in chemical reactions at postsecondary level is expected to have been strengthened, based on their prior knowledge acquired in the upper secondary school. In short, postsecondary students should be able to explain the phenomenon of chemical reactions more cohesively, by referencing chemical changes to the particles involved, viewing chemical reactions as a dynamic process, and being aware that energy change is in relation to chemical bonding. Nonetheless, the concept of chemical spontaneity is not introduced to postsecondary students.

Undergraduate chemistry at Malaysian universities resembles that at other universities. Undergraduate chemistry programmes in Malaysia offer related courses to prepare students in the workforce (Ministry of Education Malaysia, 2008), that usually include study in the area of physical chemistry, inorganic chemistry, organic chemistry, and chemical analysis and other applied chemistry areas – an advancement of their acquired chemistry knowledge acquired in the postsecondary school. For example, along with familiar topics in physical chemistry, topics such as chemical thermodynamics, chemical kinetics, and quantum mechanics are typical. Students also learn about coordination compounds and solid state chemistry in inorganic chemistry, and additional topics such as organic reaction mechanism, organic synthesis, and organic spectroscopy introduced in organic chemistry. However, different emphasis would be given to certain area, depending on the need of the programmes. For example, an industrial chemistry programme offers courses that support students in industries such as chromatography, polymers, and industrial chemical process. In short, with the training accumulated from upper secondary school up to the university level, one can expect that a chemistry undergraduate student would be able to explain chemical reactions in terms of chemical structures, kinetics, and energy in a more coherent fashion compared to postsecondary schools students, applying more advanced chemistry knowledge, *inter alia*, molecular orbital theory, reaction order, transition state theory, and entropy.

1.3.4 Issues in Malaysian Science Education

As mentioned above, science education in Malaysia has undergone various reviews since the Integrated Curriculum for Secondary School (KBSM) Science was first introduced in 1989. Unlike the Integrated Curriculum for Primary School (KBSR) Science¹, secondary school science remains unchanged in terms of its content and organisation despite the curriculum reviews. Even with the removal of ETeMS, current secondary school science is changed only in terms of language, not content knowledge or organisation. There was no attempt to keep up with current advancements in chemistry such as nanotechnology, alternative energy, and chemistry for environmental conservation in the curriculum reviews. Thus, the rather outdated curriculum makes the gap between school chemistry with the real world wider and the chemistry studied less relevant. In the above discussion, it is noted that the Malaysian Government has seriously attempted to improve science education. However, despite various actions taken by the government in the hope of improving students' learning, difficulties in learning science persist. During the adoption of the British science curriculum in the 1960s, it was considered that students were facing problems understanding the science concepts because instruction was in English so in the 1970s, teaching and learning science was conducted in Malay with the Malaysian based science curriculum (Kassim, 1989). In 2003, science and mathematics were taught again in English, but has been then decided to revert to Malay as the medium of instruction in 2013. In summary, despite (or perhaps because of) the language policy and the increasing use of technology in teaching and learning in science, learning science still seems difficult for Malaysian students. For example, Figure 1.3 below shows one of the 2007 TIMSS test items (Martin, Mullis, & Foy, 2008, p. 97), where most Malaysian students (13-14 year olds)² were unable to apply the knowledge of conservation of mass in chemical reactions to solve the problem.

¹ Previously known as Man and Environment

² At this age, Malaysian students are in Form 2 and have been introduced to the idea particulate nature of matter.

The mass of substances A and B are measured on a balance, as shown in Figure 1. Substance B is put into the beaker and substance C is formed. The empty beaker is put back on the balance, as shown in Figure 2.

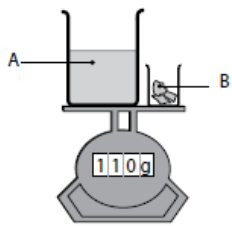
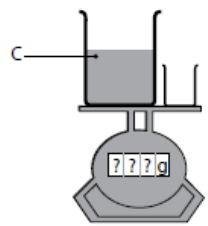



Figure 1

Figure 2

The scale in Figure 1 shows a mass of 110 grams.
What will it show in Figure 2?

(Check one box.)

☐ More than 110 grams

☒ 110 grams

☐ Less than 110 grams

Figure 1.3 2007 TIMSS Test Item on the Knowledge of Conservation of Mass

For this TIMSS study, the international average for the correct response for this item is only twenty three percent, but it is even lower for Malaysian students, that is, fourteen percent. This suggests that many students especially Malaysian students, have not really grasped the principle of conservation of mass despite learning about matter, and this observation is also reported in other studies (Lajium, Ismail, & Mohd. Yunus, 2005, August; Lay, 2009).

1.4 Rationale and Significance of the Inquiry

Most of the literature on students' understanding of chemical reactions concentrates on students' conceptions about the conservation of mass, equilibrium, kinetics or thermodynamics – each area typically investigated in isolation in the alternative conceptions research (Fensham, 2001). Löfgren and Helldén (2008, p. 481) noted out that in “order to develop successful teaching approaches to transformations of matter, we need to know more about how young students develop an understanding of these processes.” The present study thus has the potential to contribute to the literature about our understanding of students' mental models about chemical reactions as a whole (from conservation of mass through to thermodynamics) – from primary up to

the university levels. It also seeks to identify how instructional exposure, to teaching and curricular models, influences students' development of their mental models for chemical reactions. Furthermore, it is hoped that this work will inform chemistry educators across educational levels in Malaysia and worldwide about the nature of mental models for chemical reactions, and help in the design of curriculum and teaching approaches to prepare students for the real world of chemistry.

Additionally, research of students' mental models about chemical reactions will expand chemistry education research, shifting away from previous isolated focus on students' conception of atomic structure and chemical bonding. Examining students' mental models is beneficial as Franco et al. (1999, p. 277) pointed out, developing an understanding of our students' mental models is useful in overcoming the "limitation of the Alternative Conceptions Movement," by providing a better integrated holistic interpretation of students conceptions in specific domains.

1.5 Assumptions

There are several assumptions employed in this inquiry. The first assumption that guides this inquiry is that students' mental models may advance as they mature. In other words, students' mental models can be viewed as 'developmental' along a continuum, which is predictable, but not a rigid, sequence of developmental accomplishments. As they are exposed to more and different kinds of chemical phenomena from school or in their daily life, and more interaction with their social milieu, students are constantly developing their mental models (Borges & Gilbert, 1999; Borges, Tecnico, & Gilbert, 1998; Coll & Treagust, 2003a). Therefore, older students are assumed to be likely to have more comprehensive mental models compared to younger ones. It is also assumed that students develop their mental models not only based on what they learned in school, but also from their daily life experiences of chemical phenomena, interaction within their social group including their peers and

cultural group (Franco & Colinvaux, 2000; Jonassen & Henning, 1999; Payne, 1991).

As a consequence, a second assumption, is that students are thought to have developed some kind of mental models with respect to chemical substances and their changes, and this understanding is likely to vary according to their level of education and experiences. In this study, students were selected from secondary schools (only Form 1 and Form 4)¹, postsecondary colleges (Form 6), and university classes (first and final year undergraduate). The selection was made from these groups based on their mental models, which are *assumed* to be constructed on their acquired knowledge in chemistry from their previous learning, as per the above discussion² (Figure 1.4). For example, Form 1 students who have just completed their primary schooling are assumed to form some mental models as a result of their learning experiences in primary school science. Similarly, Form 4 students are assumed to hold mental models that are based on additional chemistry knowledge from the lower secondary school, and senior university students are assumed to have developed mental models based their learning of various chemical systems in their chemistry courses of the previous semesters.

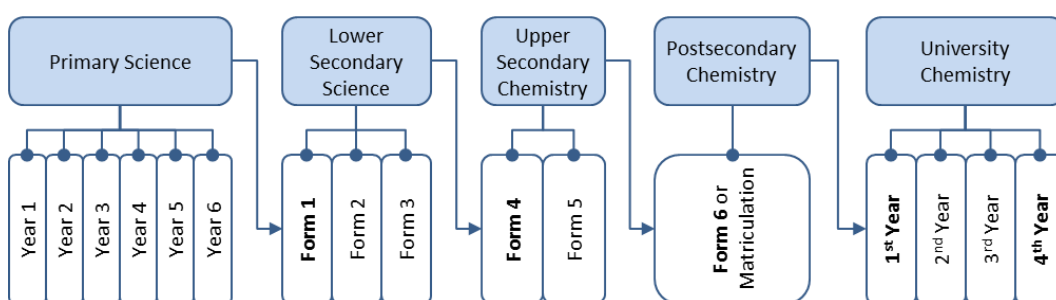


Figure 1.4 Students' Assumed Prior Chemistry Knowledge Based the Education Levels

¹ The selection of these students is also to accord the local education policy of not involving the students in Year 6, Form 3, and Form 4 who are preparing for national standard examinations.

² See also Table 4.1 on page 157.

A third assumption is that students' mental models as expressed during the interviews are not necessarily their actual mental models. Whilst this is a tenet of constructivism, of particular relevance here is that Malaysian students are not well trained to explain or express themselves verbally due to lack of communication skills (Shakir, 2009). Therefore, limited responses from the students are not necessarily indicative of limitations in their mental models. This could, for example, occur due to their difficulties in explaining what they mean because of language proficiency or lack of vocabulary. Additionally, the expressed models in the interviews can also be the students' preferred mental models which they tend to use in their explanation and prediction, even though they may have developed more advanced mental models (Coll & Treagust, 2001, 2003b).

1.6 Organisation of the Thesis

This thesis is organised into nine chapters. Chapter 2 provides the literature review, covering models and modelling in science education and students' understanding of science concepts, focusing on students' alternative conceptions for chemical reactions. Chapter 3 presents the theoretical framework used in the inquiry, which comprises constructivism and sociocultural views of learning. In Chapter 4, the methodology used in the inquiry is explained in terms of the paradigm or belief system that underpins the inquiry; the research design, data collection and analysis also are presented. The research findings are presented in Chapter 5, 6 and 7, and aligned to the research questions as outlined in Chapter 1. Chapter 5 describes the attributes of the students' mental models of chemical reactions while Chapter 6 identifies and distinguishes the types of students' mental models of chemical reactions, and in Chapter 7 presents comparison of their mental models across the students' educational level. These chapters are followed with a discussion of the findings in Chapter 8. The thesis concludes with Chapter 9, which discusses the implications of this inquiry for the teaching and learning of chemistry, teachers' professional development in terms of content knowledge, and pedagogical content knowledge (PCK) concerning

model and modelling in school science, and provides some recommendations for future research.

1.7 Summary

This chapter has described the overview of this inquiry. The background of the inquiry was discussed first, portraying the research territory and identifying the niche in this area of study. This background was followed by the purpose, brief descriptions of the key literature, and assumptions of the inquiry. This chapter also detailed the Malaysian science education context and provides justification for the inquiry. Chapter 2 explains in further detail research about models and modelling in science education and students' conceptions for chemistry concepts.

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This chapter provides a review of relevant literature about models in science and science education. It begins by describing models in terms of their structure and role as a form of representation. This section also includes the typologies of models and the role of models in science. Next, the notion of mental models is described followed by discussion of students' mental models of scientific ideas. The review continues with a by discussion of the roles of models and modelling in the teaching and learning of school science. The chapter concludes with a description of chemical reaction models.

2.1 Models and Modelling

Model as a term is omnipresent. It is used widely in different contexts in life and people understand the word 'model' in different ways other than in science. For instance, we might use it to refer to a representation of something such as buildings, landscapes, and miniature cars. We may also use the term model to refer to a variety of machines, or people who exemplify certain ideals such as fashion models. Even amongst scholars, use of the term model varies.

Therefore, it is worthwhile to examine the nature of models for the use in this study in terms of structure, which is discussed in the following section.

2.1.1 The Structure of Models

Models can be things such as graphs, pictures and formulae, or discourse such as metaphors and actions, or concrete material objects like replicas of buildings (Buckley & Boulter, 2000). Although we use the term differently, all usage comes with the notion of a model representing something for a specific purpose within a well-defined scope (Halloun, 2006). In other words, a model can be generally defined as a representation of a particular *target* such as an object, event, process, idea or system (Gilbert & Boulter, 1998; Gilbert, Boulter, & Elmer, 2000; Gilbert & Priest, 1997; Ingham & Gilbert, 1991; Oh & Oh, 2011; Shusaku & Bret, 2009).

Consider the atomic structure model based on Rutherford's and Bohr's theory, which is used widely in secondary schools. From Rutherford's observation of the Stern-Gerlach scattering experiment (in which alpha particles were used to bombard gold foil), he proposed that the atom has not only electrons as in Thomson's model of the atom, but also a nucleus at the centre (Zumdahl, 2005). At the same time, when explaining the phenomena of light emission and absorption, Bohr postulated that electrons in atoms are arranged in orbits, with definite energy levels (Goldberg, 2007). Therefore, a model of an atom can be constructed to represent the attributes¹ of Rutherford's atom and Bohr's atom by mapping or transferring the attributes of a nucleus and orbiting electron(s), in fixed energy levels, and the Solar System with orbiting planets and the sun at the centre, to the atomic model, which depicts that the electrons rotate around the nucleus in fixed orbits (see Figure 2.1). This model is then considered as a *representation* of Rutherford's atom combined with Bohr's atom as the *target*, based in its construction on the Solar System as the *source* (cf. Duit & Glynn, 1996).

¹ The word 'attributes' in this thesis is used particularly to refer the characteristics of models and mental models.

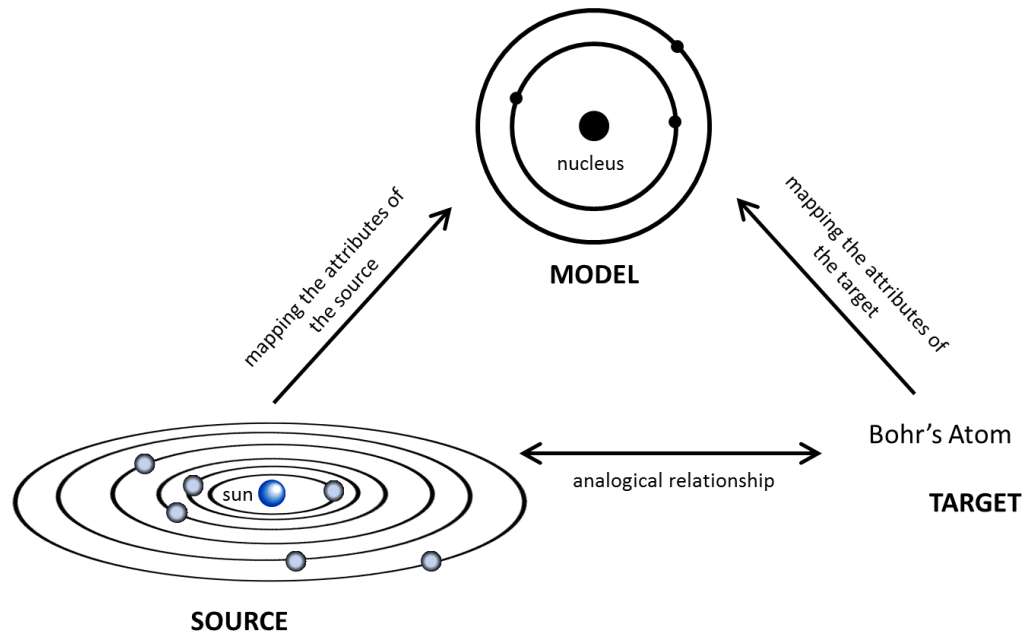


Figure 2.1 The Relationship Between Target, Source and Model (Based on Brodie et al., 1994)

The source and target are two different entities, with the source being something more familiar than the target, although they share a certain degree of similarity. Brodie et al. (1994) elaborates further, saying that

some aspects of the source of the model, from where it is derived, are transferred, in some way and to some extent, to that which is being described, to the target of the model. A model is the representation, the outcome, of that transfer. (Brodie et al., 1994, p. 5)

According to Duit and Glynn (1996), the relation between a target and a source (which also can be called an analogue) is referred as an analogy or more precisely, an 'analogical relation.' This relationship implies that a model is a form of representation of a target, which is constructed on the basis of the analogical relation between the target and a source. Duit (1991) detailed the relationship in terms of shared and unshared attributes between a source (or an analogue), a target, and a model. As shown in Figure 2.2, the model, source, and target shared the attributes that represented as the star (★) and square (■) shapes, while the unshared attributes of the target and source are represented as "O" and "#" respectively (i.e., "O" represents an attribute of the analogue that is not

shared neither with the model nor the target, and “#” represents an attribute of the target that is not shared neither the model nor the analogue).

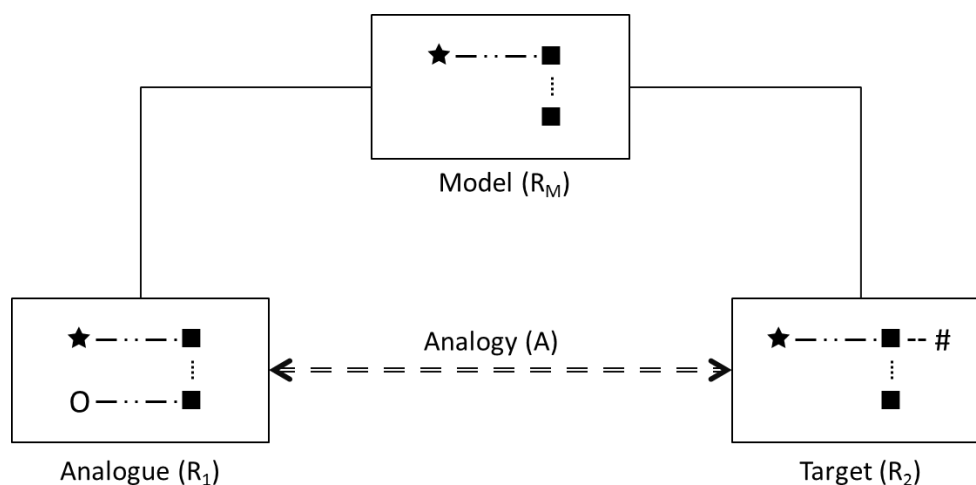


Figure 2.2 Meaning of Analogy (Based on Duit, 1991)

Duit and Glynn (1996, p. 146) emphasised that the “analogical relations are at the heart of models. It is the analogical relations that make a model a model. To construct a model, means to create and depict certain analogical relations.” This is why, models are sometime referred as ‘analogical models,’ emphasising that models are analogical “because evident point-by-point mappings between the analogue [or the source] and the science phenomena [i.e., the target] describe and explain structures and functions” (Harrison & Treagust, 2000b, p. 1017).

It is also worthwhile to distinguish an analogy from a metaphor. A metaphor compares two entities implicitly by highlighting only the qualities that do not coincide between the two entities (Duit, 1991). According to Aubusson, Harrison, and Ritchie (2006, p. 2),

analogy can be distinguished from metaphor in the sense that *in metaphor, A is said to be B but in analogy, A is like B* [italics added]. ... the metaphor student as tabula rasa¹ [footnote added], it suggests that the student has no prior science knowledge before entering a science classroom. The student is like a sponge, however, is an analogy suggesting that there are characteristics which the student

¹ *Tabula rasa* in Latin means ‘clean slate’ is an assumption of original mental blankness of human mind that filled with ideas from the senses to the external world ("Tabula rasa," 2013).

and a sponge have in common but implying there are ways in which they differ.

Thus, we can say that, for an analogy, the target is being likened to the source or analogue but for a metaphor, the source is said to be the target.

2.1.2 Typologies of Models

According to Harrison and Treagust (2000b), there are a number of benefits in having a typology of models; for example, a typology of models can help alert teachers and researchers to the conceptual demands arising from different types of models. To illustrate, understanding a concrete model is easier than understanding abstract or mathematical models. With a typology of models, teachers should be able to select the proper model type for their lessons consistent with their students' level of cognitive ability.

In general, models can be divided into two categories that are *mental models* (see Section 2.2 for further discussion) and *expressed models* (Coll, France, & Taylor, 2005). In broad terms, mental models are personal cognitive constructions, used to represent external objects or events (Rickheit & Sichelschmidt, 1999) or to support understanding, reasoning and to make predictions (Gentner, 2001). In other words, mental models are models that implicitly exist in our mind. When mental models are expressed in the public domain via action, speech, writing, text or using other types of symbols, they are called *expressed models* (Gilbert et al., 2000). Expressed models can further be classified as shown in Figure 2.3. When Expressed models that gain acceptance among a community of practice, say scientists, they become *consensus models*. Simplified versions of consensus models which are used in education, are called *curricular models*. The consensus models that are currently used in the field of science are called *scientific models*, and those scientific models that are later superseded are referred to as *historical models*. Models, that constitute elements or attributes of different historical models and that are "treated as if they constituted a coherent whole," are called *hybrid models* (Justi, 1997, p. 116). For example a representation of activation energy from the point of view

of collision theory that consists of elements activated complex and transition state, which are “formulated from different theoretical backgrounds” i.e., the former “was defined within the Transitional State Model as the configuration of atoms” and the later was a real molecule as defined by Arrhenius (Justi, 2000, pp. 216-217). Nonetheless, “the understanding of consensus, historical, and curricular models (as well as the phenomena that they represent) is often difficult, teaching models are developed to assist in that process” by either teachers or students (Gilbert et al., 2000, p. 12).

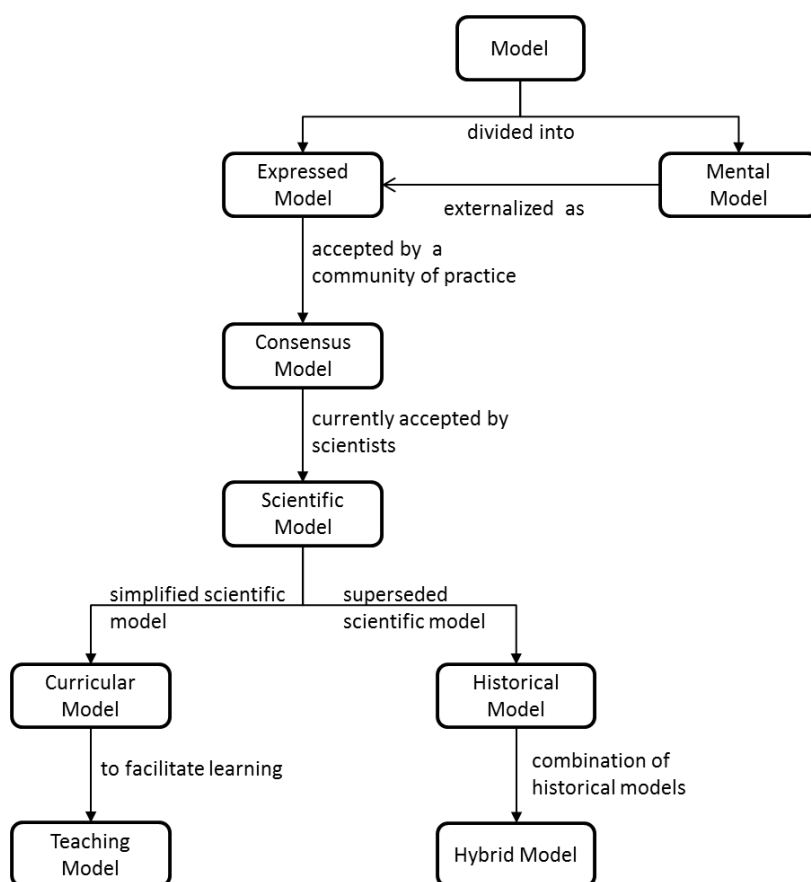


Figure 2.3 A Typology of Models (Gilbert et al., 2000)

Expressed models can be categorised based on the modes of representation which is shown in Table 2.1 (Gilbert et al., 2000). Modes of representation that describe the medium of a model represent the attributes of its target. For instance, chemical structure of the water molecule can be represented either with a concrete model of polystyrene balls showing how hydrogen and oxygen

atoms are arranged in the molecule, or a Lewis structure showing the sharing of valence electrons between hydrogen and oxygen atoms. Expressed models often require multiple modes to convey the information of the target.

Table 2.1 Modes of Representation of Expressed Models

Mode	Feature	Examples
Concrete	3 dimensional materials	Metal models of bridges, polystyrene model of molecules
Verbal	Metaphors or analogies in speech	Electrical current is like water current, activation energy is like a hill
Mathematical	Mathematical expression	Ideal gas equation
Visual	2 dimensional graphical pictorial forms	Graphics, graphs, diagrams, maps
Symbolic	Combination of alphabets, graphics, and numbers which include visual, verbal, and mathematical modes	Chemical symbols, chemical formulae
Gestural	Actions	Hand movements

Boulter and Buckley (2000) introduced an additional dimension, other than modes of representation, to the categorisation of expressed models, that is the attributes or characteristics of representation which include the type of quantification (quantitative or qualitative), behaviour through time (static or dynamic), and reproducibility of the behaviour (deterministic or stochastic¹). Based on this dimension, Boulter and Buckley (2000) derived a typology of models as shown in Figure 2.4. This typology shows the relationship between the modes of representation with a model and how it is represented. For example, based on the mode and attribute of representation, a physical simulation like a flight simulator, is categorised as a concrete-dynamic stochastic model, which the behaviour of the physical simulation is based on probabilistic functions.

¹ Stochastic involves the operation of chance. For example, every radioactive atom is subject to a fixed probability of nuclear reaction in any given time interval ("Stochastic process," 2013).

		Single mode					Mixed mode				
Attributes of representation	Quantitative	Concrete Material	Visual Pictorial	Verbal Written/oral	Mathematical Formulaic	Gestural Bodily	Gestural	Mathematical	Verbal	Visual	Concrete
	Qualitative	Static	3D model	Diagram Drawing	Analogy Description Metaphor	Showing positions	Showing positions with talk		Analogy with drawing	Diagram with labels	3D model with labels
	Dynamic: Deterministic	3D models that move	Sequenced diagrams Animations			Acting out set movements	Acting out with talk			Animation with verbal	
	Dynamic: Stochastic	Physical simulations				Hand gestures	Hand gestures with talk				Physical simulation /labels
	Dynamic: Stochastic		Graphical displays		Formulae					Graphical Display	
	Dynamic: Deterministic	Working scale replicas	Video of live phenomena		Formulae Computer simulations	Gesturing relative behaviours	Gesturing behaviour with quantities described	Computer simulations		Video with verbal	Working scale replica with verbals
	Static	Scale models	Photographs	Description with size or distance	Equations Chemical Formulae	Showing size	Showing size with talk	Equations with diagram	Description with size and gesture	Photos with labels	Being an object with verbals

Figure 2.4 Typology of Expressed Models (From Boulter & Buckley, 2000)

Likewise, Coll (2006) proposed a categorisation of models based on two dimensions, i.e., the level of representation (physical or conceptual-symbolic) and mobility (static or dynamic) of models (see Figure 2.5). Scale/iconic, maps, and diagrams are categorised as physical models, where these models represent the external characteristic of the target, while conceptual-symbolic models such as mathematical and theoretical models, represent the implicit behaviour of the target. Physical and conceptual-symbolic models can be either static or dynamic. For example, maps can be viewed as a static physical model, while wave functions of atomic structure can be viewed as a dynamic theoretical model.

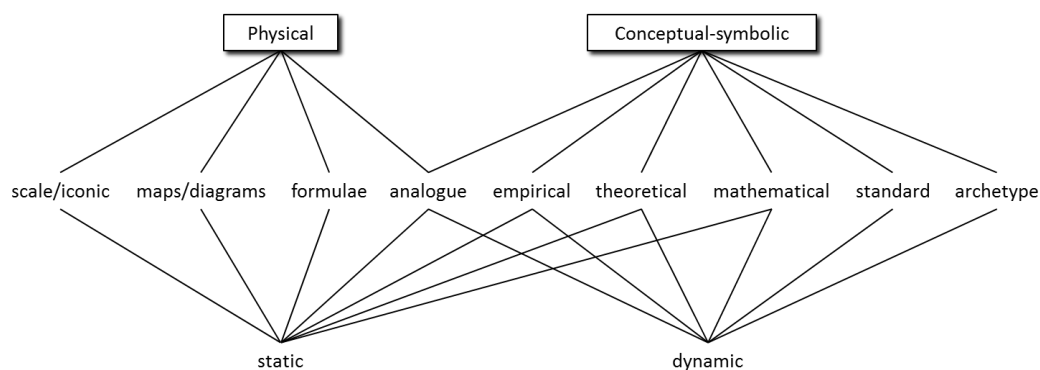


Figure 2.5 Classification of Models (Coll, 2006)

Overall, for the typologies of models presented here, most are based on what the models are representing (be it object or phenomenon). In this study, the typology reported by Gilbert et al. (2000) will be used (see Figure 2.3 on page

30). This choice is mainly justified by the simplicity of the typology of models, coverage of both expressed models and mental models, and its relation to models in science and science education.

2.1.3 Models in Science

Progress in science is often related to the production of a series of models, which are used for the simplification of phenomena, and ultimately to explain phenomena (Gilbert et al., 2000). Matthews (2007) observed that there is a vast number of models in various disciplines in science. Here, he lists many examples:

The 'billiard ball,' 'plum-pudding' and 'solar system' models of the atom, the electron orbit model for the periodic table, the 'lattice' model of salt structure, the fluid-flow model of electricity, the double-helix model of the chromosome, the 'survival of the fittest' model for population expansion in ecosystems, the particle model of light, the 'big bang' model in cosmology, the '3-body' model for sun-earth-moon interaction, full dinosaur models from bone fragments in palaeontology, the plate-tectonic model in geophysics, the scores of mathematical models in hereditary and population studies, the thousands of mathematical models in economics, engineering, and so on. (Matthews, 2007, pp. 647-648)

The great value of using models in science as representations is that they enable the complex nature of a target system, which is normally abstract, to be made more apparent or obvious (Gilbert & Boulter, 1998) by providing specific information about the nature of the target system such as its structure, behaviour, and mechanism (Buckley & Boulter, 2000). In other words, the main function of models as representations is simplification or approximation of the target system (Boohan, 2002; Coll, 2006; Gobert & Buckley, 2000), which is done by selecting or excluding certain features of the target system to create a simpler and manageable piece of information (Mäki, 2001; Oh & Oh, 2011; Van Driel & Verloop, 2002). Therefore, a given model in science is an inherently incomplete or partial version of a target, which only displays and/or performs specific attributes of the target, and thus can also be considered as an idealisation or abstraction of the target system (Portides, 2008). Although models may not be able to fully represent a target system, "any loss of accuracy is compensated for by gains in clarity" (Coll, 2006, p. 66).

Models in science perform at least two representational functions, that are representation of the reality and of scientific theory (Chamizo, 2013; Espinet, Izquierdo, Bonil, & De Robles, 2012; Frigg & Hartmann, 2006; Mäki, 2001; Morrison, 1999). In terms of representation of the reality, models can be regarded as surrogate objects that consist of a conceptual representation of a real thing. Good examples of models that represent a phenomenon are, a human skeleton model representing the human bones structure; scale models of an aeroplane, which can be used for studying the real design of aeroplane aerodynamics; and scale models of the Solar System. Scientists use such “models to represent aspects of the world” (Giere, 2004, p. 747). There are diverse aspects of the reality that are represented by a model which include observable or unobservable objects, properties, states, processes, and sequences of events (Oh & Oh, 2011). Hart (2008) says that:

The representations, concepts, relationships and explanatory entities that figure in the model are not given in the phenomenon itself. They are overlays on reality, produced through the human activities of striving to understand, predict and control the physical world. (Hart, 2008, p. 530)

A good example of model that is used to understand and predict the physical world is the weather forecast model, which is constructed based on collections of quantitative data of the atmospheric state and may include temperature, barometer pressure, humidity, and wind velocity, and the correlation of these data with the weather conditions. With this weather forecast model, we are able to predict the weather of a given location and time – to take control and manage our lives more effectively. Therefore, models can provide representations for the reality, and are used to interpret and comprehend complex natural phenomena (Hestenes, 1992).

Models in science are, however, not only representational of the real world but can also be created to express theoretical ideas. In other words, models function to represent a scientific theory by interpreting the laws, axioms or principles of that theory (Espinete et al., 2012; Frigg & Hartmann, 2006). Similar to representing the real world, this function involves various idealisations,

approximation, and assumptions of the theory of interest. The function of models in representing a theoretical idea can be exemplified by the chemical bonding models of the hydrogen molecule (Figure 2.6), which can be based on either the valence bond theory or molecular orbital theory (Suckling, Suckling, & Suckling, 1978).

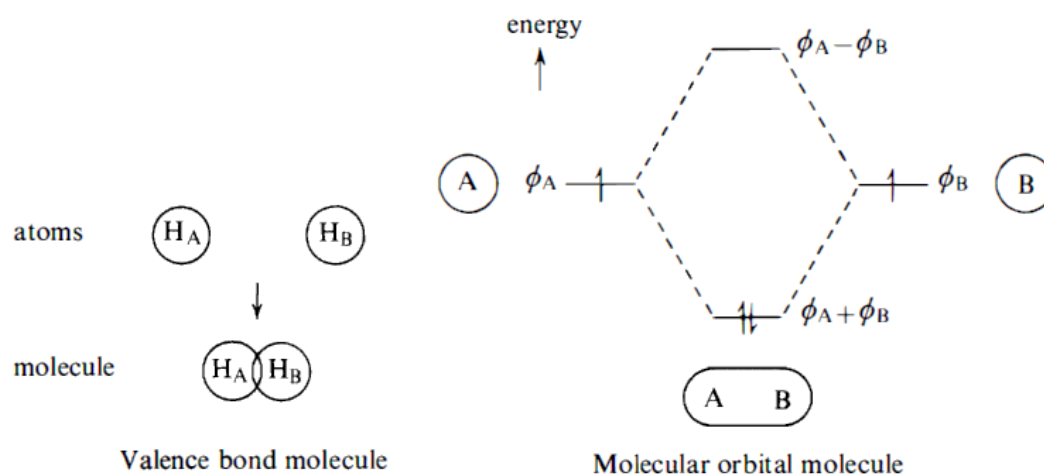


Figure 2.6 Models of Hydrogen Molecules From Different Theories (Suckling et al., 1978, p. 86)

The distinct representational functions of models as links between the real world and scientific theory are not mutually exclusive because “scientific models can at once represent in both senses” (Frigg & Hartmann, 2006, p. 741). Science itself is a way of understanding the real world, usually through the formation of theories. Thus, constructions of models based on scientific theories are indirectly a way of modelling the real world. For example, an ideal gas which can be expressed in terms of the relationship between the pressure p , the volume V , the temperature T , and the quantity n of gas in the algebraic expression $pV=nRT$, can be considered as a model for both the behaviour of gas and at the same time as a model for the kinetic theory of gas (Suckling et al., 1978). Therefore, the interrelation between models and theories and the real world can be regarded as illustrating the ‘mediator’ role of models by connecting a theory and a phenomenon (Morrison, 1999; Morrison & Morgan, 1999; Oh & Oh, 2011). Indeed, models in science serve not only as the *representational product* of science, but also, more importantly as *tools* of science (Brodie et al., 1994),

whereby, models have a variety of functions in science – beyond serving just as representations of the real world or theories. The function of models in science is to then help scientists to explain and predict phenomena; construct, interpret, explain, and test hypotheses or theories; experimenting; design and produce technologies (Frigg & Hartmann, 2006; Mäki, 2001; Rosenblueth & Wiener, 1945).

Models in science, which are developed as representations, thus do not merely portray the structure of the phenomenon, but more importantly are able to test and extend our understanding of phenomena (Kenyon, Schwarz, & Hug, 2008). In this sense, models can be considered as generative because models are used:

to explain and predict natural phenomena. A model provides an explanation for why the phenomenon behaves in the way it does, and can generate new predictions that can be tested against new data from the phenomena. The model and the phenomenon exist in a dialogic relationship; analyses of the phenomenon gives insights into potential elements, relations, operations, and rules within the model, and indicates the evidence that constrains possible models. In turn, the model generates new explanations and predictions about the behaviour of the phenomenon. (Schwarz et al., 2009, p. 634)

Scientists use models to help them comprehend and communicate about a phenomenon, including inferring, and predicting behaviour about the phenomenon (Chamizo, 2007, 2013; Espinet et al., 2012; Oh & Oh, 2011). Indeed, models in science serve great value in providing explanatory information of the target (Clement, 2000; Espinet et al., 2012; Etkina, Warren, & Gentile, 2006; Gilbert, Boulter, & Rutherford, 1998). Simplification in models is said by Del Re (2000), to be something of an idealisation, which we need in order to cope with the difficulties arising from the complexity and details of the real phenomenon. Frigg and Hartmann (2006) support this interpretation saying that models not only simplify the nature of the phenomenon of interest, but also the complex nature of the theories underpinning the phenomenon. For example, a system of billiard balls in a box is used to help our understanding of gases and their behaviour; and the analogy with Solar System, is used to help understand atomic theory (Mäki, 2001).

Models in science are, however, more than just static explanatory tools. They often play a more dynamic role in scientific inquiry which includes discovery, development, evaluation, and exposition of scientific knowledge (Coll & Lajium, 2011). Models in science are not only important for their generative capability but also make a contribution to construction of knowledge through the formation or generation of new knowledge. In other words, models play important roles not only for explanations or representations of the knowledge but also lead scientists to new insights about the target. Knowledge formation using models arises from their independence from theory, and because of this quality, they are referred as to 'autonomous agents' (Morrison, 1999), which models can be constructed entirely neither from data nor theory (Frigg & Hartmann, 2006). The London model of superconductivity is a good example of where a model can be independent to theories and contributes to the formation of new understanding of a phenomenon (Suárez, 1999).

The London equation was not derived from electromagnetic theory, nor was it arrived at by simply adjusting parameters in the theory governing superconductors. Instead, the new equation emerged as a result of a completely new conceptualisation of superconductivity that was supplied by the model. So, not only was the model constructed without the aid of theory, but it became the impetus for a new theoretical understanding of the phenomena. (Morrison & Morgan, 1999, p. 13)

Models may also be used for further development of scientific knowledge (Coll & Lajium, 2011; Gilbert, 2004; Justi, 2009). For example, Klein (1999) saw that in developing the notion of substitution reactions between alcohols and chlorine, Dumas used chemical formulae, which functions as a model that helped in developing the knowledge of organic transformations.

To some degree, models also permit scientists to manipulate and experiment with phenomena (Rosenblueth & Wiener, 1945). This function enables scientists to answer questions and to develop new questions; as a result, scientists are able to create and test new hypotheses by using models. Mäki (2001) explained this idea, commenting that the Solar System model of an atom lead to other more fruitful questions and hypotheses; ultimately leading to a deeper understanding

of atomic structure and new contributing concepts – such as the shape of the orbital and the velocity of electrons. In other words, models function to facilitate theory and hypothesis evaluation, allowing scientists to examine a model's validity through experimentation (De Vito, 1968; Frigg & Hartmann, 2006; Mäki, 2001). From experimentation, scientists can refine their understanding of the theories and related phenomenon, come to understand the limitations of their theories and the models used, and perhaps, develop new models and theories.

Finally, since models are simplified and idealised forms of a target system, they are commonly used for exposition, and explanation of complex hypotheses or theories (Coll & Lajium, 2011). In other words, models serve as communicative aids, which enable scientists to share or disseminate their knowledge and understanding to the scientific community and the public (Chamizo, 2007; Oh & Oh, 2011).

2.1.4 Modelling

Modelling can be thought as the process of forming and constructing models, and this always involves mental models (Brodie et al., 1994; Duit & Glynn, 1996). However, the term modelling can be more than just the act of producing a model. Modelling is a dynamic and continuous process of creating, testing and communicating idea (Justi & Gilbert, 2002c; Maia & Justi, 2009).

A basic view of modelling proposed by Suckling et al. (1978) see it as a linear process that involves: (1) recognition of the existence of a problem and making a decision to tackle using a model, (2) delineation of the system to be studied, (3) formulation of questions, (4) construction of the model, (5) running the model, and (6) analysing results and implications.

In contrast, Justi and Gilbert (2002a) developed a Model of Modelling as shown in Figure 2.7. Here, modelling is viewed as a non-linear process and emphasis is placed on mental models as central to the formation of models. Modelling, according to Justi and Gilbert (2002a), involves several stages: determination of

Lesh and Doerr (2003, p. 17) proposed a simpler view of the modelling cycle, which involves four steps: (1) a description that establishes a mapping to the model world from the real (or imagined) world, (2) manipulation of the model in order to generate predictions or actions related to the original situation, (3) translation or prediction by carrying relevant results back into the real (or imagined) world, and (4) verification concerning the usefulness of actions and predictions” (see Figure 2.8). In a similar manner, working from Robert Karplus’ Learning Cycle, Halloun (2006) proposed the ‘modelling learning cycle.’ This cycle consists of five phases: (1) exploration, (2) model adduction, (3) model formulation, (4) model deployment, and (5) paradigmatic synthesis” (see Figure 2.9).

Drawing from these models of modelling, there are few common characteristics that can be identified. All of these models of modelling involve cyclical processes, including the process of identifying the real world phenomena, developing the model, testing, and remodelling. Perhaps the most important aspect of modelling is that the process is a continuous activity, and the real world phenomenon of interest can be represented with various models produced in different cycles of modelling. Although the model of modelling Justi and Gilbert (2002a) proposed seems less appealing because of its complexity, it is more comprehensive compared with other approaches. This complexity occurs because they considered the function of mental models in the production of models, which identifies the relationship between the models produced in the process of modelling with the person’s mental model(s).

In summary, a model can be considered as a representation of objects or events for a specific purpose, which can be constructed from an analogical relation between a source/analogue and a target. On the other hand, mental models are considered internal mental representations, which are implicit, reside in one’s cognitive structure, and are used in reasoning. Both models and mental models coexist in the process of modelling.

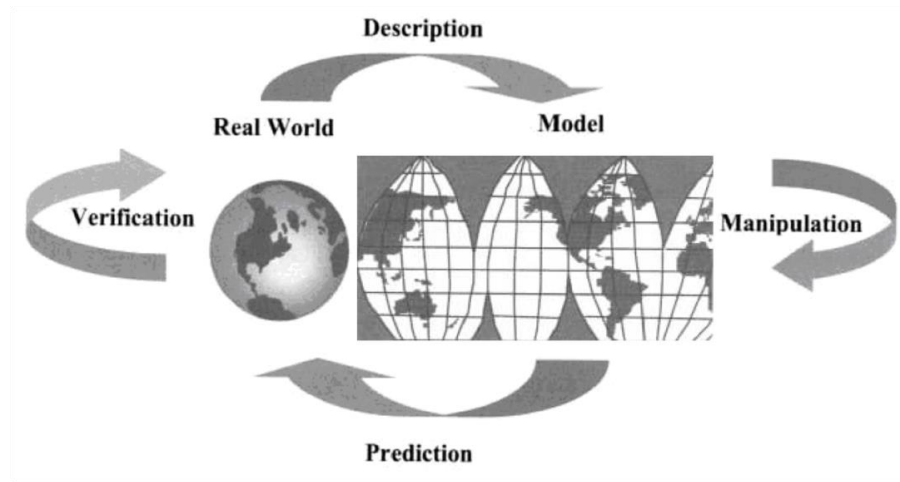


Figure 2.8 Modelling Cycle (From Lesh & Doerr, 2003)

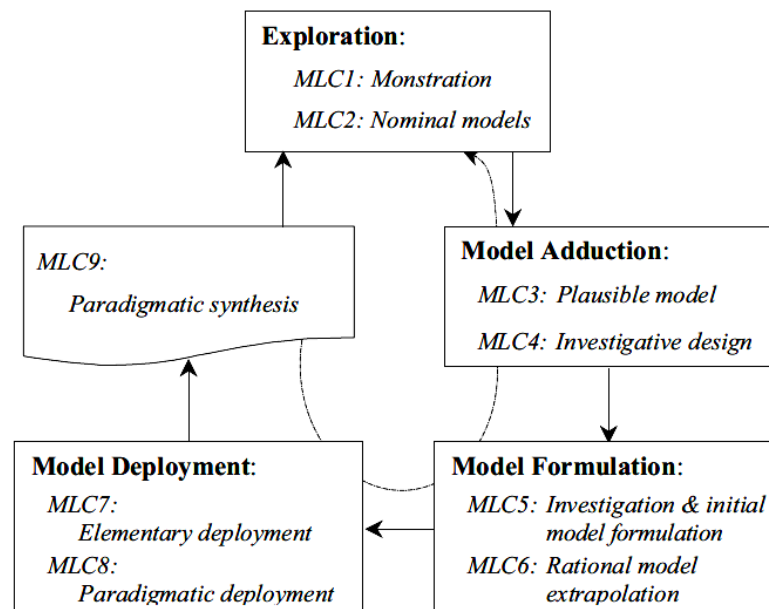


Figure 2.9 The Modelling Cycle (From Halloun, 2006)

2.2 Mental Models

In the previous section, discussions of the nature of models and modelling in science were presented. The relation between models and mental models were mentioned briefly. In this section, the idea of a mental model as an internal model is further discussed.

Johnson-Laird (1983, p. 2) argues that “if you understand inflation, a mathematical proof, the way a computer works, DNA or a divorce, then you have

a *mental representation* [italics added] that serves as a model of an entity in much the same way as, say, a clock functions as a model of the earth's rotation." This thesis was considered to be first introduced by Craik (1967), who explained:

If the organism carries a "small-scale model" of external reality and of its own possible actions within its head, it is able to try out various alternatives, conclude which is the best of them, react to future situations before they arise, [utilise] the knowledge of past events in dealing with the present and future, and in every way to react in a much fuller, safer, and more competent manner to the emergencies which face it. (Craik, 1967, p. 61)

This argument suggests that an external model for prediction or reasoning of the physical world, which is created through a mental process, can be represented as an internal model of reality in the mind, and functions similar to the external model. Craik's notion of 'small-scale model' in the mind is then further developed as a mental model, which has been developed in various fields such as cognitive psychology, linguistic, human-machine interaction, and science education (Franco & Colinvax, 2000; Thagard, 2010). These disciplines have "taken up the idea of mental models; either as an explanatory principle or as a term requiring explanation" (Rickheit & Sichelschmidt, 1999, p. 9).

For example, in human-machine interaction, mental models are mainly used as explanatory principles, in which people are assumed to develop mental models of a physical system as a means of controlling, explaining or predicting the behaviour of the physical system (e.g., Carley & Palmquist, 1992; Gentner & Stevens, 1983; Jonassen & Henning, 1999; Payne, 1991; Rouse & Morris, 1986). In cognitive psychology, on the other hand, the mental model construct is something that needs theorisation or an explanatory theory of cognitive phenomena. The cognitive psychology focuses on the nature of mental models itself, hypothesizing on its construction and the way humans perform cognitive tasks such as reasoning, inference, and language comprehension (e.g., Garnham, 1999; Johnson-Laird, 1983, 2004a, 2004b; Pribbenow, 1999; Van Dijk & Kintsch, 1983).

Despite the wide applications of the notion of mental models which have produced a wide variety of definitions, mental models as a term can be distilled out as a form of hypothetical internal representation of external objects or a body of knowledge (Carley & Palmquist, 1992; Johnson-Laird, 1989; Rapp, 2005; Rickheit & Sichelschmidt, 1999), which is used to accomplish cognitive functions or tasks such as understanding, reasoning, prediction, and problem solving (Burns, 2001; Gentner, 2001; Greca & Moreira, 2002).

2.2.1 Nature of Mental Models

Mental models as ‘the structural analogues of the world’ are among other postulated forms of mental representations such as “propositional representations which are strings of symbols that correspond to natural language” and “images which are the perceptual correlates of models from a particular point of view” (Johnson-Laird, 1983, p. 165). Mental models are also distinguished from schemas (Brewer, 1987, 2003; Chinnappan, 1998). In that:

Schemas are integrated "packets" of information that can be used to construct mental models of particular objects or situations. A mental model can be viewed as an [organised] internal representation of aspects of a world, including (perhaps) a representation of the individual. ... A mental model will often include actual or imagined event sequences. ... [Therefore,] mental model can be viewed as an integrated representation of numerous hierarchically [organised] schemas, instantiated in whole or in part, which will be used to make decisions and guide [an individual's behaviour]. ... A major function of the internal model is to allow "*mental simulations*" [italics added] of the outcomes of alternative possible scenarios. (Holyoak & Gordon, 1984, pp. 45-48)

Although mental models have been studied as a form of hypothetical construct from different perspectives, a general view about the nature of mental models that can be drawn is that they serve as a mental simulation for a system (Craik, 1967; de Kleer & Brown, 1983; Johnson-Laird, 2005a, 2010; Nersessian, 2008). In this sense, an individual is able to ‘run’ a mental model internally in his/her mind’s eye and observe the behaviour of the system without having the actual system present (de Kleer & Brown, 1983; Gentner, 2001; Johnson-Laird, 1989; Payne, 1991).

Similar to physical or expressed models, mental models are also a simplified form of what they are representing, which is often complex. In this sense, a mental model represents the target system in an analogical manner (Collins & Gentner, 1987; Payne, 1991; Pribbenow, 1999), where the structure of the mental model corresponds to, or is similar to the structure of the system that it represents (Johnson-Laird, 1989, 2004a),

A model represents a state of affairs and accordingly its structure is not arbitrary ... but plays a direct representational or analogical role. Its structure mirrors the relevant aspects of the corresponding state of affairs in the world. (Johnson-Laird, 1980, p. 98)

Therefore, a mental model is identical or similar, to a certain extent, to the structure of an external system, which is some components in the original system exist in the mental model (Greca & Moreira, 2000; Rickheit & Sichelschmidt, 1999). The components of the external system represented in mental models are claimed to be represented as icons or tokens – an iconic representation of mental models (Johnson-Laird, 2004a, 2004b, 2005b, 2010). In other words, a mental model is a set of icons or tokens, which represent entities comprised in the system (Johnson-Laird, 1983, 1989, 1996; Rickheit & Sichelschmidt, 1999). For example, an atom mental model may comprise of icons such as a sphere that represent the nucleus of the atom, smaller spheres that represent electrons, and round lines that represent orbits.

Although a mental model is considered as analogical to its external system, one important characteristic of a mental model is that it is commonly incomplete and approximate, a simpler version of the system it represents, and rather ‘unscientific’ (Halford, 1993; Johnson-Laird, 1983; Norman, 1983). It is not an exact replica (Rapp, 2005). This incompleteness means that the mental model is considered ‘synthetic’ and only represents certain aspects of the system in order to be efficient and ‘economic’ (Franco & Colinviaux, 2000; Greca & Moreira, 2000; Norman, 1983). As a consequence, mental models “contain elements that are merely imitations of reality – there is no working model of how their counterparts in the world operate, but only procedures that mimic their

behaviour” (Johnson-Laird, 1983, p. 10). As a result, mental models may lead to an “erroneous conclusion and to certain persistent cognitive illusions” (Johnson-Laird, 1989, p. 486).

Despite the fact that mental models have shortcomings, they permit people to generate descriptions of the purpose and architecture of a system, to provide explanations of its function and state, to make predictions of the state of the external system (Rouse & Morris, 1986), and ultimately, influence and control the external system (Greca & Moreira, 2000, 2002).

[Mental models] enable individuals to make inferences and predictions, to understand phenomena to decide what action to take and to control its execution, and above all to experience events by proxy; they allow language to be used to create representations comparable to those deriving from direct acquaintance with the world; and they relate words to the world by way of conception and perception. (Johnson-Laird, 1983, p. 397)

Mental model in discourse

It is argued that mental models play important roles in language discourse by allowing people to comprehend narratives, which are not necessarily described explicitly in spoken language or text, through construction and manipulation of mental models¹ (Garnham, 1987; Gottschling, 2009; Nersessian, 2008). For example, when reading a sentence, “James’ mother is sitting next to him, comforting him for his dead fish,” a reader may infer that James is holding a small aquarium with his pet fish in it, on the basis of a constructed mental model. This mental model is isomorphic with the situation portrayed in the sentence and contains at least icons that represent James, his mother, and the fish. The inference about the pet fish in the aquarium is also influenced not only by the meaning of the sentence, but also on background knowledge, and knowledge of human communication (Johnson-Laird, 2004a). Therefore, mental models in discourse function by making the “structure not of sentences but of situations as we perceive or imagine them” (Johnson-Laird, 1989, p. 471). It is embodied with

¹ In this context, mental model is referred as situation model which mental models are argued to be constructed when individuals understand a situation or context (Van Dijk & Kintsch, 1983).

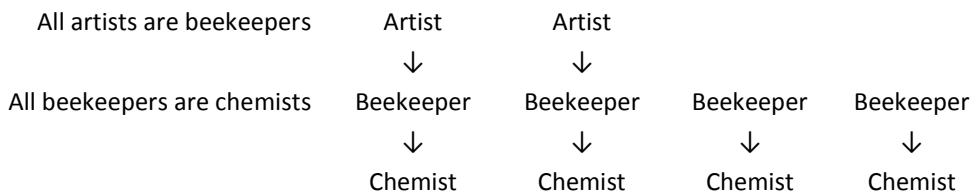
“spatial, temporal, and causal relationships among events and entities of the situation described by the narrative” which is based on the reader’s pre-existing knowledge (Nersessian, 2008, p. 23).

Broadly put, comprehension of narratives necessitates construction of mental models that track the relationships between characters, objects, and events described in the narratives which enable simulation, inferences and prediction that relates to the narratives (Rapp, 2005).

Mental model in logical reasoning

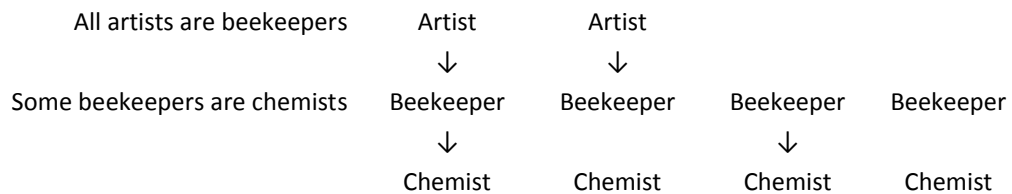
Similarly, the literature also provides evidence that mental models are necessary in human logical reasoning. This basic tenet about the roles of mental models in human reasoning (also called model-based reasoning) is incompatible with the notion in the role of formalism (e.g. rules of logic, the Euler circle, Venn diagram, etc.) in the process of reasoning (Johnson-Laird, 1989, 2004a, 2010; Rickheit & Sichelschmidt, 1999; Wild, 1996). In other words, reasoning may involve semantic (meaning-based) processes based on mental models rather than rule-based (syntactic) processes as characterised by formal logic¹ (Sternberg & Sternberg, 2012).

Take for an example, the logical premises: “All artists are beekeepers. All beekeepers are chemists.” A valid conclusion can be drawn is, “all artists are chemists,” without relying on rule-based inference like Euler circles or Venn diagram. One can construct a mental model of actors acting out as artists, some as beekeepers, and some as chemists, which be represented in the following structure (Johnson-Laird, 1983).



¹ Formal logic is a set of rules for making valid deductions, which related to pure mathematics ("Formal logic," 2013).

However, for the logical premises that: “All artists are beekeepers. Some beekeepers are chemists,” it seems many people draw invalid conclusions, for example, that some of the artists are chemists. This response suggests that it may be drawn from a possible manipulation of the following mental model (Johnson-Laird & Steedman, 1978):



Therefore, Johnson-Laird (1983) argued that human reasoners tend to make inferences by manipulating mental models, and they are constructed based on superficial representations that are expressed by premises rather than developing rules of inference; this process as shown above, does not always lead to valid deduction.

Mental model as an internal model

Mental models are also conceived as an internal model or iconic representation of a hypothetical situation, event, object or process (i.e., the target system) which serves as a structural, behavioural, or functional analogue (Nersessian, 2008; Norman, 1983; Rickheit & Sichelschmidt, 1999). In this sense, “human beings do not grasp the world directly but through an internal representation of it” (Greca & Moreira, 2002, p. 109). In this account, a mental model is regarded as a form of working model which provides a mental simulation of the phenomena (Johnson-Laird, 2004a). Put simply, this construct means that a mental model functions as a simulator in a person’s cognitive structure, and is used in understanding his/her surroundings or situations. As Gentner (2001) commented, a person using his/her mental model would be able to predict that when a glass of water is spilled on a table, the water spreads across the table and pours onto the floor. A mental model, thus enables a person to infer or predict without being exposed to the actual situation. For example, if asked “which will fall on the ground first, a feather or a golf ball?” most people will answer a golf

ball, even if they have never actually tried this experiment, based on the mental tokens/icons of both feather and golf ball simulated mentally. As a consequence, Gentner (2001) said that mental models are useful in capturing human knowledge, including incorrect beliefs, and observes that, in this role they can help reveal aspects of the learning process.

Up to this point, the examples that have been presented suggest that mental models comprise icons that are structurally or visually similar to the original system (e.g., a ball is represented as a sphere mental token). This representation is not necessarily the case. Mental models can also be in the form of analogues that not only mimic the behaviour, but have entirely different architecture to the system they represent (Johnson-Laird, 1985). For example, common mental models of electricity are the flowing water model and the moving crowd model (Gentner & Gentner, 1983); the valve model and the feedback model as mental models of the heat control thermostat (Kempton, 1986); and the 'heat threshold' and the 'rocket model' of water evaporation (Collins & Gentner, 1987). These mental models are comprised of entirely different structures to what they represent – a unique form of symbolic representation (Rickheit & Sichelschmidt, 1999). They are actually based on different domains of knowledge or situations where their characteristics are used to represent or simulate a target system in another domain (Halford, 1993; Staggers & Norcio, 1993). Despite the analogical nature of mental models, they enable people to control, make decisions, infer and reason about the behaviour of the represented system with a certain degree of efficiency, depending on the accuracy of the mental models (Gentner, 2001).

Moreover, mental models as analogical representations also play an important role in the development of scientific models. It is legitimate to say that scientific models such as the Bohr atom, plate tectonics, and the double helixes of DNA are merely physical constructions (or expressed models) of scientists' mental models (Brewer, 2003), which were developed through scientists' *thought experiments* (Gooding, 1992, 2006; Nersessian, 1992a, 1992b). In other words, scientists express their mental models as physical models in the form of speech, writing, mathematical formulae and other modes of representation, which are

available for interrogation and development. These physical models are actually scientists' mental models in the form of expressed models (Gilbert & Priest, 1997; Van Driel & Verloop, 1999). A scientist's expressed model is then either accepted by the scientific community as the scientific model (i.e., consensus model of the scientific communities) or becomes an historical model when it is superseded (Gilbert & Boulter, 1998; Gilbert et al., 2000). In other words, mental models can be conceived as "intermediate levels of analysis between the modelled phenomenon and the resulting final scientific model" (Silva, 2007, p. 837).

Given the fact that both mental models and concepts are representations of the experienced world, expressed in similar ways such as in writing, action, utterance, two dimensional graphics or prototypes, they are distinct in some aspects – although they are related. The basic distinction between mental models and conceptions lies in terms of their generality and dynamics. "Conceptions express a domain-specific understanding of particular ideas and phenomena and, as such, they are not generalizable nor integrated into overall interpretative systems" (Franco et al., 1999, p. 281). Therefore, concepts can be considered as 'pieces of knowledge' (diSessa, 1988) "that point to local representations of particular instances" (Stefani & Tsapalis, 2009, p. 521). Mental models, on the other hand, are more globally constituted with many inter-related elements, and more than just one concept (or other form of mental representations such as schemas or mental images). Mental models also serve as mental simulations which can refer to dynamic systems (Fraik, 1967; de Kleer & Brown, 1983; Holyoak & Gordon, 1984; Johnson-Laird, 2005a, 2010; Nersessian, 2008), such as a mental model of human blood circulation which simulates how blood flows from the heart to the lungs and through the body. In contrast to this dynamic feature, conceptions seem to be relatively static descriptions of a component of a system, for example, the concept of the heart.

In summary then, models, mental models and target systems are interconnected through analogical relations as shown in the Figure 2.10 (adapted from Buckley & Boulter, 2000; Chamizo, 2013; Duit & Glynn, 1996). Thus a mental model is an

internal model of a target system, and it is analogical and iconic because it is based on a source (or an analogue), and comprises similar characteristics to the target system. It provides a mental simulation that assists in discourse, inference, reasoning, and decision-making. A mental model can be articulated or constructed physically as an expressed model, which shares the same characteristics of the mental model, target system, and also the source on which the mental model is based. For example, J. J. Thomson could have a mental model of an atom with negatively charged electrons dwelling in a positively charged fluid orb, which could be represented as the “plum pudding” model of an atom (expressed model) based on the characteristic of a plum pudding (i.e., the source).

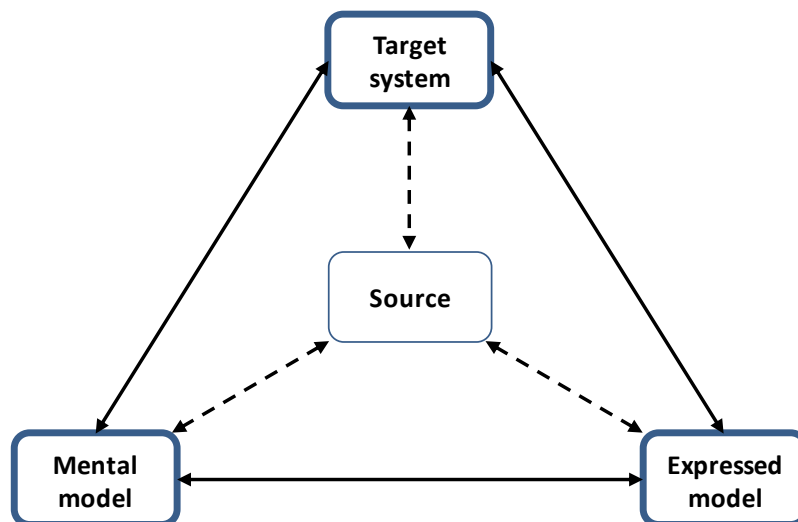


Figure 2.10 Analogical Relation between Model, Mental Model and Target System

2.2.2 Typologies of Mental Models

Although mental models are implicit in nature and more challenging to classify, there are a number of typologies for mental models reported in the literature. As with expressed models, mental models can also be categorised based on the entities that are represented by the mental models. For example, mental models that represent physical objects or phenomena such as chairs, cars, animals, and computers, can be called *physical mental models*. *Conceptual mental models* are mental models used to “represent abstractness, logical operators such as

conjunction or disjunction, truth or fiction stories,” good or bad behaviour, and physical or chemical change (Rickheit & Sichelschmidt, 1999, p. 13).

Another way of classifying mental models is based on the quality of representation of the target system. For instant, Vosniadou and Brewer (1992) classified children’s mental models of the earth into *scientific mental models*, *initial mental models*, and *synthetic mental models*. Scientific mental models can be considered as mental models that are consistent with scientific models, whereas initial mental models are mental models that children possess prior to formal learning about a phenomenon. The literature suggests that when children are exposed to scientific information about a particular phenomenon, they try assimilating the information into their naïve theoretical framework. The end results of this assimilation form what are called synthetic mental models. In other words, a synthetic model is a mixture or integration of children’s initial mental models and scientific models, which is still embedded in their naïve theory.

A similar attempt to categorise mental models based on the quality of representation was proposed by Chi and Roscoe (2002). This typology draws on the coherence, correctness and completeness of the mental model (see the Venn diagram in Figure 2.11). Chi and Roscoe categorised mental models as either *complete or incomplete*, *incoherent or coherent*, and *correct or flawed*. An ‘incoherent’ or a ‘fragmented’ mental model ($a'bc'$, $a'bc$, and $a'b'c$ regions in Figure 2.11) can be conceived of as unconnected and unsystematic knowledge. As a consequence, a person with an incoherent mental model of a certain phenomenon will be unable to give consistent and predictable explanations. Chi and Roscoe (2002) also claimed that students with a fragmented mental model often are unaware of any gaps in their understanding of the phenomenon. In contrast, a coherent mental model is made of organised propositions, and this enables generation of consistent and systematic explanations or predictions. However, coherent mental models can be correct, or flawed. For example, an organised and coherent structure in a flawed coherent mental model ($ab'c'$ and $ab'c$ regions in Figure 2.11) may be based on an incorrect belief or principles.

According to Chi and Roscoe (2002), a flawed coherent mental model shares a certain number of propositions with a correct mental model, and individuals who possess this type of mental model are typically not aware of their lack of understanding. While they are able to give consistent and adequate answers, they typically lack deep understanding. Mental models can also be characterised by virtue of their completeness. A complete mental model has most of the key propositions of the target system, while an incomplete one, as the name suggests, has many missing pieces ($a'b'c'$, abc' , $ab'c'$ regions in Figure 2.11).

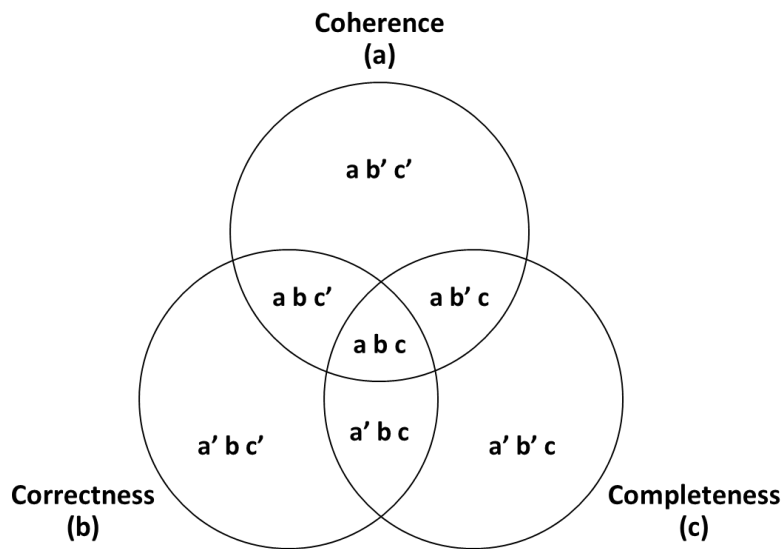


Figure 2.11 Categorisation of Mental Models

2.2.3 Students' Mental Models of Scientific Ideas

Mental models can be regarded as the products of learning. It is reported that mental models also play important roles in the process of learning because learning generally can be viewed as mental modelling (Duit & Glynn, 1996). Thus, mental models are considered important in learning science since it is assumed that they provide valuable information about students' science conceptual frameworks, or underlying knowledge structures (Coll et al., 2005; Vosniadou & Brewer, 1992). Therefore, capturing students' mental models is one way to understand the content and structure of students' knowledge of

scientific concepts, as well as reflecting students' beliefs and interpretation of a system (Norman, 1983).

There is now a large body of research on students' understanding about scientific ideas for various domains. Some examples include mental models about natural phenomena (Anderson, 1965), chemical phenomena (Chittleborough, 2004), chemical bonding (Coll, 1999, 2008; Coll & Treagust, 2001, 2002, 2003a, 2003b; Taber, 2003), matter (Adbo & Taber, 2009), chemical substances (Dalton, 2003), atoms and molecules (Harrison & Treagust, 1996, 2000a), acids and bases (Lin & Chiu, 2007, 2010), atomic structure (Park & Light, 2009), chemical equilibrium (Chiu, Chou, & Liu, 2002), organic chemistry (Treagust, Chittleborough, & Mamiala, 2004), heat conduction (Chiou & Anderson, 2010), electricity (Borges & Gilbert, 1999; Clement & Steinberg, 2002; Jabot & Henry, 2007), light (Hubber, 2006), earth and cosmology (Nobes et al., 2003; Panagiotaki, Nobes, & Potton, 2009; Straatemeier, van der Maas, & Jansen, 2008; Vosniadou & Brewer, 1992; Vosniadou, Skopeliti, & Ikospentaki, 2005), and the environment (Shepardson, Wee, Priddy, & Harbor, 2007).

Analysis of this body of research reveals common findings about students' mental models for scientific concepts. Most researchers reported that students' mental models are not consistent with the actual scientific or teaching models, and can be considered flawed, often with misconceptions (Coll & Treagust, 2003a, 2003b; Harrison & Treagust, 1996; Samarapungavan, Vosniadou, & Brewer, 1996; Taber, 2003; Vosniadou & Brewer, 1992). These mental models are also referred to as initial mental models or synthetic mental models (Vosniadou & Brewer, 1992). For example, Borges and Gilbert (1999) revealed that a common mental model of electricity held by students prior to formal learning is the 'electricity as flow' model that pictures that electric current as material flowing in the circuit; this model is considered initial mental model, and it is inconsistent with the scientific view of electricity. Besides being inaccurate, not only for secondary students but university graduate and postgraduate students as well, are also reported can be simple and realistic, or concrete looking (e.g., Coll, 2008; Coll & Treagust, 2001, 2003a). Although research

suggests that simplistic mental models are *preferred* by secondary and tertiary level students, it seems from a number of cross-sectional and longitudinal studies that students' mental models improve and advance in complexity and sophistication with formal engagement in science learning (Borges & Gilbert, 1999; Coll & Treagust, 2001, 2003b; Hubber, 2006). Nevertheless, research by Nobes et al. (2003), Straatemeier et al. (2008), and Panagiotaki et al. (2009) indicated that students may not possess mental models *per se* (initial or synthetic mental models), but instead *fragments* of knowledge, which together do not constitute stable mental models. This view contrasts with Vosniadou and Brewer (1992) who argued that students may hold stable initial mental models (in their study about mental models of Earth), constrained by sets of assumptions that they derived from everyday experiences.

Some research about students' mental models and conceptions suggests that there are a number of factors that are capable of influencing the construction of their mental models. The impact of these factors is exemplified in studies concerning children's mental models about Earth which is found to vary depending on the cultural or social context in which students learn. Nobes et al. (2003) and Panagiotaki et al. (2009), for example, argued that British children's (from various cultural backgrounds) mental models about Earth were found to be more scientifically consistent compared to those of American children reported by Vosniadou and Brewer (1992). Nobes et al. (2003) suggested that this difference could be related to school children nowadays having greater access to information about astronomy especially through the Internet than those children in Vosniadou and Brewer's study. These results are also consistent with studies of Indian children's mental models about Earth, which are influenced by folk mythologies based on children's readings of Hindu religious text depicting Earth supported by an ocean or a body of water (Samarapungavan et al., 1996). Lin and Chiu (2007) also reported that Taiwanese ninth-grade students developed a Chinese Character mental model of acid-base that identify acidity or basicity of solution based on the specific Chinese characters that was influenced by the meaning in Confucianism. In short, these

findings indicate that cultural information exerts a powerful influence on human understanding about phenomena in their surroundings.

Similarly, it is reported that students' mental models are influenced by their physical surroundings. Shepardson et al. (2007), for example, found that students in suburban and rural areas who are exposed to the natural environment were less likely to believe that the environment is influenced or modified by human activity compared with those in urban areas who viewed humans as a part of the environment in their mental models. It is also claimed that external models or representations contribute to students' development of their mental models, especially those related to scientific models. Schnotz and Kürschner (2008), for example, said that students exposed to external representations of the Earth surface are better at solving problems related to time phenomena of different time zones compared to students with no exposure to external representations. Schnotz and Kürschner (2008) maintained that the external representations used in their study affected the structure of the students' mental models.

2.3 Models and Modelling in Science Education

In the previous discussions, ideas pertaining to models and mental models can be discussed around origins, definition, and typologies. Another aspect of interest and relevant to this study in discussing models, is their application in science teaching and learning. Using models in science education has long been recognised as essential by education researchers (Anderson, 1965; De Vito, 1968). As indicated above, models play a key role in science in the representation of systems (Mäki, 2001; Oh & Oh, 2011; Silva, 2007; Van Driel & Verloop, 2002), and are useful in assisting in describing and understanding their structure or properties. Gilbert and Boulter (1998) observe that:

The great value of many models is that they enable ideas, objects, events, processes or systems - which are complex, on a different scale to that which is normally perceived, abstract, or some combination of these – to be rendered either visible or more-readily [visualised]. (p. 56)

2.3.1 Models and Students' Learning of Science

Teaching science using models, such as teaching models or curricular models (which are usually analogical models), enables teachers to present and explain phenomena that are difficult to be shown to students directly (Boohan, 2002; Brodie et al., 1994; Coll et al., 2005) by providing simplified pieces of information about the structure, behaviour and mechanism of the system (Buckley & Boulter, 2000). Such systems might include: phenomena that are too small to be seen using the naked eye such as microorganisms, living cells, and atomic structure; things that are too big to see as a whole such as Solar System and volcanoes; processes that occur too fast for detection using human senses, such as collision and flying; processes that take a long time to complete such as metamorphosis and foetus growth; and finally complex systems such as the weather system, nuclear reactors and the internal combustion in the diesel engine.

In the pedagogy of science, models are frequently used to represent the ideas or theories of science about scientific phenomena that are often abstract and conceptual – sometimes impossible for an untrained mind to comprehend. Expressed models, especially those that are concrete and visual such as scale models, maps, and diagrams, can be used to portray scientists' understanding of the phenomena. It is believed that such models promote mental model construction and manipulation of abstract structures and functions of phenomena (Harrison & Treagust, 2000b; Treagust et al., 2004). An example is the particle model of matter, which is typically represented with ball-like objects. With this concrete model of particles, students are able to perceive that matter is made from discrete particles, and they can come to understand how they are arranged in the different states of matter. Such an approach to teaching science is consistent with a constructivist view of learning, where students' ideas are developed using their familiar or previous knowledge (Boulter & Buckley, 2000; Duit, 1991; Harrison & Treagust, 1993; Matthews, 2007). For these reasons, models can be considered as instructional tools, aiding students' understanding of conceptually salient features of phenomena (Coll & Lajium, 2011). As a consequence, the application of models as instructional tools in science

pedagogy also includes the use of multiple models to represent scientific idea of the same entity or phenomena that may enhance students understanding of scientific concepts (Coll, 2006; Oh & Oh, 2011). Harrison and Treagust (2000a) reported that students who are exposed to multiple models for atoms, molecules, and chemical bonds used these models consistently in their explanations and displayed more scientific understanding of particles than students who were only involved with an 'ideal' model. In addition, Harrison and Treagust (1998) argued that the utilisation of multiple models in learning science would make students more aware of and/or understand the nature of models in science such as the limitations or errors of models.

Although there are advantages in using models in teaching (especially analogical and physical models), the representational functions of models can be a 'double edge sword,' where using models as representational tools in learning science may facilitate students' learning, but may also mislead students (Boohan, 2002; Duit, 1991; Taber, 2005). Some researchers recommend caution in the application of a model-based approach in science teaching because models can be misleading to students (De Vito, 1968; Harrison & Treagust, 1993). Models are constructed with the purpose of representing phenomena in a simpler form, but sometimes these models are oversimplified and present semiotic (sense making) challenges for learners' because "relevant detail may be missing or difficult to see, or the causes of the behaviour may be unclear or missing" (Buckley & Boulter, 2000, p. 133). This oversimplification can make it difficult for students to detect part of the system, and they may misinterpret what is being represented. Likewise, over-exaggerated features sometimes represented in models, which seem to be the real target can also often confuse students (Coll et al., 2005; Coll & Lajium, 2011). It is argued these unshared attributes of models may encourage misunderstanding and misconceptions (Al-Balushi, 2011), since students may pay attention to features that are not actually intended to correspond to the target system (Boohan, 2002). For example, ball models with colour coded atoms may encourage students' misconceptions at the submicro level of atoms and molecules such as believing individual particles are coloured,

similar to the macro properties of the substance. In other words, students may simply learn about the model itself, rather than the concept that it is meant to represent (Coll et al., 2005).

Models, besides being simplified, are also highly idealised (Al-Balushi, 2011), and some scientific models are so successful that they are regarded as fact (Schrader, 1984). This simplification may cause students to become unaware of the boundary between the model and the reality it represents (Coll et al., 2005; Harre, 1978) – a naïve realism epistemology. As a consequence, investigations often find students think that models are accurate duplicates or replicas of the reality and represent the ultimate truth about the reality (Chittleborough, Treagust, Mamiala, & Mocerino, 2005; Grosslight, Unger, Jay, & Smith, 1991; Harrison & Treagust, 2000b; Treagust, Chittleborough, & Mamiala, 2002). For example, chemistry students may think that a chemical equation that represents a specific chemical reaction such as complete combustion of hydrocarbon that produce carbon dioxide and water, as the only chemical reaction that happen in combustion.

With this naïve epistemological view of models, students also tend to use rudimentary models even though they were introduced to multiple models representing the same system, in the belief that there is one 'right' or best model to be identified and studied (Al-Balushi, 2011; Gilbert & Osborne, 1980; Harrison & Treagust, 2000b). For instance, although being aware of other chemical bonding theories or models, students (even postgraduate students) prefer using an octet rule based model despite its severe limitations for explaining chemical bonding in ionic, covalent, or metallic systems (Coll & Treagust, 2001, 2002, 2003a, 2003b; Taber, 1998). This preference of a single simple model also indicates that the students are confused about the utilisation of multiple models for a given system. For example, it is potentially confusing to students when they are introduced to the Maxwell-Boltzmann distribution law (which originates from statistical thermodynamics) for explaining chemical kinetics when they have previously only used the collision theory (Justi, 2000). Thus, although multiple models in science are crucial for better understanding of a system,

students do not necessarily appreciate the advantages of having different behaviours of the system represented by different models (Chittleborough et al., 2005; Gilbert & Osborne, 1980; Justi & Gilbert, 2003a).

Students' naïve epistemology and preference towards the use of simplistic models are indications that they do not actually understand the nature and purpose of scientific models and modelling. They are found to perceive models as explanatory or communicative tools to aid their understanding and to make things more accessible or convenient to see and/or use (Chittleborough et al., 2005; Grosslight et al., 1991; Treagust et al., 2002; Treagust et al., 2004), and are unaware of the generative role of models play in science for predicting and constructing theory and frameworks for scientific inquiry. Therefore, not surprisingly, students prefer rudimentary models over complex models, thinking that any models are applicable in any context, and often are unaware of the limitations of the models they are using.

2.3.2 Models-based Learning of Science

Although the roles of models in learning science are vital, the literature has indicated that learning science with models is not always been successful. Therefore, students' learning of science needs to go beyond learning the content of scientific or curricular models by developing

an understanding of scientists' view of the nature of "model"; suitable experience of the phenomenon that is being represented; knowledge of why the model was originally constructed and why it has to be learned; an understanding of how analogies operate; knowledge of the source from which the target model and/or teaching model is constructed. (Justi & Gilbert, 2002a, p. 384)

In other words, students' learning about consensus/curricular models, if necessary by means of teaching models, should involve at least an understanding about the various major scientific and historical models, the source from which teaching/consensus models are drawn from, the shared and unshared attributes of the source and model, and the limitation of the models as a form of representations (Gilbert & Boulter, 1998; Justi & Gilbert, 2003a; Justi & Van Driel,

2005). Ostensibly, students should come to the understanding of various typologies of models (especially scientific, historical and teaching models) involved in their learning of science, and the scope and limitation of the models introduced to them as representational tools. However, knowing such epistemological knowledge of models in school science will not expose students to the role of models in scientific inquiry. Students also need to acquire the skills of using the models. It is suggested that students use a model in an ideal situation where it will successfully represent the selected attributes of a target system (Gilbert, 2004; Justi & Gilbert, 2002a). Furthermore, if students are to come to know the generative nature of models, they need to engage in a scientific inquiry process, such as using models to solve problems, formulate questions and generate data to address those questions, design experiments, and make predictions (Buckley & Boulter, 2000; Passmore, Stewart, & Cartier, 2009; White & Frederiksen, 1998).

“The problem in science education is to develop a student's mental model of a phenomenon [and move it] towards [the] scientists' mental model” (Gilbert & Osborne, 1980, p. 7). Therefore, learning about scientific models and using models in learning science should involve the process of modelling, that is building their own models (at least their mental models) about the scientific idea for a given phenomenon (Duit & Glynn, 1996, p. 145; Gilbert & Boulter, 1998). Modelling in science and science education is then not merely a process of creation of models, it “is the experience of constructing, using, evaluating, and revising scientific models and knowing what guides and motivates their use” (Kenyon et al., 2008, p. 41). Broadly put, “students should be provided with opportunities to create, express, and test their models” (Justi & Van Driel, 2005, p. 200). Through a process of modelling that encompasses the capacity to revise and reconstruct models, and also construct models *de novo* (Gilbert, 2004; Justi & Gilbert, 2002a), students will be able to develop their mental models of phenomena and have the opportunities to share these in the form of expressed models (Gilbert & Boulter, 1998). Modelling in learning science is beneficial as it leads students to develop their scientific knowledge, sharpen their thinking skills

(Harrison, 2001; Harrison & Treagust, 1998; Whitworth & Ormerod, 1978) and deepen their understanding of the nature of science (Gobert et al., 2011; Prins, Bulte, Van Driel, & Pilot, 2008), all of which are essential to the components of an 'authentic' science education (Espinete et al., 2012; Gilbert, 2004; Koponen, 2007; Prins et al., 2008).

2.3.3 Models and Teaching Science

The literature suggests students' confusion in using models when learning science could result from the way science is taught (e.g., Fensham & Kass, 1988; Harrison & Treagust, 1996; Taber, 2008). One observation concerning teaching practices is that teachers tend to emphasise the content of the teaching or scientific models, instead of modelling *per se* (Coll & Lajium, 2011; Van Driel & Verloop, 2002). In this pedagogy, teachers do not communicate much about the nature of models used in science teaching and their role in constructing knowledge about the system that the models are intended to represent. This lack of communication suggests that teachers are not aware of or do not pay much attention to their students' ideas about models and modelling (Justi & Gilbert, 2003a). It seems that students are being immersed into the realm of models, instead of the reality, without knowing the origin or theoretical background of models (Justi, 2000; Matthews, 2007).

The way teachers use models in school science could be related to the teachers' view of models as instructional or communicative tools, with the purpose of "making the abstract more concrete" which is considered pivotal in facilitating understanding of science content (Justi & Gilbert, 2003a, p. 55). Rarely do teachers recognise that models are used in aspects of scientific inquiry like experimentation, formulation of hypothesis or predictions, improving or even building new theories, and generating new questions (Barnea, Dori, & Finegold, 1995; Oh & Oh, 2011). Teachers tend to see models as instructional tools of science content rather than being an aspect of the nature of science (Schwarz et al., 2009; Van Driel & Verloop, 1999). Additionally, similar to students, teachers are also reported to be confused between physical models and the reality (Justi

& Van Driel, 2005; Smit & Finegold, 1995). This confusion is demonstrated by their transferring of unshared attributes of models to the target system. For example, teachers are reported to think that bacteria are coloured (Farmer, 1994), and that scientific models represent absolute 'truth' (Justi & Gilbert, 2003a). These findings signify that teachers' understanding of the nature of models and modelling in science are limited (Crawford & Cullin, 2004; Van Driel & Verloop, 1999).

An inevitable complication in teaching science with models is that models (like teaching models and curricular models) are used with the intention of modelling other models. For example, models about chemical bonding in molecules are derived from the model of atomic structure (Coll, 2006; Coll & Lajium, 2011). In short, some models that are utilised in teaching science are actually built upon other underlying models. Hence, models applied in school science are also observed to be built from various historical models, which mean that some teaching models are hybrid models (Justi & Gilbert, 2003a, 2003b). For example, chemical kinetics as taught in schools discusses activation energy from the point of view of collision theory, with the introduction of the 'activated complex' species which is formulated from a quite different theoretical background (Justi, 2000). Although hybrid models may be useful in delivering the content of science to the students, they:

do not allow the history and philosophy of science to make a full contribution to science education. They do this by denying the role of distinct models in the history of science and of the role of progression between these models in the philosophy of science. Moreover, when hybrid models are used, the gaps of validity between the attributes of a given model cannot readily be addressed, no questions requiring different ways of thinking about a phenomenon can be raised, and no different approaches to the interpretation of a phenomenon are possible. (Justi & Gilbert, 2003a, p. 58)

Therefore, the utilisation of hybrid models in textbooks and in the teaching of science may prevent both teachers and students from acknowledging the nature of models and modelling in science.

Inevitably learning school science is essentially model based because science education can be considered as a process of learning science, learning about science, and doing science (Hodson, 1992). Consequently, models and modelling serve a central role in science education where: (1) scientific/historical models are means to present scientific ideas to students, (2) learning how to use models that enables students come to acquire the epistemological knowledge of science, and (3) modelling activities (creating, expressing, and testing models) gives students opportunities to acquire the skills of generating scientific knowledge (Justi & Gilbert, 2002a, 2002b, 2002c). Therefore, in order for models and modelling to serve the purpose of science education, they need to be taught effectively, and the improvement of model based teaching is critical (Coll & Lajium, 2011; Van Driel & Verloop, 1999). An area needing improvement is developing teachers' content knowledge about the nature of models (Justi & Gilbert, 2002c, 2003a). This development may include knowledge about the uses of models, representational and generative roles of models and the typologies of models in science and school science (Gilbert, 2004), which may also help teachers realise the role of models and modelling in science education. However, such knowledge will not ensure the effectiveness of model based teaching. Development of teachers' pedagogical content knowledge (Shulman, 1987) is equally important. This form of knowledge includes the ability to develop effective teaching models, conduct modelling activities, play their roles in modelling based teaching, and understanding how students construct mental models when teaching specific content to particular groups of students (Gilbert, 2004; Justi, 2009; Justi & Van Driel, 2006).

2.4 Models of Chemical Reactions

Chemistry is the science of matter. An important part of chemistry is the understanding of the changes of matter, both in physical changes and chemical changes. The following sections describe some models that attempt to explain the chemical reactions.

2.4.1 Transmutation Model

The foundations of understanding chemical reactions or transformation of matter probably dates from the Greek philosophers, about 300 BC. At this stage, chemical reactions, or rather the formations of substances were viewed as the change of elements (which varied slightly among the Greek philosophers such as fire, water, air and earth) into new substances – a *transmutation model*. The theoretical ground for the transmutation model of material transformation is mainly philosophical or mythical (Cobb & Goldwhite, 1995; Ede, 2006; Leicester, 1965). For example, Thales said that the cosmos and matter originated from water, and his student Anaximander expanded Thales' idea explaining that materials are made from '*apeiron*' – an entity that makes up the whole world. The Greek philosophers' transmutation model of chemical reactions can be presented as the chemical equation below.



The idea of materials being made from minute particles can also be traced back to Greek philosophy. Anaxagoras believed that materials were formed from minute particles of elements, which he called 'seeds,' whereby these seeds combine with other similar seeds to form materials. Empedocles also asserted that materials were from elements (i.e., earth, water, air and fire) in different proportions and that the transformation of substances was influenced by anthropomorphic qualities: 'Love' and 'Strife.' To him, elements are united in formation of materials by Love and then, Strife separates the elements into distinct self-contained masses (Parry, 2012). These ideas of material transformation may have been the basis of Aristotle's matter theory which influenced the understanding of chemical reactions in Middle East and Europe until the seventeenth century (Ede, 2006).

2.4.2 Particle Model

Similar to Anaxagoras' 'seeds' idea, Democritus viewed matter as being formed of indivisible particles – the atomic notion of matter. The essence of his theory

was that the unchangeable solid atoms of elements, earth, air, water and fire could be entangled together to form visible substances (Leicester, 1965). Democritus's atomistic matter, although rejected by Aristotle, influenced the Western Europe philosophers in the 1600s especially Boyle and Newton (Cobb & Goldwhite, 1995). This atomistic view of matter is consistent with the idea of the *particle model* of chemical reactions. The basic idea of the particle model is that a chemical reaction is a process of interactions between particles (or corpuscles) as a result of a force, and that they combine in a specific form, which Boyle refers to as 'minima naturalia,' equivalent to the modern concept of molecule (Ede, 2006). At this stage, chemical reactions were explained on the basis of forces interacting between particles.

In the 1700s, the particle model of chemical reactions was further advanced through Lavoisier's work. Among other important features of chemical reactions based on Lavoisier's ideas, was the idea that mass is conserved, and that there are more than four elements that contribute to chemical reactions. However, up to this point, the particle model of chemical reactions had not departed much from the transmutation models of chemical reactions (Leicester, 1965).

Only when Dalton in 1808 proposed that the particles or elemental atoms remain the same even if they combine with other type of atoms, did we see the basis of the modern understanding of atomic theory (Ede, 2006). In this sense, chemical reactions involve interactions between specific particles, and due to these interactions, rearrangement of atoms occurs to form new substances. Therefore, in chemical reactions, only the atomic composition of substances changes when new substances are formed, but the atoms remain the same, which therefore the mass is conserved (*law of conservation of mass*). For instance, when hydrogen and oxygen react to form water, this is just a process of rearrangement of atoms of hydrogen and oxygen (Figure 2.12) and the mass of hydrogen and oxygen before the reaction the same with the mass of water formed after the reaction, assuming that the reaction happened in a closed system.

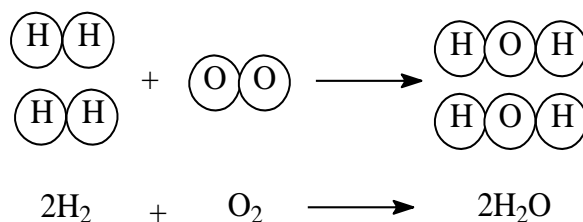


Figure 2.12 Particle Model of Water Formation

The particle model also differentiates between a chemical reaction and a physical change. In physical changes shown Figure 2.13, the composition of water, that is two hydrogen atoms (represented as white spheres) and one oxygen atom (represented as red sphere) remains unchanged, but the *arrangement* of water molecules changes when the physical state change.

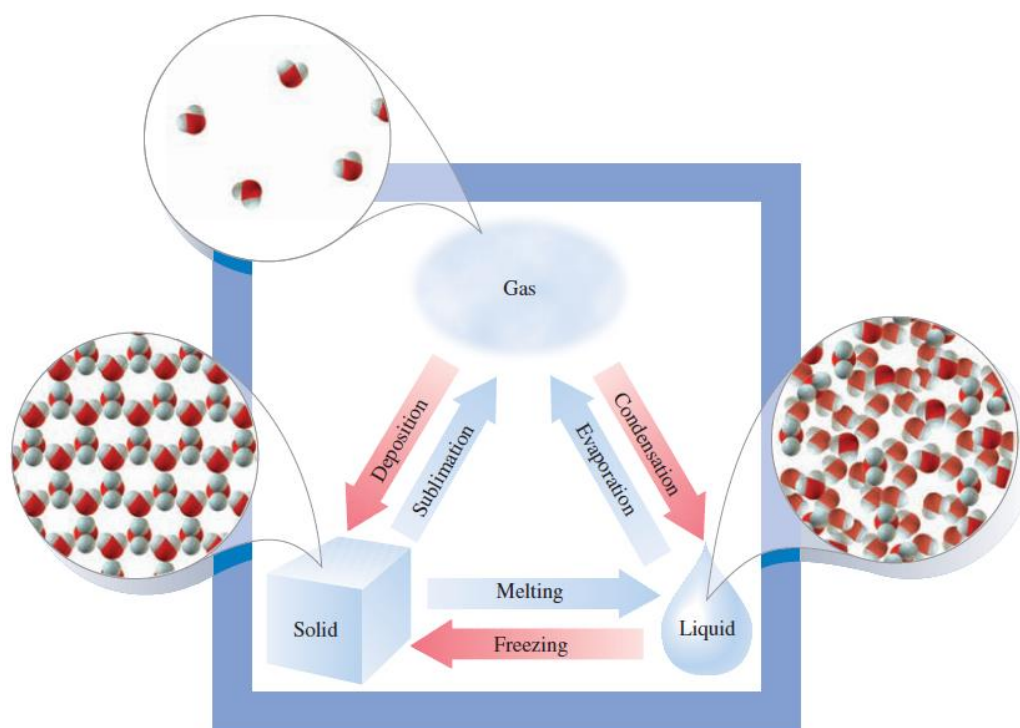


Figure 2.13 Water Particles in Three Different State (Whitten, Davis, Peck, & Stanley, 2007, p. 11)

In summary, the particle model can be considered the foundation of understanding chemical changes with advancement in understanding derived from knowledge of atomic particles. Thus, particle model of chemical reactions

offers particulate representations of chemical reactions and also the fundamental idea in explanation for other aspects of chemical reactions.

2.4.3 Collision Model

A refined model of the particle model of chemical reactions based on chemical kinetics is the collision model. In this model, the collision of molecules is the first step in chemical reactions (Upadhyay, 2006), and the basic assumption is that the reactants molecules are represented as hard spheres with definite radii (Wright, 2004). In order for a chemical reaction to occur, the molecules or particles of reactants, need to undergo a process of collision – the more frequent the collisions, the higher the probability for a chemical reaction to occur. Therefore, the collision model of chemical reactions explains the rate of reaction or the ‘speed’ of reaction. The frequency of collisions is considered as a function of the chemical reactions; the greater the collision frequency, the more often reactions occur, and the greater rate of reaction. However, not all collisions will lead to chemical reactions, and a collision that leads to chemical reactions is referred as an *effective collision*. Taking the reaction between H_2 and I_2 as an example, Figure 2.14 shows an ineffective collision of H_2 and I_2 , as no species are formed. An effective collision is illustrated in Figure 2.15, when a new species of molecules, HI , is produced after the collision.

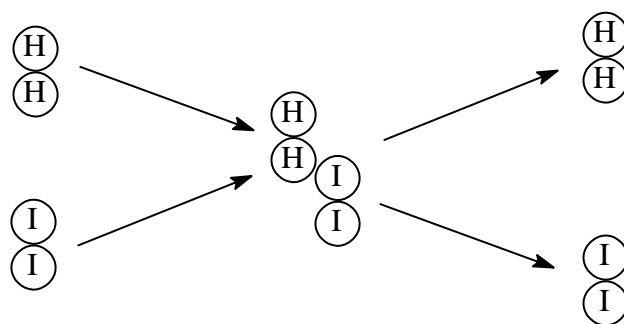


Figure 2.14 Ineffective Collision

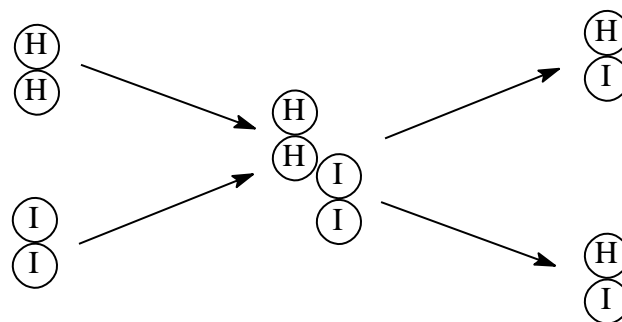


Figure 2.15 Effective Collision

We often observe that chemical processes are faster at higher temperatures, and this observation led Arrhenius in 1889 to propose that for molecules of reactants to change or react, we need sufficient energy, which he referred to as the *activation energy*, E_a (Suckling et al., 1978) – sometimes referred to as the *critical energy barrier*. This energy is considered the minimum requirement for the molecules to react, and it can be acquired through the transfer of kinetic energy during collisions. In other words, for an effective collision that leads to a chemical reaction, the energy barrier needs to be achieved, or exceeded.

The relation between temperature, activation energy and the rate of reaction is given by Arrhenius as,

$$k = Ae^{\left(\frac{-E_a}{RT}\right)}$$

where k is the rate constant at temperature, T . A is variously known as the integration constant, the pre-exponential factor, or the frequency factor (Latham & Burgess, 1977). The frequency factor, A is related to the Maxwell-Boltzmann distribution function, and indicates the fraction of molecules that attained or exceeded the activation energy (Suckling et al., 1978). In other words, only a limited number of molecules collide with the energy equal to or more than the activation energy that lead to an effective collision, and this occurrence increases with temperature (see Figure 2.16).

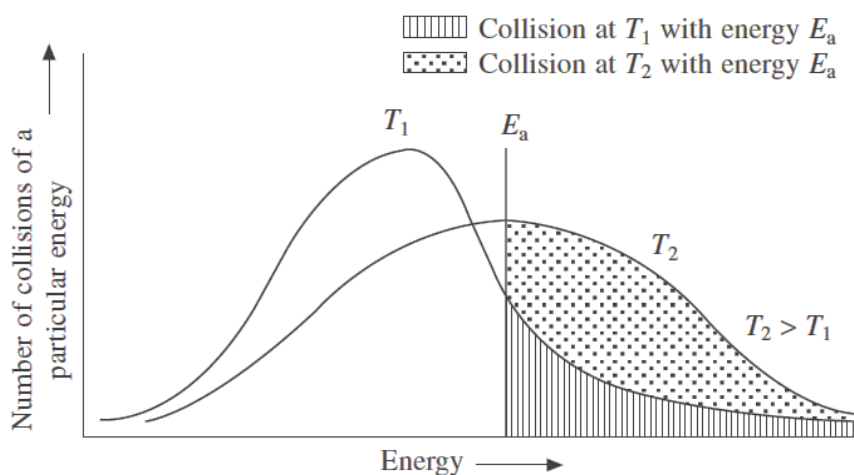


Figure 2.16 Collision with Activation Energy at Different Temperature (From Upadhyay, 2006)

Although the collision model explains the increase of reaction rate with temperature, and describes the process of chemical reactions as mathematically expressed by Arrhenius, it is found to overestimate the reaction rate (Suckling et al., 1978). This overestimation indicates that molecular collisions at the activation energy level do not necessarily lead to chemical reactions, and therefore, there must be other factors that contribute to effective collisions.

In the 1930s, a model of chemical reactions, as a refinement from the collision model, was developed and became known as the *transition state* model or *activated complex* model (Suckling et al., 1978). The idea of an activated complex was first introduced by Rene Marcelin in 1915, and further established by Henry Eyring and M. G. Evans and M. Polanyi (Laidler, 1985). In the transition state model, the transformation of the molecules is not an immediate result of the collision. This model considers that the collision of reactant molecules forms an intermediate species called the *activated complex*, which is in equilibrium with the reactants as it is unstable, decomposing to form the products (Suckling et al., 1978; Upadhyay, 2006). Figure 2.17 represents the collision of reactant molecules to form an activated complex, which is in an excited state, and that decomposes into molecular fragments of the reaction products.

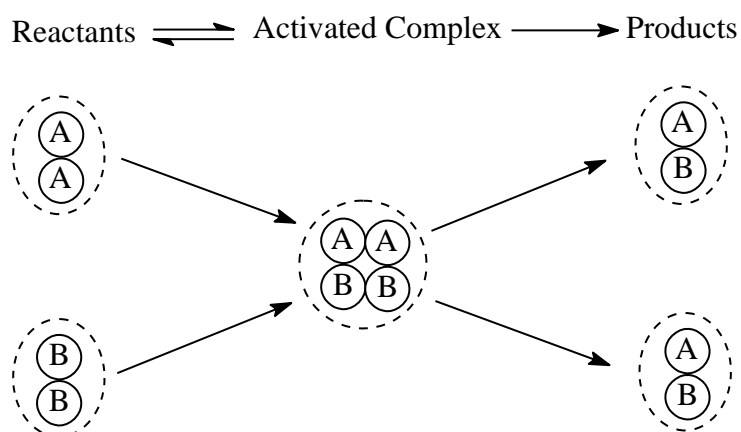


Figure 2.17 Formation of Activated Complex

Instead of considering that the rate of reaction is directly proportional to the number of collisions, the transition state model predicts the rate of reaction is based on the concentration of the activated complex. The concentration of the activated complex depends on the energy supplied to the reactants to form the activated complex, which is portrayed in Figure 2.18. The activated complex will only form when the reactant molecules collide at or more than the activation energy. Observation of an activated complex became possible when femtochemistry¹ was introduced in the 1980s by Ahmed H. Zewail. This technique enables the capture of the formation and decomposition of the activated complex in femtoseconds.

Since the formation of an activated complex is similar to the basic notion of a chemical reaction, in that it involves change in energy and randomness, and rearrangement of atoms, therefore the formation of an activated complex is consistent with the thermodynamic model of chemical reactions. Its formation can be interpreted based on the energy and randomness.

¹ Femtochemistry is an area of physical chemistry that studies chemical reactions on extremely short timescales, approximately 10^{-15} seconds (one femtosecond).

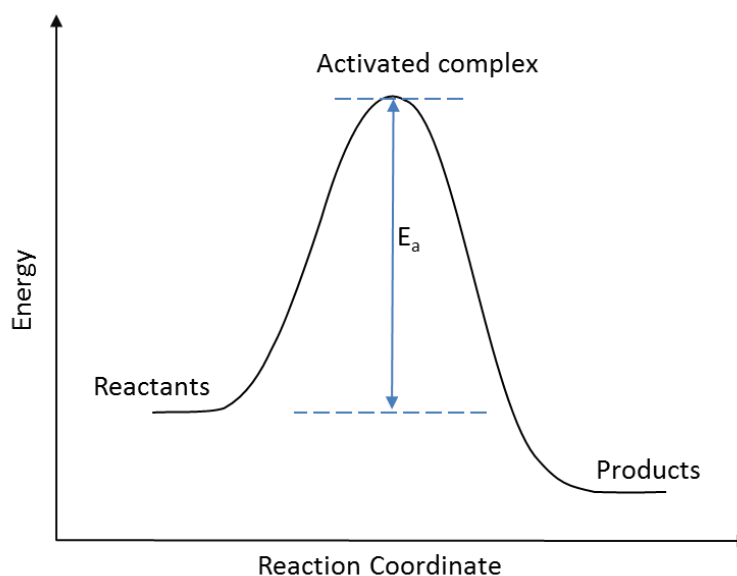


Figure 2.18 Energy Profile of Reaction

2.4.4 Thermodynamic Model

Chemical reactions in thermodynamics are portrayed mainly in terms of the change of energy that is studying the relation of chemical changes to energy changes. An important thermodynamic aspect of chemical reactions is work¹ – how a chemical reaction is able to achieve some kind of motion against an opposing force. For example, a chemical reaction happening in a battery does work when it pushes electric current in a circuit and internal combustion in a vehicle does work when pushing pistons (Atkins & Jones, 2010). To do work, energy is required. Therefore, energy can be described as the capacity of a system to do work. The more energy a system has, the more work it is potentially able to do. For example, a “hot compressed gas can do work more than the same gas after it has expanded and cooled” (Atkins & Jones, 2010, p. 237), or a mixture of kerosene and air has more potential to do work than the mixture of products formed after combustion. Although energy can be transformed from one to another, the energy of the universe is conserved – this is the First Law of Thermodynamics (Zumdahl & Zumdahl, 2010).

¹ Work is calculated by multiplying the opposing force by the distance moved against it (Atkins & Jones, 2010, p. 237).

Although the *universe* that we live in now is a complex entity, it consists of the *system*, where the part of the universe that we set for its boundaries separates it from the rest of the universe, the surroundings (Jenkins, 2008; Zumdahl, Zumdahl, & DeCoste, 2007). Therefore, a chemical reaction can be considered as a system in the universe involving reaction and chemical change. The burning of a candle is an example of a chemical reaction system, while the surroundings include the air in the room and anything else other than the reactants (i.e., candle and oxygen) and products (i.e., carbon dioxide and water). The relationship between system and surroundings can be *open*, *closed* or *isolated*. An open system, as in the burning candle example, enables the exchange of matter and energy with the surroundings. While, a closed system only allows the interchange of energy with the surroundings, at the same time maintaining the amount of the matter in the system. However, in an isolated system, nothing is exchanged, neither energy nor matter. Most importantly, any transformation of matter happens in the system and the surroundings, the total amount of energy and matter of the universe remains constant.

The total energy of a system is referred as its internal energy (U) which includes all the energy of the particles in the form of potential energy¹ and molecular kinetic energy², however, the internal energy of a system cannot be measured directly but only in terms of its change (Zumdahl, 2009). A system may exchange energy with its surroundings by a flow of work (w) or heat³ (q) or both (Brown, LeMay, Bursten, Murphy, & Woodward, 2012). The magnitude of the internal energy⁴ of a system is changed when heat is transferred out or into the system or when work is done on, or by, the system. Thus, internal energy change of a system can be expressed as:

¹ Energy based on position or composition such as chemical bond.

² Energy based on the motion of objects.

³ In thermodynamics, heat is the energy transferred as result of temperature difference. Heat should not be confused with thermal energy which is the total kinetic energy of particles at certain temperature.

⁴ At constant pressure and assumption of a small amount of work done by the system, the internal energy change is estimated as equal to the heat flow which is specifically referred as the enthalpy, H . Therefore, enthalpy is normally used as measure of internal energy change for a chemical reaction.

$$\Delta U = q + w$$

where ΔU represents the change in the system's internal energy, q represents heat, and w represents work.

When a system transfers its energy through heat flow or work (done by the system) into the surroundings, the internal energy of the system will drop, $\Delta U < 0$ (see Figure 2.19). In other words, the internal energy of the final state is lower than the initial state. At the same time, the surroundings will gain the amount energy that the system has lost. Processes that result in transfer of heat from the system (i.e., the releases of heat) into the surroundings are called *exothermic*.

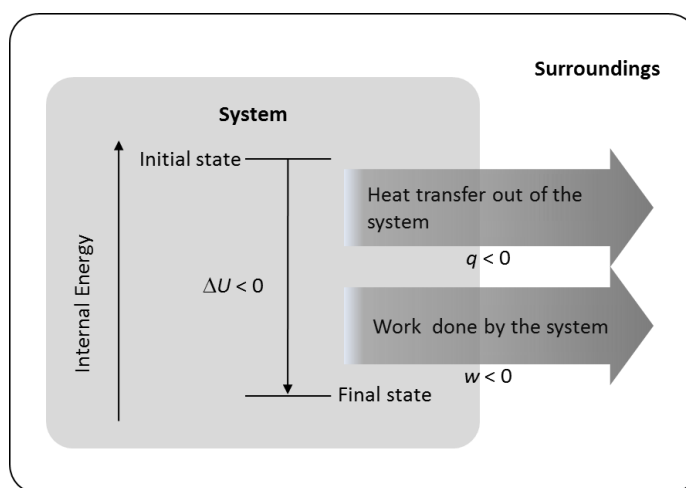


Figure 2.19 Internal Energy Change Through Transfer of Heat and Work into the Surroundings

On the other hand, when energy is transferred via heat or/and work from the surroundings into the system, the internal energy of the system will increase ($\Delta U > 0$), meaning the internal energy of the final state is higher than the initial state (Figure 2.20). The energy gain in the system is the same amount of energy lost to the surroundings. In this case, the process that the energy is transferred into the system (i.e., the absorption of heat) is called *endothermic*.

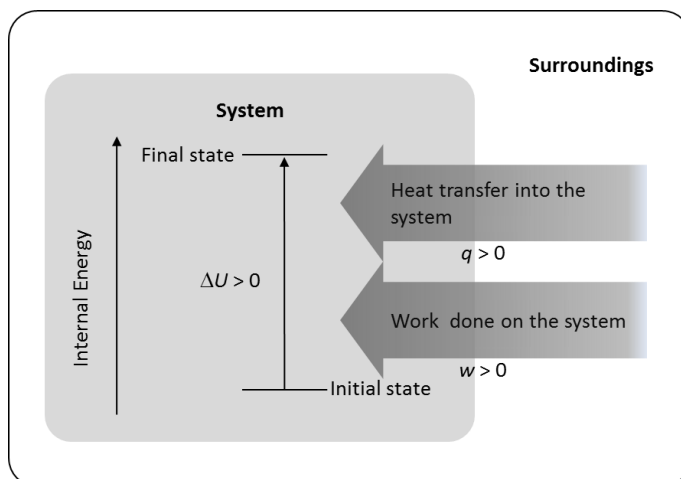


Figure 2.20 Internal Energy Change Through Transfer of Heat and Work into the System

The system can do at least two types of work, that is expansion work, which is due to the change in volume of a system, and non-expansion, such as raising a load or electrical work (Atkins & Jones, 2010). Expansion, work done by a system at constant pressure can be expressed as:

$$w = -P\Delta V$$

where ΔV represents change in the system's volume, and P represents pressure. Therefore, the internal energy change of a system under constant pressure can be written as:

$$\Delta U = q_p - P\Delta V$$

where q_p represents the heat at constant pressure. And this can be rearranged to:

$$q_p = \Delta U + P\Delta V$$

This expression estimates the heat transfer of a system at constant pressure, q_p which is known as the enthalpy change, ΔH . Thus,

$$\Delta H = q_p = \Delta U + P\Delta V$$

For most processes, which do not involve a gas or are at a constant pressure, work is considered too small ($-P_{ex}\Delta V \approx 0$). Therefore, the enthalpy change at constant pressure is a good estimate of internal energy change, $\Delta H = \Delta U$ (Moore, Stanitski, & Jurs, 2011).

Although thermodynamics concern only with the change in energy that happens in a system from the initial state to the final state, it is also important to understand the how energy is transferred in the process of chemical reactions. In a chemical reaction, most of the energy change results from the breaking and formation of chemical bonds as reactants are converted into products (Moore et al., 2011). In bond breaking, which happens to reactant molecules, energy must be transferred into the system – an endothermic process. While, in bond formation (forming the products), energy is released to the surroundings – an exothermic process. Since both processes happen in any chemical reactions, the internal energy change actually represents a *net* energy transfer, the sum of energy that was transferred into the system for bond breaking and the energy released from the system for the bond formation (Zumdahl, 2009). For exothermic reactions such as combustion of hydrogen, the energy released in bond formation for the production of water molecules is much higher than the energy absorbed for bond breaking in hydrogen and oxygen molecules. Since, potential energy is related to the chemical bond, energy release in an exothermic reaction is also indicative of the decrease of the potential energy (see Figure 2.21).

For endothermic reactions such as the reaction between ammonium thiocyanate, NH_4SCN and barium hydroxide octahydrate, $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$, the energy released in bond formation is lower than the energy that transferred into the system for bond breaking. For endothermic reactions such as this, the potential energy of the system increases (see Figure 2.22).

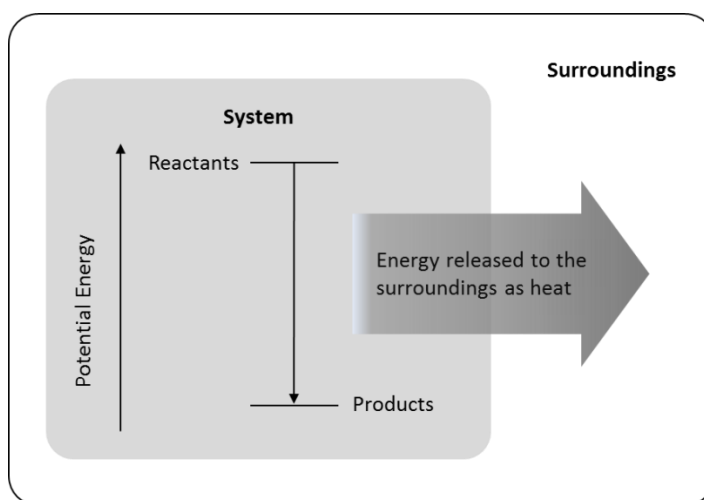


Figure 2.21 Change of Potential Energy in Exothermic Reactions

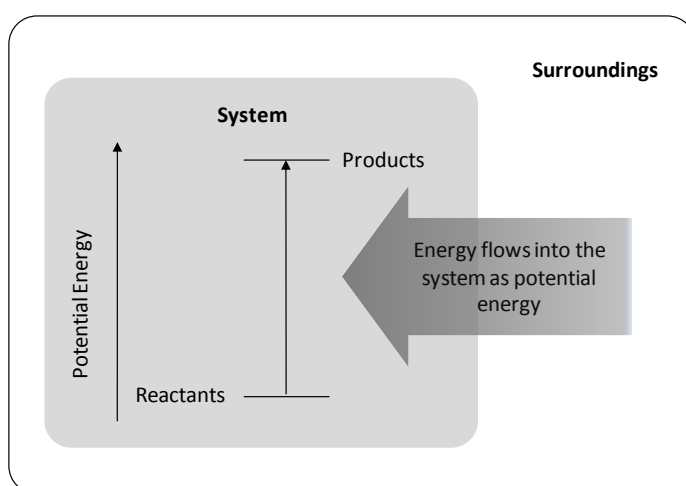


Figure 2.22 Change of Potential Energy in Endothermic Reactions

Scientists during the nineteenth century noticed that exothermic reactions readily occur but also that some endothermic reactions also occur readily at room temperature. However, a model of chemical reactions portrayed solely as a process of losing or gaining potential energy is not able to explain *spontaneous*¹ chemical reactions. Referring back to the example of an exothermic reaction, the burning of a candle is a spontaneous process; when it is burning, it keeps on burning – producing carbon dioxide, water and heat. However, it is not possible to heat carbon dioxide and water together and reform the candle. Scientists also

¹ A process is spontaneous if it has a tendency to occur without being driven by an external influence (Atkins & Jones, 2010, p. 288).

observed that gases always expand to occupy empty spaces (Figure 2.23) rather than clump together to leave empty space (Figure 2.24).

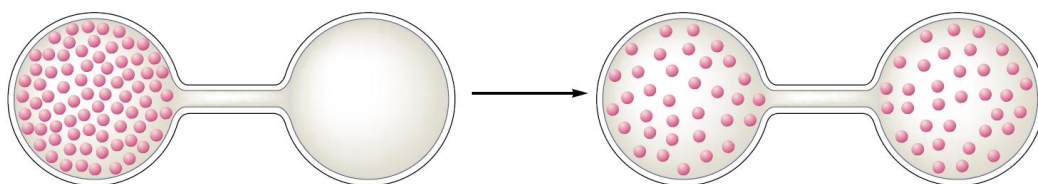


Figure 2.23 Spontaneous Process of Gas Spreading into Empty Space (From Zumdahl et al., 2007, p. 347)

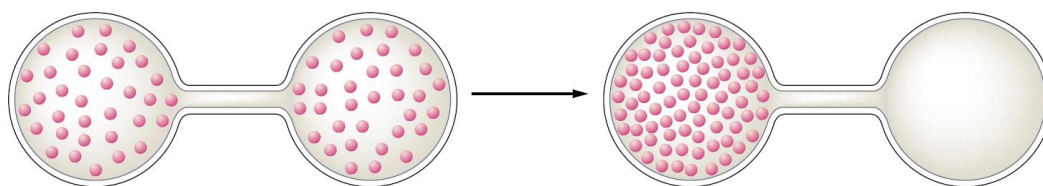


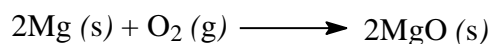
Figure 2.24 Non-spontaneous Process of Gas Clumping into Isolation (From Zumdahl et al., 2007, p. 347)

Scientists considered that a chemical system is driven by the spread of energy and matter. Energy spread means that the energy concentrated in a chemical system is 'stored' in the reactants and then dispersed into the surroundings. This phenomenon is why we often observe that exothermic reactions are spontaneous. Matter often tends to disperse or to occupy space. A typical example that we can observe is the drying of clothing, where even in very cold conditions, clothes still get dry, because of the tendency of water molecules to occupy open space. Scientists concluded that both energy and matter spread lead to a condition of disorder or randomness of the universe (either increase of randomness in the system or/and surroundings). In short, a spontaneous chemical reaction involves the process of dispersion of energy and matter, which increases the degree of the overall randomness, or disorder, of the universe. In thermodynamics, dispersal of energy and matter is expressed as the *entropy*, S – an index that indicates the degree of dispersal of energy (Sözbilir & Bennett, 2007). High entropy indicates great disorder, and vice versa. For example, a gas is more random compared with a liquid; therefore, one should expect a gas system has higher entropy. Similarly, a gas at a higher temperature will be more

disordered and has higher entropy compared with gases at a lower temperature. Similarly, complex molecules are more disorder and have higher entropy compared with simple molecules (Moore et al., 2011). Even if a process is able to disperse energy, the effectiveness of the dispersion depends on the state of randomness of the surroundings. At higher temperatures, which are already highly disordered, dispersion of energy of a system is not as high as it would be if the process was occurring at a lower temperature. In short, entropy change is proportional to the energy dispersed to the surroundings, and inversely proportional to the temperature.

The relation between entropy and the tendency of energy and matter to spread is captured in the Second Law of Thermodynamics. In any spontaneous process, the entropy of the universe ($\Delta S_{univ} = \Delta S_{sys} + \Delta S_{surr}$)¹ increases, and this is achieved through the dispersal of energy, that is the net entropy change of the system and surroundings should increase. In other words, the entropy change of the universe is positive, $\Delta S_{univ} > 0$.

For exothermic reactions, the release of energy or heat contributes to an increase of entropy of the surroundings, which means exothermic reactions are usually spontaneous (Atkins & Jones, 2010). Although an exothermic system may undergo a decrease of entropy, the increase of entropy in the surroundings (due to the dispersion of energy to the surroundings), usually results in an increase of entropy for the universe in total, provided the entropy increase of the surroundings compensates the decrease of entropy of the system. This can be seen in the highly exothermic combustion of magnesium,

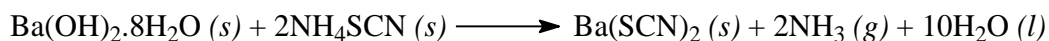


where the system undergoes a decrease in entropy as indicated in the formation of solid product, MgO. Similarly, an exothermic reaction that experiences an increase of entropy in the system certainly results an entropy increase for the

¹ Gibbs free energy was formulated to take into account simultaneously both the entropy change for system, and surroundings in determining reaction spontaneity.

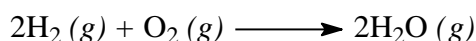
universe. Thus, an exothermic reaction is mainly driven by the dispersion of energy to the surroundings.

For spontaneous endothermic reactions, such as,



the absorption of energy from the surroundings results a decrease of entropy of the surroundings, but the increase of entropy of the system is high enough to compensate for the surroundings entropy decrease, which results an increase of total entropy of the universe. Hence, a spontaneous endothermic reaction is driven by the energy dispersion to the system.

It is important to note that spontaneous reactions do not necessarily occur at a high rate. For example, the reaction of water formation,



involves an energy change of -285kJ mol^{-1} , which makes it a highly exothermic reaction; an indication of a spontaneous reaction. However, this reaction takes place very slowly unless initiated by an energy source such as a spark (House, 2007). It is the same case with diamond. Thermodynamically in theory, diamond can spontaneously change into graphite, but this process is extremely slow. Thermodynamics view of chemical reactions enable prediction “whether a process will occur but gives no information about the amount of time required,” and therefore, both thermodynamics and kinetics are need to describe chemical reactions fully (Zumdahl, 2009, p. 412).

2.5 Summary

The literature above suggests that models and modelling play a significant role in science and science education. Science involves the creation of models, and scientists construct models to represent scientific phenomena, and use them as tools to discover new knowledge. Learning science can be considered as a process of understanding what scientists understand about scientific phenomena

as portrayed or represented in various types of models such as analogical models, physical models, and theoretical-symbolic models. In other words, learning science can be seen as a process of modelling, which involves producing models and mental models either directly from the phenomena, or from what has been modelled by the scientist. Mental models are considered crucial in the learning of science, apart from the process of modelling; they are also a good indicator of students' understanding of science concepts since they provide insights into students' representation of scientific concepts. Mental models, as either representation tools or reasoning tools, are used directly or indirectly by science educators in examining students' ideas or conceptions about science concepts such as atomic structure, chemical bonding, and chemical reactions. It is widely reported in the literature that students' mental models are either not consistent with the scientific or teaching models, contain some misconceptions, or consist of a form of synthetic-hybrid models.

Apart from learning about the nature of chemical materials, chemistry education also emphasises students' acquisition of knowledge about interactions of matter and energy. This knowledge is not only important for their academic goals, but also helps them to understand the world around them, through understanding the most fundamental ideas of chemistry, *inter alia*, particulate nature of matter, particle collisions, and dispersal of mass and energy. Therefore, it is considered important for chemistry educators to understand students' mental models of chemical reactions in order to assist students acquiring knowledge of much chemistry. Although there are some studies on students' understanding of chemical reactions, most are limited to addressing specific chemical reaction concepts in isolation, such as conservation of mass or matter, redox reactions, acid and base reactions, spontaneity of reactions, and chemical kinetics. Little attention has been given to understanding students' mental models, around the whole notion of chemical reactions. It is therefore, of interest to study students' mental models of chemical reactions in a holistic sense due to the interrelated nature of chemistry concepts.

In chapter 3, students' learning in science is discussed in detail.

Chapter 3 Students' Learning in Science

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Chapter 3 provides a review of students' learning in science, and theoretical consideration of the nature of students' learning in science. It begins with an introduction to students' conceptions of scientific knowledge and a discussion of the nature of students' alternative conceptions. This account is followed by a description of students' conceptions or ideas related to different aspects of chemical reactions. The chapter then concludes with some theoretical views of students' conception of scientific concepts.

3.1 Students' Alternative Conceptions in Learning Science

An indication of students' struggle with the learning of scientific ideas is evident in their considerably different understanding compared with that of the scientific community. Many of these non-scientific ideas are commonly referred to as alternative conceptions and have been studied intensively by many science educators (e.g., Barke et al., 2009; Barker, 2000; Black & Lucas, 1993; Driver, 1983; Driver, Guesne, & Tiberghien, 1985b; Driver, Squires, et al., 1994; Duit, 2009; Fensham, Gunstone, & White, 1994). There are various terms used when referring to students' non-scientific ideas other than alternative conceptions; such as naïve conceptions, pre-conceptions or children's science (Gilbert & Watts, 1983). Some authors refer to students' ideas as alternative frameworks – either referring to an individual's cognitive structure or as a generalised form of

students' collective ideas (Taber, 1998). Most importantly, it is argued that alternative conceptions and misconceptions should be viewed differently. Alternative conceptions are used to "acknowledge that students have constructed their own understanding of the concepts under consideration" (Treagust, 1995, p. 328). However, it has been pointed out that misconceptions should be seen as erroneous conceptions, which are "clearly inconsistent with accepted conceptions" (Abimbola, 1988, p. 180). Here in this study, the term 'alternative conception' is used to mean students' different conception of scientific ideas regardless of whether these conceptions are entirely erroneous, or partially consistent with the scientific view.

3.1.1 Characteristics of Students' Alternative Conceptions

Students' alternative conceptions are highly dependent on their senses, and often reported that any non-tangible entity is considered not to exist by many students (Gilbert, Osborne, & Fensham, 1982). Believing that sugar disappears during dissolution (Driver, 1985; Schollum, 1982), and similarly water in the evaporation process (Tytler, 2000), and that there are no forces acting on stationary objects (Stein, Larrabee, & Barman, 2008) are some examples of such thinking. Additionally, students' alternative conceptions are reported to be personalised, in that students are thought to construct their own individual meaning or interpretation of any kind of experience including scientific phenomena (Driver, Guesne, & Tiberghien, 1985a; Gilbert et al., 1982). A feature of students' personalisation of their alternative conceptions is their frequent use of everyday language meanings such as, explaining electricity as identical to road traffic flow (Fleer, 1994), chemicals are seen as harmful substances (Cavallo, McNeely, & Marek, 2003; Nicoll, 1997), and 'particles' as minute, visible solids instead of atoms, ions or molecules (Gilbert et al., 1982). Besides the use of everyday language, students' alternative conceptions are also tended to be anthropocentric. For example, they associate their conceptions with human nature when describing scientific phenomena (Trumper, 1993), saying things like "atoms *wanted* or *needed* to gain or lose electrons," or "the atom *enjoys* forming

a compound" (Taber, 1998, p. 603; Taber & Watts, 1996, p. 557). Therefore, it seems that students' alternative conceptions are often context-dependent.

Given that students' alternative conceptions are often personalised and anthropomorphic, alternative conceptions can be argued to be synthetic in nature, meaning that instead of discarding their preconceptions, students are assimilating or fusing their preconceptions with the formal knowledge introduced in school (Vosniadou, 2012). For example, young children ostensibly perceive Earth as a hollow sphere with flat ground on it where the living things are – a combination of the preconceived idea of a flat Earth, with the scientific view of a spherical Earth (Vosniadou & Brewer, 1992).

Although alternative conceptions appear to be context-dependent and ad hoc in nature by being personalised, anthropomorphic and materialised, the literature consistently asserts that students' alternative conceptions are stable, tenacious and highly resistant to change by conventional instruction (Driver & Easley, 1978; Driver et al., 1985a; Vosniadou, 2012; Wandersee et al., 1994). A recent example is reported by Rushton, Hardy, Gwaltney, and Lewis (2008), who maintained that students continued to think that energy is released in bond breaking throughout their university study. Likewise, Stavy (1995, p. 142) asserted that primary school students persistently relate weight to states of matter such as thinking that melted ice weighs less than solid ice, and liquids are heavier than gases because a gas has no weight. This stability of alternative conceptions probably occurs because they are actually coherent and theory like, at least from the students' point of view (Driver et al., 1985a; Vosniadou, 2012). The coherent nature of their alternative conceptions seems to provide students with consistent explanations and predictions for the phenomena that surround them. For example, Feher and Meyer (1992) suggested children have developed non-haphazard consistent ideas about light and colour, meaning they are able to make correct predictions of the colour of objects under various lights. However, their ideas are based on the belief that colour is a property of the object and is changed by coloured light. Therefore, one cannot expect alternative conceptions to be replaced by scientific views easily (Vosniadou, 2012), but rather there is a

gradual, slow, redevelopment through constant refinement and reorganisation (Smith, diSessa, & Roschelle, 1993). Nevertheless, in some cases, students' alternative conceptions are changeable, but this depends on the complexity of the scientific concepts encountered by students (Chi, 2005). There are also a variety of research reports that certain alternative conceptions diminish as students age (Paik, Choo, & Go, 2007; Pella & Voelker, 1967; Stavridou & Solomonidou, 1998).

3.1.2 Students' Conceptions as Implicit Knowledge

Despite the recognition of the importance of students' alternative conceptions in science education, the almost endless catalogue of alternative conceptions from various areas of science does not seem to offer any indications as to how we might draw upon this knowledge and enhance the teaching and learning of science (Talanquer, 2002, 2006). Much of the work reported in the literature emphasises identifying students' alternative conceptions (as presented in the previous section). Although this approach has been invaluable information to chemistry teachers, "it fails to explain the origins or nature of the full range of alternative ideas" especially in the chemistry domain, where studies have heavily concentrated on the explicit aspect of students' conceptions (Taber & García-Franco, 2010, p. 99).

From the discussion above, it is clear that students' explanations about chemical phenomena and other scientific ideas are based on common sources including everyday life experiences. There is some evidence that alternative conceptions reported are rooted in students' intuitive and implicit knowledge (Maeyer & Talanquer, 2010; McClary & Talanquer, 2011; Talanquer, 2002, 2006; Viennot, 2001). This knowledge is referred to using a variety of labels¹, and studied in a variety of ways including implicit assumptions, heuristics (Talanquer, 2002, 2006), phenomenological primitives (p-prims) (diSessa, 1988), intuitive rules

¹ The literature refers to this type of knowledge in numerous labels such as common sense (Talanquer, 2006; Viennot, 2001), cognitive constraints (Maeyer & Talanquer, 2010), preconscious cognitive elements (McClary & Talanquer, 2011), and implicit knowledge elements (Taber & García-Franco, 2010).

(Stavy & Tirosh, 2000), core intuitions (Brown, 1993), experiential gestalt of causation (Andersson, 1986a; Lakoff & Johnson, 1980b), and presupposition (Vosniadou, 1994). Nonetheless, most of these studies are domain specific such as mathematics, astronomy and physics, but less attention has been given to chemistry.

One component of secondary school students' (11-16 year olds) intuitive knowledge in the chemistry domain is that students think that chemical substances have underlying qualities or inherent essences¹ that contribute to the properties of the chemical substances (Taber & García-Franco, 2010; Talanquer, 2006). With this intuitive knowledge, students believe that there are components that control the properties (e.g., colour and texture) and reaction of substances, as if the characteristics of substances are independent of the substances. Consequently, based on this intuitive knowledge, students perceive chemical reactions as mere changes of the inherent components of matter, without any changes happening in the chemical structures or speciation² of the substances, that is the components changed but not the substances. For example, silver metal may change its colour in a chemical reaction, but students may still consider the same initial silver metal but only the 'component' that gives the metal its colour that has undergone a change. Besides assigning properties of materials to inherent components, secondary school students are also found intuitively to consider the properties of substances as inherently natural (Taber & García-Franco, 2010; Watts & Taber, 1996). For example, a chemical reaction happens because it is thought to be natural for substances to react with each other, and so no further explanations are required. The most important characteristic of this intuitive thought is that the properties of substances (such as being shiny, or reacting with another substance) are not related to the substances itself, but believing there is/are source(s) or component(s) that determine the properties of the substances. For instance,

¹ Also referred as essentialism (Talanquer, 2006) or inherent property (Taber & García-Franco, 2010).

² Formation of new species.

students may explain that the colour of trails from the dissolution of potassium permanganate is the colour that coming out, leaving the potassium permanganate crystals behind (Taber & García-Franco, 2010), suggesting the crystals left behind will become colourless eventually.

Tenth-grade Lebanese students were reported as being unable to differentiate between macro and submicro qualities (Jaber & BouJaoude, 2012). This inability refers to what is described as continuity from macro to submicro levels of matter, where students intuitively develop the idea that matter can be continuously divided into particulate-like pieces (Talanquer, 2002, 2006). Thus, the macro attributes or qualities are transferred to the submicro level. For instance, copper atoms are reddish because the copper metal is reddish and the metal expands when it is heated because the atomic volume increases at a higher temperature. This conception differs slightly from the above intuition (thinking that chemical substances have underlying qualities or inherent essences) because students recognise the relationship between the properties of substances and the substances itself.

Differences between macro and submicro attributes may also be evident in students' treatment of scientific constructs (e.g., chemical bonding, orbital, orbit, energy and force) as some tangible matter or material, which is referred to as materialisation (Viennot, 2001) or substantialism (Talanquer, 2006). In other words, tangible characteristics of matter such as colour, shape and weight are transferred into common abstract scientific concepts. Some examples of the materialisation of scientific idea include the thought that: heat is assumed to be stored in chemical substances (Boo, 1998; Boo & Watson, 2001), energy including light, heat, and electricity, to be some kind of physical substance (Erickson, 1979; Reiner, Slotta, Chi, & Resnick, 2000), and the formation of chemical bonds to be similar to building a structure where energy is needed to construct or break bonds (Barker & Millar, 2000).

Transferring the tangible into abstract scientific concepts is similar to anthropomorphism, in this case transferring human characteristics to the

scientific construct such as an “atom enjoys forming compounds” (Taber & Watts, 1996, p. 557), “water [molecules] dance around more because they are hot” (Selley, 2000, p. 395), the name of groups in the Periodic Table (e.g., halogens, alkali metals, and noble gas) are likened to family names (or surnames) of elements (Treagust, Chittleborough, & Mamiala, 2003), energy is like food for particles (Taylor & Coll, 2002), and atoms are imagined to have human body parts (Al-Balushi, 2009).

Scientists, philosophers, and students alike, are thought to seek reasons to explain any events in their surroundings. Intuitively, students like other human beings, seem to think that events happen or are caused by certain external agents or factors. This thinking is referred to as the causality intuition, which is considered to be the most common intuition to be found in any of the science disciplines (Andersson, 1986a; Bliss, 2008; Taber & García-Franco, 2010; Talanquer, 2006, 2010; Tamir & Zohar, 1991; Viennot, 2001; von Wright, 1971). Students from various levels of education, including university, often seek causal or active agents they consider directly responsible for events, acting on the other, passive, counterpart. Examples of chemistry alternative conceptions related to the causality notion include: the view of chemical reactions occurring as the result of more reactive reactants (Boo, 1998; Boo & Watson, 2001); heat energy or flame as an agent for change of substances (Taber & García-Franco, 2010; Trumper, 1993; Watson & Dillon, 1996); and chemical reactions occurring as the result of various actions toward chemical substances by external agents such as other chemical substances, surroundings, and human interventions (Hatzinikita, Koulaidis, & Hatzinikitas, 2005).

Contrasting with the nature of causality intuition, another common intuition is based on the notion of intentionality, the *teleological intuition* (von Wright, 1971), which arises as a consequence of students believing that everything has a certain purpose or intention. Thus, any event that occurs is to fulfil a certain intention after the events had occurred. Instead of looking for the cause (or rather being unable to identify the cause), students create an intentional purpose for the event of interest. Teleological intuition can be considered as

important as the causality thinking in chemistry, as it is also found to be a common underlying assumption for students' alternative conceptions. For example, chemical bonding being the result of atoms needing to be joined, a chemical reaction occurring to achieve stability, an octet configuration or a lower energy level (Taber, 2001; Taber & García-Franco, 2010; Taber & Watts, 1996), and a chemical system needing to achieve an equilibrium state (Talanquer, 2010). Teleological thinking is usually associated with anthropomorphic elements such as 'wanting,' 'need to,' 'to become,' 'to satisfy' and many more (Taber, 2001; Taber & García-Franco, 2010; Taber & Watts, 1996; Talanquer, 2006) as noted above.

3.2 Students' Understanding of Chemical Reactions

Chemistry educators have often observed that learning chemistry is particularly difficult at any level of education (Nakhleh, 1992). A factor that may contribute to the difficulties in learning chemistry may be due to the complexity nature of concepts used in chemistry, as in other sciences, that are abstract in nature, and as noted in Chapter 2 (page 55), they are usually presented to students using a variety of models. Besides that, the models used in the representation of chemistry concepts cover at least three different levels of chemistry – macro¹, submicro² and symbolic. According to Johnstone (1991), difficulties in learning chemistry (as well as other science area) are not because of these levels of representation, but rather the demands that incurred in understanding them simultaneously. Gabel (1999, p. 549) added that the difficulties may also occur because representation or models of chemistry concepts occur "predominantly on the most abstract level, the symbolic level." Therefore, the complex nature of chemistry can lead to various student difficulties for even the most fundamental ideas of chemistry, such as chemical reactions. Some of the difficulties in

¹ Also commonly referred to as macroscopic.

² There are various terms used similar to the term 'submicro' in the literature, discussed intensively in Gilbert and Treagust (2009). For this current study, the term 'submicro' is used to refers to the level of atoms and molecules, entities that cannot be seen through optical microscopes. Other literature, reviewed in this thesis, used the term 'microscopic' or 'sub-microscopic' are actually referring to the same entities.

understanding chemical reactions are discussed in detail in the following sections.

3.2.1 Students' Conceptions About Chemical Reactions

Although the basic idea of chemical reactions as a process of change in the chemical composition of chemical substances, various studies have indicated that the idea of chemical reactions is considered difficult by many students (Johnson, 2002; Nakhleh, 1992; Papageorgiou, Grammaticopoulou, & Johnson, 2010). A common difficulty reported in the literature is the identification of chemical reactions, or differentiating chemical reactions from physical changes (Ayas & Demirbas, 1997; Eilks et al., 2007; Glassman, 1967; Palmer, 2006). Ahte and Varjola (1998), reported that 20% grade 7-9 (ages 13-16) and 10% grade 10-12 (ages 17-19) Finnish students viewed dissolving and changing of physical state as chemical reactions. While in other work, there is evidence that students, especially primary and secondary are not readily able to identify burning as a chemical reaction. For instance, French primary school students (grade 6) (Méheut, 1985), and American secondary (grade 9, 11 and 12) and university students (Abraham, Williamson, & Westbrook, 1994) were reported to consider the burning of a candle as melting, and New Zealand secondary students (Form 2, 3, and 4) thought that heating sugar until it changed into a brown frothy liquid giving off visible fumes was melting (Schollum, 1981a). This difficulty in differentiating chemical reactions and physical changes is also consistent with Schollum (1981b) who reported that New Zealand secondary school students (Form 2, 4, and 6) viewed adding water into orange cordial and dissolution of sugar are chemical changes. Tsaparlis (2003) reported that more than half of Greek tenth-grade students (ages 15-16) were unable to categorise change of matter into chemical reactions or physical changes correctly when presented with a list of examples of chemical phenomena such as rusting, boiling, bleaching, and freezing.

Students' confusion is also observed when terms related to physical change such as melting, change of physical state and evaporation are used in describing

chemical reactions. For example, Abraham, Grzybowski, Renner, and Marek (1992) said that 15% of the American eighth-graders in their study, used changes of physical state or form as evidences of chemical reactions happening in a burning candle. Similar observations were also reported by Boujaoude (1991), who found that American eighth-graders (ages 13-14) thought burning process such as burning wax as a melting process, burning alcohol as evaporation, and burning of wood as changing into ashes, therefore not chemical reactions. The difficulty of distinguishing between chemical reactions and physical changes is not only seen among secondary and primary school students. Tsaparlis (2003) recounted that about half of the Greek first year university chemistry students (ages 18-19) in a study were found to have identified chemical events such as adding salt into soup, adding sugar into tea, and even water boiling as chemical change.

The literature indicates that although students recognise that changes happen in chemical reactions, they are not necessarily aware of the formation of new substance(s). Chemical reactions are perceived by these students as a process of 'mixing' of substances or changes in physical characteristics, that is morphological modification such as change in shape, texture, and colour, whereby the initial substance(s) is/are thought to be unchanged. For example, Johnson (2000, 2002) found that British primary school students (ages 12-14) explained the formation of copper oxide, by describing that oxygen turned into solid and mixed with copper and insisted that copper oxide was not a single substance. This observation is consistent with Hall (1973) who reported that primary school students (ages 12-14) think that barium nitrate, ferric oxide, and lead carbonate remained chemically the same after being heated.

In other studies, it was found that although students may recognise the formation of new substances, they do not necessarily consider that the initial substances undergo any kind of fundamental transformation. Andersson (1986b, 1990) argued that such explanations of chemical reactions can be of the *displacement* type. In this notion, students hold the idea that new chemical substances are produced but to them the new substances have merely

“appeared” from the initial chemical substances, without any changes. For instance, when asked to explain the rusting of iron, secondary school students holding the displacement model will reason that the rust “comes out” from iron, or from air and water (Gedrovics, Cedere, & Mozeika, 2009; Schollum, 1981b). Similarly, some primary school students (ages 6-12) argued that there must have been water present in the fuel when explaining “formation of fog produced on the inside of the jar placed over the methylated spirits burner” (Rahayu & Tytler, 1999, p. 306), and damp wood produces water when it is burnt (Méheut, 1985). However, Gómez Crespo and Pozo (2004) reported from their cross-age study using a questionnaire, that this modification view of chemical reactions was only heeded by a small proportion of Spanish 7th, 9th, 11th graders, and university students. Additionally, students’ explanations of chemical reactions can also be of the *modification* type, when students think the products of a chemical reaction are the same as the reactants but in different or modified forms (Andersson, 1986b, 1990). The new substances are then considered the same as the initial substances but some of their identity has changed. For example, Schollum (1981a) saw that secondary school students (Form 2-5) argued that heating sugar until it became brown produces another form of sugar with a different colour or taste, but that it is still sugar. Students’ views of transformations of matter as a modification or displacement process probably arise due to confusion between chemical reactions and physical changes as mentioned earlier. According to Watson, Prieto, and Dillon (1997), students’ displacement and modification ideas often coincide with physical change explanations. Johnson (2000) argued that such explanations of chemical reactions may indicate that students are unwilling to accept that products in chemical reactions are actually new substances produced from the initial substance(s).

Even though students may recognise that in chemical reactions, the initial substances undergo changes and new substances are formed, their explanations of chemical phenomena are rarely based on the scientific view, and deviate from what scientists understand. For instance, students’ notions of chemical

transformation can also be of the *transmutation* type, whereby chemical species are thought to be totally transformed into different chemical species or energy (Andersson, 1986b, 1990), and are also destroyed such that the initial substances cease to exist after the chemical reaction (Van Driel, De Vos, Verloop, & Dekkers, 1998). There were several studies that reported such an idea. For example, some Australian primary school students (Year 1-6) thought that soot was formed from the flame (Rahayu & Tytler, 1999); about 40% of 10 years old Spanish students did not represent magnesium atoms in their drawing of the magnesium oxide structure as they had done in the original magnesium metal structure (Merino & Sanmarti, 2008); about half of 14-16 year old students (from Spain and England) explained the combustion of various materials such as wood, candle, match, and magnesium based on transmutation producing other substances (Watson et al., 1997); and New Zealand Form 2-4 students thought that gas in the gas burner was being consumed by the flames and turned into heat (Schollum, 1981a). However, Gómez Crespo and Pozo (2004) in a cross-age study involving Spanish seventh-graders (ages 12-13), ninth-grader (ages 14-15), eleventh-grader (ages 16-17), and final-year university students, found that the transmutation notion of chemical reactions was held by less than 20% of students, and diminished as the educational level increases.

3.2.2 Chemical Reactions at the Particulate Level

The research mentioned above concentrated on students' conceptions of chemical reactions at the macro level. It seems from the literature, students' views about the process of chemical reactions or the transformations of matter at the submicro level are little understood. For instance, Hesse and Anderson (1992) reported that American high school students, even though exposed to kinetic ideas in chemical and physical change, fail to invoke the particulate nature of matter when explaining the rusting of an iron nail, the oxidation of copper metal, and the burning of a wood splint. Similarly, in a longitudinal study, Löfgren and Helldén (2008, 2009) conducted a series of interventions introducing the idea of particulate nature of matter. However, they found that only a fifth of the Swedish students at the age of 16 were able to use the submicro ideas in

explaining the phenomena of fading leaves left lying on the ground, disappearance of the wax of a burning candle, and the appearance of mist on the inside cover of a glass of water. Additionally, Kermen and Méheut (2009) also reported that twelfth-grader French students did not mention particle collisions in their explanation of chemical equilibrium.

When students do attempt to apply the idea of the particulate nature of matter in explaining chemical reactions at the submicro level, their views about the process of chemical reactions are often different from the scientific model. Cokelez, Dumon, and Taber (2008) said that some French tenth-graders think that molecules and atoms do not undergo any kind of change in chemical reactions, and this conception may indicate the application of the 'conservation principle' as a reasoning or heuristic principle of thinking by students. This belief is quite similar to those students who do not use particle theory, either believing that chemical substances remain unchanged in chemical reactions and only turn into a different form or that other substances just appeared in the reactions. These students believe that the characteristics of the macro level are transferred into the submicro level, and this conception is referred to as 'continuity' (Talanquer, 2006). This belief is also similar to those of students who think that particles from the initial substances are combined to form new types of particles (Eilks et al., 2007).

Students need to grasp the idea of the particulate model of matter to explain the phenomena of chemical changes or physical changes scientifically (Papageorgiou & Johnson, 2005), i.e., linking between the macro level with the submicro level (Øyehaug & Holt, 2013). However, the literature suggests that students have their own views of chemical reactions at the submicro level. For example, Ben-Zvi, Eylon, and Silberstein (1987), and Kern, Wood, Roehrig, and Nyachwaya (2010) reported on high school students' drawing representations of chemical reactions at the submicro level, and found that students depicted chemical reactions as a static process, where the formation of new substances was portrayed only as reorganisation or rearrangement of the atoms from the initial state to the final state.

The literature indicates that students are at least able to argue that change in atomic composition of the initial and final state of the chemical substances happens in chemical reactions. However, there is little work concerning students' understanding on what happens to the initial particles during chemical reactions. The only reported work found is based on Lee's (1999a, 1999b) work with Singaporean chemistry lecturers' and student teachers' (science graduates pursuing one-year post-graduate teaching program) submicro representations of the magnesium oxidation reaction. In both studies, most of the lecturers and some student teachers shared the same view of formation of intermediate in chemical reactions. Intermediates¹ here were hypothetical chemical species formed in the transitional stage between reactants and products (see Figure 3.1).

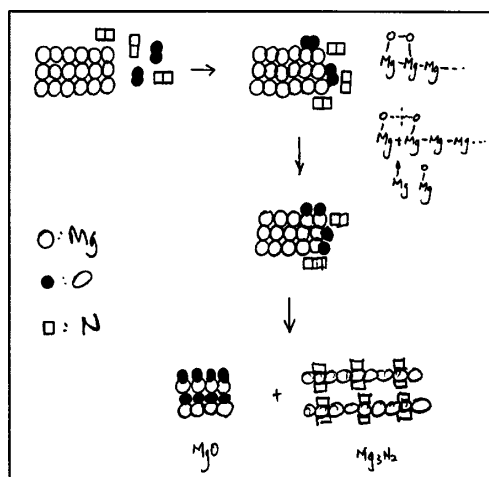


Figure 3.1 Intermediates in a Chemical Reaction (From Lee, 1999a, p. 1010)

However, some of the student teachers in the study thought that the metal lattice and oxygen molecules break into either individual atoms or ions before they react with each other (see Figure 3.2). Lee argued that the formation of free atoms in chemical reactions indicates that the student teachers did not relate chemical bond with energy, but are purely applying the octet rule.

¹ Probably more accurately referred to as the 'activated complex.'

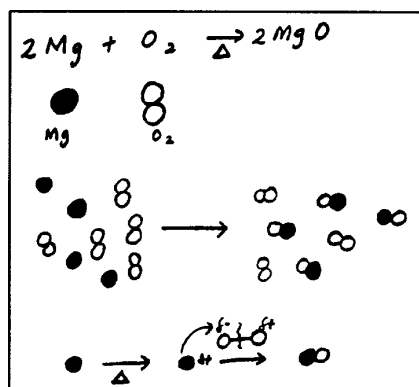


Figure 3.2 Formation of Free Atoms in a Chemical Reaction (From Lee, 1999a, p. 1010)

3.2.3 Conservation of Mass

Another prevalent concern about students' understanding of chemical reactions is related to one of the most fundamental principles – the conservation of mass. Although this notion is considered simple by most practicing chemists, it seems that students struggle to grasp and apply the idea of conservation of mass both in chemical reactions (Driver, 1985; Hesse & Anderson, 1992), and physical changes (Lajium et al., 2005, August; Lay, 2009; Martin et al., 2008).

It is commonly reported that students almost always have mass-density confusion when predicting mass change in chemical reactions, thinking that solid products such as precipitations increase the mass of a chemical system, since a solid is thought to be heavier than a liquid or gas. For example, Barker and Millar (1999) in their study with British advanced level students (age >16) indicated that about 30% of the students interpreted that the production of solid in precipitation reactions is responsible for mass increase. Other studies also saw similar observations; for examples Özmen and Ayas (2003) found about 20% of tenth-graders (ages 15-16) in Turkey predicted the mass in the precipitation of barium sulfate will increase because of the formation of solid precipitate that was thought to weigh more than the original liquid. Agung and Schwartz (2007) reported that more than a third of Indonesian eleventh-graders (ages 17-19) thought that the formation of precipitate indicates an increase in the total mass of the chemical system. Besides that, Driver (1985) said that two-thirds of

students aged between 9 and 14 years think that a water-sugar solution has less mass compared to the initial masses of sugar and water, arguing that the sugar solution is in liquid form, which weighs less than the solid form of sugar. A similar situation occurs in the case of gas formation in a chemical reaction, where a gas is thought to be lighter than a solid or liquid, or does not have mass, leading students to think of reduction of mass in a chemical system when gas is produced (cf. Agung & Schwartz, 2007; Barker & Millar, 1999; Stavy, 1995).

Stavy (1990, 1995) suggested that students construct intuitive proposition or rules regarding the relation between mass or weight where the physical state of matter in gas and liquid always weigh less than when solid. In addition, the mass of the reacting mixture is thought to reduce because the initial substances have been 'used up' in the reaction, and the destruction of matter is also plausible to the students. Some examples from the literature are: Grade 8 American students (ages 13-14) believed that matter can be destroyed in the burning process which causes loss of weight (Boujaoude, 1991); a third of British 15 year olds students suggested that rusty nails would weigh less, and most arguing that the rust 'ate' away the nail (Driver, 1985); American high school students held the idea that the 'using up' of oxygen when burning wood in a closed container, caused a loss in total weight (Glassman, 1967); and some British advanced level school students (age >16) predicted that the mass of a sealed flask containing a piece of phosphorus and water will decrease after combustion of the phosphorus because the phosphorus has been used up (Barker & Millar, 1999).

3.2.4 Chemical Reactions and Energy

In addition to students' difficulties in constructing an acceptable understanding of the processes mentioned to date in chemical reactions, students' learning about the role of energy in chemical reactions is reported to be an even greater challenge. The abstractness of concepts such as temperature, heat, energy, entropy, spontaneity, endothermic and exothermic, combined with the abstractness of particle concepts makes it even more difficult for students to develop their mental models of chemical reactions.

The most prominent difficulty concerning energy and chemical reactions is probably rooted in students' notion of energy as a form of matter or rather quasi-matter. This view is evident from various past studies with Canadian primary school students (Erickson, 1979), British secondary students (Watson & Dillon, 1996), and New Zealand secondary school students (Schollum, 1981a, 1981b) who considered heat as substance akin to air or steam. Similarly, Carson and Watson (1999) argued that even British university students' explanations of enthalpy is based on the idea of energy as quasi-matter, such as thinking that enthalpy change is a form of energy that is being supplied to or used for the reaction. Additionally, these studies also observed that students who expressed the idea that energy is quasi-matter may also assume that heat is a product of exothermic reactions especially in combustion. This finding is consistent with Watts (1983, p. 215) who encountered British students (ages 14-16) who viewed energy as a by-product of a situation like a "waste product as with smoke, sweat or exhaust."

Another possible link to students' views regarding energy as quasi-matter is students' conception of energy being stored in chemical substances, especially in describing the combustion reactions. In another example, elementary school students in Cyprus (ages 11-12) said that chemical energy is stored in a battery without understanding how (Papadouris, Constantinou, & Kyratsi, 2008). In different studies, some students think that energy is stored at the submicro level. Stylianidou and Boohan (1998) also reported that some British Year 8 students (ages 12-13) viewed energy as being stored between particles while, Boo (1998) and Boo and Watson (2001) identified that Singaporean Grade 12 students (ages 17-19) believe that chemical energy is stored in fuel and food, which is changed into heat energy but considered that oxygen does not contain chemical energy (i.e., heat energy comes only from the breaking of bonds in fuel and food alone instead of from the interaction between the food and oxygen). This view is also shared by university students in other studies, who explain that in an exothermic reaction, the energy being stored within the chemical bonds is released when

the chemical bonds are broken (Barker & Millar, 2000; Ebenezer & Fraser, 2001; Galley, 2004).

The literature suggests that although students appreciate an exothermic reaction involves a release of energy, most are not able to explain the origin of the energy. Some students at the higher level of education (age >16) fail to relate energy changes with change of chemical bonds (Ebenezer & Fraser, 2001; Greenbowe & Meltzer, 2003), and these students are often reported to inaccurately explain the direction of energy transfer in the breaking and formation of chemical bonds in exothermic reactions. These students tend to think that energy is released when breaking of chemical bonds occurs, and absorbed in the formation of chemical bonds (Barker & Millar, 2000; Boo, 1996, 1998; Boo & Watson, 2001; Ebenezer & Fraser, 2001; Galley, 2004; Yalçinkaya, Taştan, & Boz, 2009). Boo (1996, 1998), and Boo and Watson (2001) asserted that these students may have developed materialisation ideas of chemical bonds, thinking that a chemical bond is like a building structure that requires energy to build it and conversely, releases energy when it is dismantled. Besides materialisation of the chemical bond, Barker and Millar (2000) also maintained that the thought of energy release in the breaking of chemical bonding could originate from the conception of energy as quasi-matter itself.

Besides that, secondary school students (Grade 7 and 10) were also reported to identify chemical reactions as always being exothermic, and always releasing energy. In other words, students assumed that 'being exothermic' or 'release of energy' is a specific characteristic of chemical reactions (Eilks et al., 2007; Yalçinkaya et al., 2009). Nevertheless, most of the studies mentioned here concentrated on exothermic reactions such as combustion and metal oxidation, with rather less attention being paid to endothermic reactions.

3.2.5 Tendency of Chemical Reactions to Occur

Although primary school students may not have been exposed to ideas as to why chemical reactions happen (Taber, 2000), young students presented intuitive explanations of why chemical reactions occur which were anchored in personal

ideas (Löfgren & Helldén, 2008). Greek primary school students (ages 12-13) in the study by Stavridou and Solomonidou (1989) were, for example, found to argue that chemical reactions are changes of matter that is induced artificially by either human actions/interventions or from other factors in cause-effect events such as heat, temperature, or condition (i.e., agents of changes). Similarly, physical changes were also considered to be natural occurrences by students, where changes occur without influence by agents. Hatzinikita et al. (2005) called this explanation an 'agentive explanation,' where at least one agent or factor is necessary for the production of changes. The agent can be one or both of the chemical substances or other conditions that are responsible for the change happening or cause a substance to undergo changes.

Students at higher levels of education may be able to explain and solve mathematical equations related to entropy, spontaneity and Gibbs energy (see Section 2.4.4), but they often fail to invoke their knowledge about chemical thermodynamics when explaining the occurrence of chemical reactions (Boo, 1998; Boo & Watson, 2001; Sözbilir, 2003; Sözbilir & Bennett, 2007; Teichert & Stacy, 2002). High school and university students (age >16) are also commonly reported applying causality reasoning when explaining why chemical reactions occur. They think that chemical reactions involve causal agents. Explanation of reactions such as burning and metal oxidation is based on causal agents, which include heat energy and reactive or 'stronger' substances; they rarely explain chemical reactions according to the notion of entropy increase or Gibbs free energy (Boo, 1996, 1998; Boo & Watson, 2001; Goedhart & Kaper, 2003; Thomas & Schwenz, 1998). The tendency of chemical reactions to occur is also explained based on the stability heuristic or the reasoning, that products are more stable than reactants (Yalçinkaya et al., 2009). This mode of thinking is similar to what Taber (1998, 2009) has coined 'octet thinking,' where his students thought that chemical species such as ions are more stable than its original atoms when they achieve a stable octet electronic configuration.

The scientific explanation of why chemical reactions occur, is based on the Second Law of Thermodynamics, where chemical reactions tend to proceed or

are spontaneous when the process results in an increase of the entropy of the universe (Atkins, 2005; Zumdahl, 2005). However, the literature indicates that the conception of entropy is often neglected by students even at the higher level of education. Perhaps this scientific construct is simply beyond most students' comprehension, since in many cases, students' ideas about entropy are distorted or even wrong (Sözbilir, 2003). Examples of such alternative conceptions include: thinking an increase of entropy as the same as an increase in temperature (Johnstone, MacDonald, & Webb, 1977); interpreting visual disorder as an indicator of chaos, randomness, or instability (Sözbilir & Bennett, 2007) instead of understanding entropy as a degree of energy and matter dispersal (Atkins, 2005, 2011).

Struggling to understand ideas from thermodynamics, students at the university level who are normally introduced to chemical kinetics separately, are often further confused when the notion of energy is used in both thermodynamic and kinetic aspects of chemical reactions. As noted by Ribeiro, Pereira, and Maskill (1990), students did not distinguish between kinetic, heat, and potential energy referred to in thermodynamics and kinetics. For example, they were confused by the relation between entropy and kinetic energy (Johnstone et al., 1977; Sözbilir & Bennett, 2007), and tried to predict the rate of reaction using thermodynamic measures such as the enthalpy, equilibrium constant and Gibbs energy (Cakmakci, 2010; Sözbilir, Pınarbaşı, & Canpolat, 2010).

Based on these observations, many students fail to see the holistic nature of chemistry concepts, that is the understanding of how reactions occur, why some reactions are fast or slow, why reactions actually occur, and why some release or absorb energy, despite being exposed to scientific ideas of chemical reactions in the formal education. These findings may be an indication that students either do not construct mental models of chemical reactions close to the scientific models or do not use them as a tool to understand their everyday experiences. Nonetheless, attention on how students construct and use their mental models of chemical reactions has been rather limited, especially in terms of chemical energetics and spontaneity.

3.3 Theoretical Perspectives of Learning Science

Science education in general has developed according to the theoretical foundations that have influenced the policy and practice in school science (Murphy, 2012). Historically, learning science has been seen as transfer of facts from teacher to student – a transmission view of learning based on behaviourism (Allen, 2010). The basic principle of behaviourism is that learning science is a behavioural change induced by stimuli, reinforcement, and punishment, which emphasised science as a collection of facts that need to be memorised, reinforced, and practiced. In other words, a student is considered to be a knowledge recipient from an external source (Collins, 2002). However, the behaviourist view of learning science has been criticised for being limited in explaining and taking into account the phenomena of students' alternative conceptions of scientific ideas when considering how students learn science (Allen, 2010). This criticism suggests that students' learning of scientific ideas is more than just 'absorption' of knowledge, but rather a process through which they construct their own ideas. Helping students engage in the process may be enlightened from a constructivist and sociocultural theory of learning science.

3.3.1 Constructivism Views on Learning Science

Although studies of students' alternative conception in science education were not originally based on constructivism, a constructivist¹ view of knowledge is considered an important and influential framework for making sense of science learning in schools (Garnett, Garnett, & Hackling, 1995; Gilbert & Swift, 1985; Prawat, 2008; Smith et al., 1993; Taber, 2006). The core tenet of constructivism is that knowledge is not transmitted from one person to another, but rather 'actively constructed' in the mind of the learner (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Driver & Erickson, 1983). Therefore, learners are no longer to be perceived as passive recipients of knowledge, but rather actively interacting with

¹ Here, the term constructivism or constructivist is used as epistemology, i.e., assumptions about the nature of knowledge. See Section 4.2.3 on page 108 as to why some authors use this term as a paradigm.

the knowledge to make sense of it. This view implies that students' alternative conceptions may be the result of or be an artefact of classroom teaching.

Personal constructivism

The origin of constructivism can be traced to ancient Western and Eastern philosophies. However, the constructivist view of human learning is considered to be most inspired by Piaget (Pritchard & Woollard, 2010; Taber, 2006), who developed it into what is called *personal constructivism* – also known as individual or psychological constructivism (Moreno, 2010).

The foundation of Piaget's work is what is normally referred to as *genetic epistemology*¹, a development theory of knowledge (Campbell, 2009), which introduces the idea of a schemas or schemata (Piaget, 1970). Schemas are thematically organised patterns, units of action, or thought that are stored in long-term memory, and used to create understanding of the phenomenon surrounding the learner (Pritchard & Woollard, 2010). These schemas are formed from human interaction with the physical surroundings and with other humans (Moreno, 2010) – they comprise emotion, sensation, motor movement, and perception (Muller, Carpendale, & Smith, 2009). For example, a schema of a bird would probably include interlinked information such as a kind of animal that: has a beak, is able to fly with wings, and makes a chirping sound. Within this schema, one can identify a bird based on this existing information and new information such as a bird being warm-blooded, having feathers, and being colourful – this new knowledge will be integrated into the schema, making it more detailed and organised. The schema of 'bird' is also linked to other schema, such as schema of cat, airplane, insect, and many more, which together make the bird schema more coherent and distinct from other schemas.

Piaget believed that schemas are a unit of knowledge that develops through the process of assimilation or accommodation. When new information is fairly close to existing a schema or does not contradict the existing information, assimilation

¹ Piaget did not actually coin or invent the term genetic epistemology (Gruber & Voneche, 1977, p. 735).

occurs to fit this knowledge into the existing schema. Thus, assimilation is actually an information enrichment process of the schema through its interaction with the external environment (Piaget, 1955) – adding more non-contradicting information into the schema. This interpretation implies the previous information in a schema has not been altered by the new information in the assimilation process. For instance, “I didn’t know that birds lay eggs” – the new information that birds lay eggs is assimilated into the schema.

On the other hand, accommodation occurs when the existing schema is unable to incorporate the new information, in this case, the schema has to be modified or changed. Unlike assimilation, accommodation brings about a modification of the existing information and how it is interconnected so that the new information can be fitted into the schema. Accommodation of schema may also involve putting in new restrictions into the schema, or even construction of new schema or subschema (Campbell, 2009). For example, within the existing bird schema that birds fly, new information like penguins and ostriches are also birds, does not fit to the existing bird schema, so it has to accommodate the new information by introducing a new rule saying that “not all birds fly.”

Therefore, Piaget’s theory about schema indicates that knowledge construction involves an interaction between learner’s previous knowledge with the new information, which also implies that the newly constructed schema tend to differ from the given information. In assimilation, changes to the new schema can be considered insignificant and even in accommodation, the new schema will tend to retain the characteristic of the previous schema. These conceptions imply that there is no total replacement of the original schema or knowledge, which explained the constructivist nature of Piaget’s genetic epistemology, a development view of knowledge (rather than replacement of knowledge).

Radical constructivism is a form of psychological constructivism that takes a more ‘radical’ position (Costantino, 2008), breaking away from “the tradition of cognitive representationism” (von Glasersfeld, 1993, p. 24). Radical constructivism is usually related to the work of Ernst von Glasersfeld.

What is radical constructivism? It is an unconventional approach to the problems of knowledge and knowing. It starts from the assumption that knowledge, no matter how it be defined, is in the heads of persons, and that the thinking subject has no alternative but to construct what he or she knows on the basis of his or her own experience. (von Glasersfeld, 1995, p. 1)

What this definition means, is that although radical constructivism accepts that knowledge is not transmitted from the world and constructed within the individual's mind (Bodner, Klobuchar, & Geelan, 2001; von Glasersfeld, 1982), it asserts that any external world is just a construction of an individual, and no human can ever be certain of knowledge about it. In contrast with Piaget's arguments, radical constructivism strongly asserts that knowledge is not built upon prior knowledge, but that knowledge does not exist "separate from the knower" (Tobin & Tippins, 1993, p. 4). Von Glasersfeld argued that in order for constructivism to fit in science, it need to be radical, taking the position that creation of new knowledge is not necessarily based on the existing knowledge because:

[t]he history of scientific ideas shows all too blatantly that there has been no over-all linear progression. The shifts from the geocentric to the heliocentric view of the planetary system, from Newton's spatially stable to Einstein's expanding universe, from the notion of rigid atomic determinism to that of a statistical basis and the principle of uncertainty, from an Earth with permanently arranged land masses to Wegener's continental drift – and other upheavals could be mentioned – are incontrovertible signs that fundamental concepts were relinquished and replaced by ideas that were incompatible with earlier pictures of the world. (von Glasersfeld, 2001, p. 32)

This perspective implies that learning as construction of knowledge is a way for a learner to create their own world, similar to what scientists do, creating their world differently from what it was before. In terms of learning science, it is a process of replacing a learner's prior knowledge with the scientific view. This process has been coined as the 'children as scientist' view of learning, where a child learning science mimics the scientists' sense making processes (Driver, 1983; Gilbert et al., 1982). The learner is seen as a 'scientist' in his or her own right, constructing their own knowledge about their world.

Social constructivism

Personal and radical constructivism views the construction of knowledge as solely an individual mental effort – something similar to Einstein's creation of relativity. However, Driver and Easley argued that:

What is so often overlooked is the extent to which knowledge about the physical world consists of constructions about which there has to be social agreement. One function of instruction which cannot be achieved through simple interaction with the environment is to communicate the agreed conventions concerning useful ways of analysing and interpreting events. (Driver & Easley, 1978, p. 76)

This dimension of learning highlights the inadequacy of personal or radical constructivism in explaining students' learning in science, such as students' difficulties in understanding the logical method of science, inconsistency in using scientific ideas, and that students' ideas are different across different cultures (Solomon, 1993). Recognition of the social influence in learners' construction of knowledge resulted in a new 'strain' of constructivism, opposing personal constructivism (Marin, Benarroch, & Gomez, 2000) – *social constructivism*¹ which is also known as *contextual constructivism* (Cobern, 1993).

In social constructivism, we seek to encapsulate the social aspect in learning, where knowledge is considered to be “constructed when individuals [are] engaged socially in talk and activity about problems or tasks” (Driver, Asoko, et al., 1994, p. 7). Construction of knowledge by a person, thus does not rely entirely on their personal capacities, but also on social influence. Therefore, individuals' social milieu such as culture, belief, language, ideologies, and values, shapes their view of reality (Costantino, 2008; Solomon, 1987, 1989, 1993). For example, “in southern Africa, scientific ideas are sometimes rejected by pupils in favour of traditional beliefs based on folk medicine and witchcraft” which

¹ Literature concerning social constructivism is often found to refer Vygotsky and his successor's works, which is actually a school of thought on its own – sociocultural theories (discussed in Section 3.3.2 on page 102). However, sociocultural theories have been indicated to be different from constructivism in terms of epistemological and ontological assumptions (Hatano, 1993; Packer & Goicoechea, 2000).

indicates that individuals do not construct their conception entirely in isolation but are also influenced by the ideas of people around them (Allen, 2010, p. 4).

Social constructivism also recognises the nature of the social construction of knowledge, seeing it as a challenge for science education. The challenge lies in the nature of scientific knowledge, which is sometimes viewed as insulated and personally constructed, and may not be compatible with the learning nature of humans as social beings (Solomon, 1987, 1993). Solomon considered that:

Social influences are pervasive and strong, and that they spring from a familiar uneradicable style of knowing which can discourage access to the realm of scientific thinking. But the problem cannot be avoided. Our pupils are strongly social beings for whom the teaching of a rigidly insulated science which makes no contact with the everyday context is simply not an option. (Solomon, 1987, p. 79)

Although social constructivism appreciates the role of the social context in learning science, the construction of knowledge often focuses on individuals, neglecting the important role of teachers and other adults (e.g., the scientists, researchers, and practitioners) in the learning process (i.e., on the pedagogy).

Debates over constructivism

Research based on constructivism has shown great growth as noted by Phillips (1995), and constructivism is now recognised as a major educational philosophy and highly influential on pedagogy (Elkind, 2004). Although there are indications that constructivism has been widely adopted, constructivism is not without criticism from both philosophical and educational perspectives.

Perhaps, the most controversial assertion arising from constructivism is its standing on the nature of knowledge, which is typically seen as anti-realist. As noted above, to constructivists, knowledge is constructed rather than passively absorbed. To some, this assertion is problematic. According to Fox (2001), constructivism's position on human learning is misleading, as it suggests that human learning can only be understood through this view. However, there are other ways to view human learning. As Fox noted, learning can also be

associated with genetic factors – especially in language acquisition and motor skills, which he believed *are* gained through passive absorption:

Yet in so far as human beings have a distinctive cognitive system, different from that of, say, seagulls or chimpanzees, it is virtually all inherited. Our ability to perceive, to learn, to speak and to reason are all based on the innate capacities of the evolved human nervous system. (Fox, 2001, p. 26)

Similarly, constructivism also has been criticised for denying that learning can occur passively, asserting that learning *must* be an active process. There is some evidence that learning can occur without going through such a process, as Fox (2001) argued:

This, the most central and insistent claim of constructivism, seems, as it stands, to be either misleading or untrue. Human beings and animals in general, certainly do acquire knowledge of their environments by acting upon the world about them (for example by investigating habitats and by eating things); however, they are also acted upon. We do things and we have things done to us; we act and we react, and clearly we can learn from both types of experience. ... Why, then, should constructivism emphasise only one pole of human experience? (Fox, 2001, p. 24)

In short, constructivism's claim about learning may be misleading, because it is rather one sided, denying the various ways humans learn, and seems to rule out other possible ways of learning such as reading and listening.

Another fundamental criticism of constructivism is its epistemological standing. As Osborne (1996, p. 56) argued, in constructivism "truth is replaced by the notion of variability" and "knowledge exists only in the mind of the [cognising]." He continues:

Thus truth becomes an act of faith, and knowledge has pragmatic validity in that truth is what works. The only requirements should be that it fits with experience and is coherent and subject to empirical verification both personally and in the wider society. (Osborne, 1996, p. 57)

From this school of thought, criticisms have arisen about constructivism's stance that knowledge is subjective, provisional, and uncertain. If one accepts such a

view, this suggests that there is no way of knowing that one has improved or increased in knowledge (Osborne, 1996).

Constructivism in science education does seem to have its critics, although it is acknowledged for its contribution in identifying the importance of prior knowledge in learning. The stance that constructivism takes on the inseparable nature of knower and knowledge, seems to have engendered some difficulty in education according to its critics. Matthews (1998, p. 8), for example, commented on this aspect of constructivism:

The difficulty for constructivism posed by teaching the content of science is not just a practical one, it is a difficulty that exposes a fundamental *theoretical* [original italicise] problem for constructivism – if knowledge cannot be imparted, and if knowledge must be a matter of personal construction, then how can children come to knowledge of complex conceptual schemes that have taken the best minds hundreds of years to build up? (Matthews, 1998, p. 8)

Constructivism also puts science teachers in the position of finding the appropriate pedagogy to help science students in the construction of abstract science concepts for which they have no connections with prior conceptions – without teachers actually conveying something new to them (Matthews, 2002). According to other critics, it seems that constructivism does not offer any better pedagogy to science teachers than the behaviourism (Elkind, 2004). In other words, constructivist teaching is not really a practical way of teaching. In order for students to construct their own knowledge, they should experience an environment that leads them to the construction of particular phenomena. However, in science, many scientific concepts have been developed using sophisticated equipment, which is not typically available in schools (Matthews, 1998, 2002). For example, Rutherford's experiment, which led him to conclude that an atom has a nucleus, uses equipment beyond the reach of most schools. Even if such rare experiments were somehow made available to schools, would their display really lead students to construct knowledge similar to the scientist?

Hence, science education enacted via more extreme constructivist positions might well lead to the presentation of a distorted picture of the history and

success of science (Nola, 1998). This distortion may occur because science, even contemporary science, is based on objectivist or realist ways of knowing. Therefore, a constructivist way of teaching might well be seen as contradicting the way scientific knowledge and thinking have been developed. Additionally, Nola also pointed out that the denial of theoretical truth may mislead students to deny the virtue of scientific knowledge. This disbelief then could lead students to a denial of scientific knowledge, and the very existence of the phenomena.

3.3.2 Sociocultural Perspective of Learning Science

As discussed above, constructivism seems to have given an in-depth understanding to science educators about students' learning, and constructivism's main assertion is that learning requires construction of knowledge by a cognising being. This notion somewhat contradicts more traditional views of learning, which typically portray students as rather passive recipients of knowledge. However, according to some schools of thought, neither constructivism nor traditional teaching provides an adequate vehicle for students learning, because whilst students are more than passive receivers of knowledge, when taught via a constructivist-based pedagogy, they are still often found to develop alternative conceptions (Kozulin, 2003). Wilson (1981, p. 29) commented that "for science education to be effective, it must take much more explicit account of the cultural context of the society which provides its setting" including the economic, political, social, religious and philosophical, and language context. Early awareness of the cultural dimension of science learning was signalled by science educators such as Jacobson (1957), in his observations of children's science growing out of their immediate environment. Likewise, Billeh and Pella (1970) in cross cultural comparisons of the learning of biology concepts, and Mori, Kitagawa, and Tadang (1974) in their work on the effects of different language on the speed conception, came to the view that culture is a factor in science learning.

The insight into understanding of learning as social interaction can be provided by “sociocultural” or “cultural-historical” theory, stemming from the work of Vygotsky. The fundamental tenet of this theory is that the human inner mental processes ought to be understood through an appreciation of their sociocultural context or background (Van der Veer, 2007) which can be conceptualised around the concepts of *mediation*, *psychological tools*, and the *zone of proximal development (ZPD)* (Kozulin, 2003).

According to Kozulin and Presseisen (1995, p. 68) “the interaction between the individual and the environment is never immediate, it is always mediated by meanings that originate outside the individual, in the world of social relations.” In a simplistic view of understanding (as portrayed in Figure 3.3), the interaction between an individual and the world is somehow facilitated by an agent, referred to here as a mediator, to make meaning and this process of facilitation is referred to as mediation. The act of mediation is also viewed as an artificial or instrumental act (Wertsch, 2007).

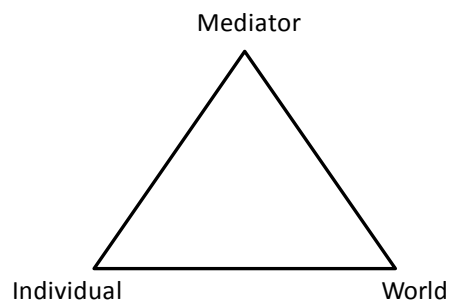


Figure 3.3 Representation of Mediation (Based on Daniels, 2001)

Kozulin (2003) suggested that there are two basic mediators; human and symbolic. Human mediation can take different forms such as the presence of adults providing a non-threatening learning environment to challenge, and provide feedback. Symbolic mediators, also known as *psychological tools*, can be as simple as physical activities such as casting lots, tying knots on a string and counting fingers. The psychological tools may also include high-order mediators such as signs, symbols, writing, formulae and graphic organisers which are devices for mastering mental processes (Kozulin, 2003; Kozulin & Presseisen,

1995). These psychological tools or symbolic mediators are unique from one culture to another, and they are appropriated¹ by individuals according to particular situations in a culture, which implies the cultural role in an individual's learning (Kozulin, 2003). Vygotsky recognised the importance of language as a symbolic mediator in mediated learning. In the learning of science, for example, language is used by students "as a tool for thought and communication as they gradually learn to use the special language of science" that is used by scientists to explain natural phenomena (Howe, 1996, p. 47).

Although symbolic and human mediators exist independently, these mediators are inseparable in their function of mediation. Symbolic mediators may have "rich educational potential but they remain ineffective if there is no human mediator to facilitate appropriation," and the same applies to the human mediators without symbolic tools "would not help the learner to master more complex forms of reasoning and problem solving" (Kozulin, 2003, p. 35). Thus, the relation between symbolic mediators and human mediators implies that symbols may only be used by individuals as psychological tools if their meaning is properly mediated by human mediators, which can be via another human being or in the form of an organised learning activity such as a mediated learning experience (cf. Kozulin & Presseisen, 1995), situated learning through a community of practice (Lave, 1988), or apprenticeship (Rogoff, 1995). Thus, human mediation implies that a classroom is a sociocultural system where teachers as human mediators facilitate the development of knowledge and meaning by supporting students' involvement in their own learning and helping them to work together (Moll & Whitmore, 1993).

In Vygotsky's "Mind in Society" as well as introducing the concept of human mediation, he also introduced the concept of the *zone of proximal development* (ZPD), which he 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

¹ Appropriate here means that something is taken as one's use.

collaboration with more capable peers” (Vygotsky, 1978, p. 86). Thus, the zone of proximal development can be seen as a learning potential in terms of the psychological functions of an individual that are emerging and have not yet fully developed or matured (Chaiklin, 2003; Kozulin, 2003). It is assumed that interaction within the zone, between a more competent and less competent learner, results in the less competent person human becoming more proficient compared to their initial competence (Chaiklin, 2003). So if, a child has already developed adequate mental function, he or she will be able to develop further competency through interaction or collaboration with a more knowledgeable other (typically a teacher). In other words, a child will be able to take advantage of assistance (perhaps the mediation experience) only if he or she is intellectually able to understand the purpose of it. Thus, the mediation process needs to happen within the zone of proximal development for it to be effective.

Based on the concept of zone proximal development, Vygotsky proposed some ideas about children’s acquisition of scientific concepts. In his elaboration of the interrelation of children’s learning and development, Vygotsky said that preschoolers’ concepts, which he refers to as the *spontaneous concepts*, are mainly unsystematic, empirical and unconscious, due to their tendency to generalise their concrete experiences in the absence of formal instruction (Karpov, 2003; Karpov & Bransford, 1995). In contrast, Vygotsky refers the more formal concepts that represent the generalisation of the actual phenomena as ‘scientific concepts’ (Karpov, 2003). Spontaneous concepts, as used by Vygotsky here, are perhaps equivalent to what constructivists refer to as alternative conceptions. However, Vygotsky considered spontaneous conceptions as an important and necessary basis for facilitating children’s transition to higher learning:

The development of a spontaneous concept must have reached a certain level for the child to be able to absorb a related scientific concept. ... In working its slow way upward, an everyday concept clears a path for the scientific concept and its downward development. It creates a series of structures necessary for the evolution of a concept's more primitive, elementary aspects, which give it body and vitality. Scientific concepts, in turn, supply structures

for the upward development of the child's spontaneous concepts toward consciousness and deliberate use. Scientific concepts grow downward through spontaneous concepts; spontaneous concepts grow upward through scientific concepts. (Vygotsky, 1986, p. 194)

That is to say, spontaneous concepts play an important role in children's acquisition of scientific knowledge, rather than being problematic in teaching science. Spontaneous concepts and scientific concepts may differ greatly, but both are crucial in the development of children's minds. These spontaneous concepts provide affordance for the acquisition of scientific concepts and once the scientific concepts have been acquired, they act as everyday life knowledge, meaning that children's spontaneous concepts have become more structured (Karpov, 2003). In addition, Karpov (2003) also noted that the acquisition of scientific concepts does not only restructure and raise students' spontaneous concepts to a higher level, they also function as mediating tools in their thinking and problem solving. Similar to other psychological tools, scientific concepts need to be mediated to students by human mediators who provide conditions for the formation of a zone of proximal development for the appropriation of the scientific concepts (Murphy, 2012). Without mediation, learning science in school as a discovery of scientific knowledge is mostly unsuccessful and may lead to the development of spontaneous rather than scientific concepts (Karpov, 2003).

3.4 Summary

This chapter has presented the key issues for students' learning in science. In the early part of this chapter the main features of students' alternative conceptions and implicit knowledge in science were described and discussed in detail, including students' conceptions about chemical reactions, reaction processes at the particulate level, conservation of mass, energy, and spontaneity. Insight into these conceptions or ideas held by students about various aspects of chemical reactions, is crucial to inform this inquiry in data collection and analysis which is described in the next chapter.

In order to make sense of the nature of students' learning about chemical reactions, various theories of science learning were described, including constructivism and sociocultural theories of learning. In personal constructivism, knowledge is thought to be constructed solely by the individual and developed gradually. In an extreme view, students' learning of science is compared to the development of science, discovering new theories of the same phenomena. This learning theory is opposed by social constructivists, who emphasise the influence of the social context of learning science, and the mismatch between the nature of socially constructed knowledge and the nature of scientific knowledge. Nonetheless, both variants of constructivism focus on the construction of knowledge as an individual effort and this interpretation implies that students will have prior knowledge of their world even before their formal instruction begins. On the other hand, sociocultural theories of learning offers a new dimension of students' learning in science by seeing learning as a mediated process. The most important characteristic of sociocultural theory as opposed to constructivism, is the appreciation of the role of adults especially teachers and the communities of practice, as mediators of students' construction of knowledge. Insight about students' ideas or conceptions of scientific knowledge, especially in terms of chemical reactions and learning theories, is considered invaluable as a guide in the design of this inquiry.

The next chapter describes in detail the methodology and methods used in this study.

Chapter 4 The Design of the Inquiry

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Chapter 4 describes the methodology for this inquiry. It begins with an overview of research design, and the philosophical foundation of research. This overview is followed by a discussion of the research methods and approaches for data collection. The discussion continues with a description about the nature of qualitative interviews, and a detailed explanation of the development of the interview protocol for the inquiry along with the procedure used for the interviews. The chapter concludes with discussion on the enhancement of the trustworthiness of the inquiry, and consideration of ethical issues.

4.1 Research Design

Research design establishes how a research project is conducted (Denscombe, 2010). It describes components of the inquiry including the theoretical perspective of research, details of the procedures by which the inquiry is conducted including sampling, methods of data collection, analysis of data, and other aspects of the research plan (Blaikie, 2000). In the research design, it also provides justification for the choice of strategy employed in the inquiry in relation to the research questions (Denscombe, 2010), explaining how the research methods provide suitable information that answer the research questions, and demonstrating the sense of 'fit for purpose' of the research design.

Additionally, a research design also explains how key components of research such as the philosophical assumptions, research methods and plans, purpose and research questions link and are consistent with each other (Denscombe, 2010). These aspects are further discussed in the following section.

4.2 Philosophical Foundations of Research

A researcher especially in the social sciences needs to consider the philosophical foundation of the research that is to be accomplished. This aspect is considered essential because the philosophical assumptions are the backbone or the framework for the research, underpinning the perspective adopted for the research, shaping the design of inquiry and the question, and setting the limitations of the research (Denscombe, 2010).

4.2.1 The Nature of the Paradigm

The way in which one engages in research is influenced by the belief systems or paradigms one holds. Paradigms are described as sets of "assumptions and perceptual orientations shared by members of a research community" that determine "the view of research communities [hold] towards phenomena and research methods to be employed to study those phenomena" (Donmoyer, 2008, p. 591). The assumptions or paradigms are based on, but not limited to,

ontological, epistemological and methodological assumptions. These assumptions or beliefs are “basic in the sense that they must be accepted simply on faith (however well argued); there is no way to establish their ultimate truthfulness,” meaning that advocates of any particular paradigm “must rely on persuasiveness and utility rather than proof in arguing their position” (Guba & Lincoln, 1994, pp. 107-108).

Perhaps, the most salient aspect to discuss in a paradigm is ontology – the “starting point of research” (Grix, 2004, p. 60). Noonan (2008) states that:

Ontology derives from the Greek words for thing and rational account. In classical and speculative philosophy, ontology was the philosophical science of being. Its general aim was to provide reasoned, deductive accounts of the fundamental sorts of things that existed. Ontology was not concerned with the specific nature of empirical entities, but rather with more basic questions of the universal forms of existence. (Noonan, 2008, p. 577)

An ontological question usually translates into a question like, “What is the nature of reality?” (Creswell, 2007). The answer to this question, according to those that subscribe to a realist ontology, is that the world exists independent of human experience, is knowable, and this knowledge is value free (Madill, 2008). In addition to this, realists assume that knowledge of ‘the way things are’ can be summarised independently of time and context, that is because the world is viewed as independent from human influence, knowledge about the world is uniform regardless of changes in human progression. In contrast, researchers who subscribe to a relativist ontology consider that realities are “multiple [in] form, intangible [in] construction, socially and experientially based, and local and specific in nature” (Guba & Lincoln, 1994, p. 110). As the name implies, these realities are relative to something else, and influenced by things such as languages, societies, and cultures, meaning that according to relativists there is no universal truth (Smith, 2008), a very different stance to that taken by realists.

Epistemology, also known as a theory of knowledge (Lemos, 2007; Rescher, 2003), is a philosophical view of knowledge, which centres in debates about “the origin, nature, limits, methods, and justification of human knowledge” (Hofer &

Pintrich, 2002, p. 4). An epistemological question focuses on the relationship between the 'knower' and 'what is to be known.' According to Guba and Lincoln (1994), the answer to epistemological questions is derived from the ontological basis of the paradigm. For example, a realist ontology will likely result in a dualist-objectivist epistemology. For dualist-objectivist epistemology, it is assumed that the 'knower' and 'what is to be known' independently co-exist, and the 'knower' is in principle at least able to investigate 'what is to be known' without influencing it, or being influenced by it (Pettit, 2010). On the other hand, advocates of interpretivism/constructivism assume that the investigator, and the object under investigation interact with each other in the creation of the knowledge (Guba & Lincoln, 1994) because knowledge or truth is believed to be relative to time, place, society, and culture (Siegel, 2010).

Methodology addresses the question about how we come to gain knowledge of the objects that we want to investigate. Again, the manner one goes about answering this question is influenced by the ontology and epistemology beliefs one holds (Guba & Lincoln, 1994). Realists, who attempt to put themselves in a position separate from the object under study, rely on experimental and manipulative approaches, with the understanding that data or knowledge is being gathered from the object. In other words, a realist researcher will rely on instruments as tools, to come to know about the reality – putting themselves aside as much as they can, in order to maintain 'purity' of data. In contrast, believing that knowledge is relative to other elements, relativistic methodologies are hermeneutical¹ and dialectical². These terms mean that knowledge is created or interpreted, based on the knower's previous knowledge through interactions between and among the knower and the object being studied.

It is also worthwhile to clarify the application of the terms methodology and method, since they are often used interchangeably in the literature. While, methodology deals with how knowledge is generated, methods are specific

¹ Originated from Greek, which mean to understand and interpret (Freeman, 2008).

² From the Greek word *dialegein*, means 'to argue' or 'converse' (Schwandt, 2007).

techniques and procedures or tools for gathering and analysing the data about the reality (Blaikie, 2000; Schwandt, 2007). These methods range from in-depth interviews, discourse analysis, questionnaires, standardised tests, and observations.

To simplify the complexity in understanding research paradigms, a directional relationship between paradigm assumptions with research methods and sources can be drawn (Grix, 2004). A methodological approach in research is underpinned by the ontological and epistemological assumptions that the researcher adheres to, which in turn determine the selection of methods and sources. In other words, the choice of methods and sources are justified by the underpinning assumptions of the paradigm. The relation between these research elements is shown in Figure 4.1.

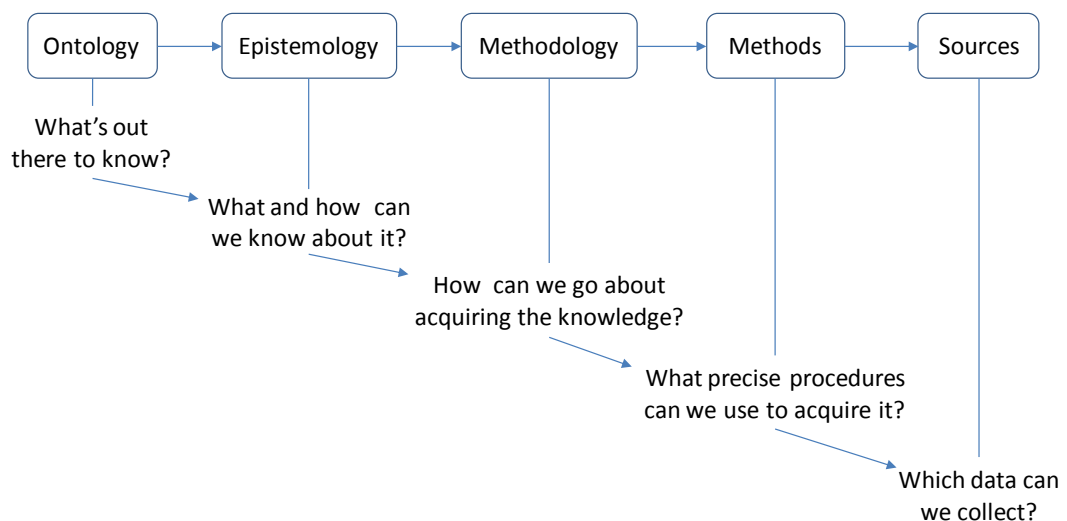


Figure 4.1 Interrelationship Between Paradigms, Assumptions, and Research Methods (After Grix, 2004, p. 66)

The key paradigms of positivism, interpretivism/constructivism, postpositivism and critical theory are briefly described in turn, to explore each of this paradigm in terms of its ontological, epistemological, and methodological assumptions. Such insights are important for the design and selections of research methods for this current study.

4.2.2 Positivism

The positivism tradition in social science is associated with the nineteenth-century French philosopher, Auguste Comte (Neuman, 2006), and is an approach explaining social phenomena by adapting the model of natural sciences to study human behaviour (Denscombe, 2010). Since it has its roots in natural sciences, terms such as ‘empiricism,’ ‘objectivism,’ and ‘scientific method’ are used, sometimes interchangeably, with positivism (Grix, 2004). Other varieties or forms of positivism include logical empiricism, postpositivism, naturalism, and behaviourism (Neuman, 2006).

In positivist paradigm, an “apprehendable reality is assumed to exist, driven by immutable natural laws and mechanisms” (Guba & Lincoln, 1994, p. 109). In other words, there is an absolute real world that can be accurately measured and represented – a realist ontology. Since, this reality is independent of human control, the object in the real world is assumed to be separate from the observer – a dualist epistemology. In other words, the researcher and reality are separate entities, neither influencing the other. Therefore, knowledge is discovered from reality “as through a one-way mirror” (Guba & Lincoln, 1994, p. 110), and it is considered to arise solely from reality, which is related to empirical or measurable assumptions.

The ultimate purpose of positivism-based research is to gain explanatory knowledge by discovering the universal causal laws of human phenomena. *Deterministic* assumptions underpin this paradigm, a belief that events in both the natural and social worlds are determined by other circumstances or conditions, providing humans the power to predict, infer and control the world. Therefore, it is assumed in this absolute views of reality that “there are fundamental laws expressible as universal generalisations governing both the natural and social worlds and discoverable through scientific activity” (Scott &

Usher, 2011, p. 13), which is an attempt to provide a *nomothetic* knowledge¹ of the social phenomena. In this perspective, the real world is studied as an entity that can be manipulated, controlled, and experimented on by the researcher (Cohen, Manion, & Morrison, 2007; Neuman, 2006), which enables people to take control the world around them by applying the knowledge. Positivists also ascribe to the tenet that reality should be represented with *parsimony* – meaning that the phenomena should be explained in the most simplistic way possible without dichotomy of meaning. Parsimonious explanations are achieved through the process of law-like generalisations or nomothetic explanations using inductive-deductive methods of reasoning (Cohen et al., 2007).

Positivist research of social phenomena, similar to the natural sciences, emphasises empirical theory in discovering knowledge, ascribing to ‘scientific methods,’ employing standard procedures to ensure replication by other scientists (Cohen et al., 2007). In these scientific methods, data are gathered based on observable attributes using human senses (e.g., eyesight, smell) or special instruments (e.g., microscopes, surveys, mass spectroscopy). It also places emphasis on scientific methods that are considered objective and value-free, that is the methods not be based on values, opinions, attitudes or beliefs but adhere strictly to rational thinking and systematic observation (Neuman, 2006). This emphasis enables researchers to operate independently of social and personal prejudices, biases and values. Since the main goal in positivist research is to gain generalised knowledge of the social phenomena, it also emphasises data collection from a representative sample drawn from a larger population. Through an inductive process and mathematical analysis, the data gathered from the sample can be extrapolated or generalised to the whole population (Corbetta, 2003). In short, positivist research offers an attractive approach to

¹ Nomothetic knowledge comprises knowledge claims that have the character of a law like generalisation to provide universal explanation or covering law (Jupp, 2006; Schwandt, 2007). *Nomos* in Greek means law (Neuman, 2006).

social phenomena with a promise of the power to predict and control the 'messy' and 'chaotic' social world (Grix, 2004).

However, despite being successful in the natural sciences, positivism has been subjected to philosophical criticism especially when applied in the study of social phenomena. One of the prevalent criticisms is its emphasis on value-free and objectivist scientific methods in social research in the hunt for the ultimate truth. This approach is considered dehumanising, and even unethical because it encourages researchers to endeavour to eliminate humans' confounding or contaminating influences on empirical data, which some interpret to mean treating humans as mere objects in ways that are deceptive, intrusive, and even exploitive (Guba & Lincoln, 1989, p. 120). For example, to ensure value-free and objectivist scientific methods in social research, human participants may not be made aware that they are being observed or what sort of data is being collected from them and how it will be used. Even though the ethical issues may be safeguarded through protection of human participants, a value-free and objectivist assumption is considered problematic since it disregards the reactions phenomenon involving human respondents (Lincoln & Guba, 1985). Humans, unlike physical objects or animals, are not passive beings but are "capable of a variety of meaning-ascribing and interpretative action" (Guba & Lincoln, 1989, p. 99), and these issues make the scientific claims of absolute truth impossible to establish.

Besides the incompatibility of positivist assumptions in social phenomena, positivism's assumption that it is possible to establish absolute truth about reality is also said to be unfounded (Lincoln & Guba, 1985). Positivism's deterministic assumption is said to be inconsistent with a key scientific principle – Heisenberg's Uncertainty Principle¹, which implies that the real world cannot be fully controlled. This assumption of absolute truth is similar to the reductionism, the positivist goal of nomothetic knowledge. Current scientific

¹ The Heisenberg Uncertainty Principle states that when we have a precise measurement, at the same time we cannot be that certain of other measurement. For example, if we are certain of the speed of an object, we cannot be certain of its location and vice versa.

thinking is that we are unlikely ever to be able to develop scientific theories for entities such as the atomic structure, chemical bonding and conservation of matter that are deterministic in nature. Therefore, positivism is criticised for failing “to understand the multiplicity and complexity of the life world of individuals,” which been “reduced to an oppressive uniformity through the imposition of scientific categories” (Scott & Usher, 2011, p. 29). Despite these criticisms, according to some authors, positivism remains relevant in educational research, since as Scott and Usher (2011) argued:

There are many who would argue that there are few who nowadays believe in positivism. There is much truth in this argument, since positivism has undoubtedly been subjected to a great deal of hard critique, probably to the extent where few would wish to support it purely as an epistemological position. However, it would be a serious mistake to therefore think of positivism simply as a philosophical curiosity, fit only for the dustbin of history. It could be argued, on the contrary, that this is far from being the case, since it still remains a dominant philosophy in practice, and of course is particularly alive and well in the practices of technical rationality, itself still influential in educational research, practice and policy making. (Scott & Usher, 2011, p. 14)

4.2.3 Constructivism

Constructivism and interpretivism are terms that appear in the social science and philosophy literature, which are commonly used interchangeably. Even more challenging to novice researchers is that the term constructivism¹ is also commonly used in science learning. Although the methodological and philosophical aspects of these paradigms arguments are unique, they “share the goal of understanding the complex world of lives experience from the point of view of those who live in it” (Schwandt, 1994, p. 118).

The interpretivist/constructivist paradigm asserts that reality does exist, but not separately from the knower (Tobin & Tippins, 1993). These realities exist, but they are multiple and socially-negotiated, ungoverned by natural laws, and

¹ Technically speaking, constructivism is an epistemology, but given its common usage as a paradigm, here the term constructivism is used to mean a paradigm with no obvious distinction from interpretivism, except where explicitly stated otherwise. See also Section 3.3.1 on page 77 where constructivism is termed a learning theory.

constructed “by individuals as they attempt to make sense of their experiences” (Guba & Lincoln, 1989, p. 86). That is to say, realities are products of human interactions and beliefs (Neuman, 2006). From a constructivist perspective, it is impossible to separate the knower from reality, consistent with a relativist ontology. Guba and Lincoln (1989) considered that knowledge of phenomena is constructed based on the knower’s prior knowledge, and is dependent on the sophistication of the knower – thus ascribing to a constructivist epistemology. Hence, from an interpretivist point of view, the knower does not gain or collect data from reality. Instead, individuals construct their knowledge through experience and social interactions (Costantino, 2008). The knowledge cannot be transferred from reality to the knower, because of the position of the knower who is part of the reality; he/she has to construct the knowledge in order to understand the phenomena he/she is interacting with. In addition, knowledge is both personally and socially constructed as Tobin and Tippins (1993) observed:

When we think of knowledge, it is convenient to think in terms of both the individual and the social components. Just as it is sometimes useful to think of an electron as a particle and at other times a wave, so it is sometimes useful to think of knowledge as an individual construct and at other times as a social construct. But all times knowledge is both social and individual, a dialectical relationship existing between the individual’s contribution to knowledge and the social contribution. (Tobin & Tippins, 1993, p. 6)

Based on a constructivist point of view, the knowledge constructed is assumed to be open to revision or even entirely replaced with new constructions; indicative of a hermeneutic methodology (Guba & Lincoln, 1989). This perspective is significantly different from the traditional positivist view, where the ultimate goal is to be able to control and predict things better. As a consequence, from an interpretive view of research, the process of knowing changes “from the focus on explaining the phenomena to an emphasis on understanding” (Costantino, 2008, p. 116).

Interpretivism or constructivism as a referent in research is quite similar to how it is used to understand student learning. Since constructivism asserts that truth can never to be fully known, the researcher is not seen as a truth seeker, but

rather as a learner (Tobin & Tippins, 1993). Therefore, research can be seen as a process of learning, and the researcher plays the role as a learner. This role means that the researcher:

Is to make personal sense of experience and in a socially mediated way, to build knowledge in a given field. To undertake research in a given area, then, becomes a process of personal learning, ensuring that knowledge is tested for viability in the personal and social setting in which it is to be used. The tests of viability are associated with the evidence for the particular knowledge claims and the extent to which use of the knowledge in particular situation leads to plausible solutions. (Tobin & Tippins, 1993, p. 15)

The notion of data 'collection' in interpretivist research is not the same as from a positivist viewpoint. From a constructivist perspective, data is gathered based on the researcher's personal theoretical framework, which is similar to the idea of students making sense of phenomena based on their prior knowledge. Data 'creation' and interpretation are considered concurrent events, and are seen as a component of a dialectical process (Tobin & Tippins, 1993). Therefore, prior knowledge from previous studies is crucial in the process of data creation and interpretation in constructivist-based inquiries. A researcher lacking in knowledge in a given field of study, might mean he or she is not able to generate fruitful data. In other words, looking at research from a constructivist perspective, means that research in that particular field will progress by building theory from one study to the next. This perspective on research means new 'theory' is expected in every research inquiry, and better understanding is achieved rather than confirming the theory again and again as positivist researchers might seek to do.

Since the reality in interpretivist ontology is viewed as multiple and relative, generalisability is not the main goal of research. Instead, what the researcher has learnt from the research and what others can learn from it are more important. An interpretive/constructivist approach is, therefore, *idiographic*¹, providing symbolic representation or detailed descriptions of a social

¹ Idiographic explanation is an "in-depth description or picture with specific details but limited abstraction about the social situation or setting" (Neuman, 2006, p. 91).

phenomenon (Neuman, 2006). Knowledge or theory constructed from the research should allow the community of readers to be able to judge the research, and a process of negotiation of meaning will take place as interpretive methodology is consistent with hermeneutical and dialectical ways of knowing. To do so, constructivist-based research should provide a comprehensive description of the research process, in order for “readers to understand the context of the study and to maintain the links between the theory and the context in which it is grounded” (Tobin & Tippins, 1993, p. 19).

Despite widespread acceptance of constructivism and interpretivism in social research as an alternative to positivism, they have been subject to some inevitable criticism. In opposition to the positivist assumption of objectivism, constructivism takes the roles of humans’ beliefs and interactions in the construction of knowledge, into account when seeking to explain the phenomena of human reactions. However, Rex (1974, p. 4) pointed out that although “patterns of social relations and institutions may be the product of the actors’ definition of the situation, there is also the possibility that those actors might be falsely conscious.” The inference is that reliance in constructivist-based research on the construction of knowledge means we can be misled by human (i.e., the actor) subject intentions. Thus, constructed knowledge can be seen as a product of the humans’ intention (e.g., maybe just to please the researcher), but may not represent their actual belief/s. Others argue that constructivism seems to have abandoned the importance of scientific procedures entirely, and it has been questioned with regard to its ability to provide accurate information. The criticism is mainly centred on the rationale of “rejecting the approach of physics in favour of methods more akin to literature, biography, and journalism” (Cohen et al., 2007, p. 25). In disregarding the need of objectivism, constructivist-based research, is considered to be subject to threats arising from subjectivity. These threats are considered problematic because in constructivist/interpretivist research:

There is also the very perplexing issue of what happens when we move from raising questions or writing highly speculative essays to

the giving of answers. It is not at all clear how we obtain reliable knowledge, which can be made public and plausible. (Bernstein, 1974, p. 154)

Indeed, the practicality of constructivism informing educational decision making and policy is questionable. As Scott and Usher (2011) point out:

For many educators, particularly those with a strong commitment to notions of the sovereign self and its innate capacity for self-direction, notions such as the hermeneutic circle and unconscious background would not be readily acceptable. Certainly, for those concerned with policy making and looking for steers from research, notions of indeterminacy and necessary incompleteness are highly problematic. For radical educators, an interpretivist [or constructivism] emphasis on understanding the world is secured at the expense of changing it. (Scott & Usher, 2011, p. 34)

Constructivism is also criticised for its “narrowly micro-sociological perspective,” just as positivism, is criticised for its stand on broad “macro-sociological persuasion” (Cohen et al., 2007, p. 26). The criticism of constructivism here is based on the argument that constructivism has neglected the power of external-structural-forces such as stratification, economic and political power in shaping the reality of an individual (Layder, 2006). It seems in constructivist terms that the reality constructed by an individual, stands on its own without being influenced by the individual’s social milieu – probably disregarding the existence of human society.

4.2.4 Postpositivism

The postpositivism paradigm can be considered as a derivative of positivism since it is still similar in its inquiry aim (explanation to provide prediction and control), nomothetic knowledge of reality, and exclusion of normative value (Guba & Lincoln, 1994; Lincoln & Guba, 2000). Postpositivism assumes there is a real world that exists but the real world is imperfectly ‘apprehended’ (Guba & Lincoln, 1994) – a critical realist ontology (Denscombe, 2010). This assumption means, because of human imperfectness, the real world can only be estimated, and cannot be ever fully understood, as it is usually beyond human perception.

In other words, the reality is sometimes unobservable and unpredictable by human knowledge.

Epistemologically, postpositivist views have largely abandoned the dualism assumptions because they are considered impossible to maintain. However, similar to positivism, postpositivism observes objectivity as a 'regulatory ideal' in maintaining the rigor of knowledge through critical tradition and community (Guba & Lincoln, 1994). Therefore, although the real world exists and it can be manipulated or measured as in the positivist perspective, knowledge drawn from it can always be falsified, and the knowledge that withstands falsification is the best knowledge at that point of time and best represents the real world. Replications of findings are an indication of the higher probability of truth but can never be an absolute truth. It can be also observed that postpositivism assumes that knowing the reality can only be done via theories (Denscombe, 2010), which mean that knowledge is not discovered *per se* from reality, but rather 'theorised' and yet to be falsified. Postpositivist research is, therefore, an on-going improvement of the theories but cannot be perfected and is open to refutation. These epistemological notions are considered to have some constructivist/interpretivist flavour, acknowledging "that it is impossible for researchers to understand the world in an entirely objective, neutral way" (Denscombe, 2010, p. 127). Postpositivism recognises that researcher's values and beliefs somehow influence research findings but still values scientific methods as useful in investigating social phenomena to determine causes and effects. Nonetheless, postpositivism avoids relativism, which is associated with constructivism, since this stance will contradict its goal to generate nomothetic knowledge.

4.2.5 Critical Theory

Another opposition to positivism but also favouring constructivism is critical theory¹. Critical theory can be referred to as a ‘blanket term,’ denoting several alternative paradigms, among others, neo-Marxism, feminism, materialism and participatory inquiry (Guba & Lincoln, 1994) which is heavily influenced by Jurgen Habermas’ early works and his predecessors in the Frankfurt School in Germany (Cohen et al., 2007; Neuman, 2006). Critical theory seems to agree with most of constructivism’s antagonism towards positivism, striving for a ‘telescopic’ view of social reality, by attempting to manipulate it but ignoring the social context. At the same time, critical theory criticises the constructivist approach for being too subjective and placing over-emphasis on the ‘microscopic’ view rather than a broader context (Neuman, 2006; Scott & Usher, 2011). The aim of critical theory is *emancipatory*; it not only seeks knowledge of the world and to control it, but also to reveal beliefs, interest, practices, and ideology that act to limit human freedom, justice, and democracy. The intention of this aim is to bring about social and individual transformation of social democracy (Cohen et al., 2007; Scott & Usher, 2011).

Critical theory seems to agree with the positivist assumption of realism but at the same time accepts the constructed notion of reality in constructivism. Critical theory assumes that perceived or ‘apprehendable’ reality does exist but with human influence, such that it is changed or shaped over time by “social, political, cultural, economic, ethic, and gender factors and then crystallised (or reified) into a series of structures” that are assumed to be real, natural and immutable reality – an historical realism ontology (Guba & Lincoln, 1994, p. 110). In short, the reality is a reified structure, socially shaped over time, which is perceived or taken to be ‘real.’ Therefore, the “social world is full of illusion, myth and distortion” but it is real because it shapes social relations (Neuman, 2006, p. 96). For example, the geocentric universe, which is historically reified in Babylonian,

¹ Critical theory was coined as a term in 1937 by Frankfurt School thinker, Max Horkheimer (Edgar, 2006). It is also labelled as transformative paradigm (Mackenzie & Knipe, 2006; Mertens, 2009).

Greek, and Roman civilisations, to be the 'real universe' for the people of that pre-Galileo era.

Epistemological aspects of critical theory are similar to constructivism, with some 'value added.' As in constructivism, knowledge about reality according to critical theory, is constructed, but through the influence of values and cultural interaction between the researcher and the would-be known social reality. In this sense, knowledge or research is not neutral since what is considered as knowledge of the perceived reality depends on "the social and optional power of the advocates of that knowledge" (Cohen et al., 2007, p. 27). In other words, knowledge can be different among different communities, such as knowledge about the atom in schools can be different to that among scientific communities. As a result, a participatory approach is necessary to get an in-depth understanding about the perceived reality of a community, in which the researcher needs to get acceptance and trust by the community members in order to understand their culture (Mertens, 2009).

Critical theory may utilise quantitative and qualitative methods, similar to both positivist and constructivist research, however, critical theory tends to be pluralistic, and uses evolving methodologies, in which there is no specific or standardised set of methods in research (Mertens, 2009). Qualitative methods are included to establish a dialogue between researchers and community members but mixed-methods designs can be considered to address informational needs about the community. The most important characteristic of critical research that differentiates it from positivist and constructivist research is the formation of a methodological design that involves a partnership between researchers and community members. In critical theory, researchers need to get more from their study by accepting several interpretations from peers as well as the community members (Mertens, 2009).

Although critical theory is now gaining popularity, several criticisms have been voiced. One noticeable assumption of critical theory is the emancipation of society and individuals through the knowledge constructed from critical

researches. However, it is claimed that the relation between emancipation and the revelations of limiting or disempowerment factors of human freedom (or ideology critique) “is neither clear nor proven, nor a logical necessity” (Morrison, 1995, p. 67). This criticism questions whether the revelations about the disempowerment factors are necessary for the emancipation of a person or society because emancipation can be achieved by means other than ideologies critiques. Furthermore, awareness of these factors can be an obstructing factor in itself when bring about emancipation (Cohen et al., 2007).

Another criticism of critical theory is the role of the researchers. In addition to its focus on seeking knowledge, critical theory also has a political agenda. The task of the researcher is not to have an ideology or to have an agenda, but to be value-free, neutral, and objective (Morrison, 1995). However, this role contrasts with the emancipation demand in critical theory. To achieve emancipation, one of the researcher’s tasks is to expose concern or to reveal ideology issues among the communities. This role requires the researcher to act as a ‘critical connoisseur’ providing an ideological critique, thus, the researcher cannot avoid acting ideologically (Morrison, 1995). For example, a researcher or evaluator of an educational programme cannot function without being judgemental in order to improve the educational programme.

Finally, since critical theory also encourages the participation of community members as researchers, it is criticised as being unrealistic or over-optimistic in aim of emancipation. This involvement is said to be unwarranted because the reality involves much greater powers that are unaffected by a small group of society. For instance, teachers and administrators may have some degree of power in a school but probably no effect on the larger society because most of the power or ideology in that society are beyond their control (Cohen et al., 2007).

4.2.6 Adaptation of Constructivism for the Inquiry

In the previous sections, various research paradigms have been scrutinised, and the assumptions, purpose, and criticisms of each taken into consideration. On

the basis of these critiques, it appears that constructivism/interpretivism is the most suitable framework for this inquiry.

The justification for this paradigm selection is based on the goal of the inquiry and also the nature of mental models themselves. The main goal of this inquiry is to explore students' mental models of chemical reactions. It is an in-depth study, trying to make sense of how students from multiple educational levels, represent chemical systems in their cognitive constructs, particularly in terms of their mental models. In other words, the primary goal of the inquiry is to reveal students' views in the forms of their mental models of the reality i.e., chemical phenomena. As a result, the inquiry expects multiplicity of reality, rich and complex data, with the meanings arising from social situations. Therefore, the constructivist paradigm seems to be an appropriate framework for the inquiry because the "data are socially situated, context-related, context-dependent and context-rich," where the researcher needs "to understand the context because situations affect behaviour and perspectives and vice versa" (Cohen et al., 2007, p. 167).

Although students' mental models of chemical reactions can be expected to be based on their exposure to chemistry knowledge, we remain uncertain about the nature of students' views about chemical phenomena. This uncertainty leads to inquiry for idiographic knowledge rather than nomothetic knowledge, which again is compatible with the constructivist paradigm.

Further justification for the adoption of constructivist inquiry is based on the nature of mental models themselves. "Mental models are complex and inherently epistemic; that is they form the basis for expressing how we know what we know," which is not readily assessable or understood by others (Jonassen & Henning, 1999, p. 38). In fact, the construct of mental models for a particular entity is based on the interpretation of the researcher from the responses or information given by the respondents. Additionally, it is also argued that "language is the key to understanding mental models" (Carley & Palmquist, 1992, p. 602), which implies that examining mental models is not as

direct as measuring a physical entity, but rather consist of making sense out of it through discourse interaction between the researcher and respondents. Indeed, mental models are not directly accessible, only inferred from human communication such as gesture, speech, writing or other symbolic forms (Gilbert & Boulter, 1998; Justi & Gilbert, 2000). For these reasons, the construct of mental models implies a relativist ontology, which is most suitably to be framed within the constructivist paradigm.

The inquiry was motivated by recognition of students' difficulties in learning science, and the findings can be useful for the improvement of chemistry teaching and learning (i.e., informing chemistry teaching and learning). Critical theory also has the potential for guiding the inquiry, however, this inquiry does not attempt to make an intervention or to provide emancipation at this point. Participants' involvement as collaborative researchers might improve the students' learning in science, but such practice is considered incompatible with the intention of this research, which is attempting to 'capture' the students' mental models at different levels of education rather than developing them. In other words, critical theory may not provide insights into the actual students' mental models but rather altered forms of their mental models due to interactions with the researcher.

4.3 Research Methods

As mentioned above, research methods are specific techniques, tools or procedures of gathering, and analysing data. This is discussed in detail in the following section and followed with justification of the selection of data collection methods for the inquiry.

4.3.1 Quantitative and Qualitative Methods

Research methods have traditionally been described as quantitative or qualitative. However, Scott and Usher (2011) maintained that the distinction between quantitative and qualitative methods should not be based solely on the research instruments but also on the way they are used because some of the so

called quantitative instruments can be used to collect data which is analysed qualitatively. In these instances, these instruments are simply devices for gathering information. This distinction is echoed by Blaikie (2000, p. 272) who emphasised that the qualitative and qualitative distinctions are appropriate to classify “methods and data, for researchers who use these methods and data, and for research in which they are used.”

In terms of data collection, quantitative methods “require the use of standardised measures so that the varying perspectives and experiences of people can be fit into a limited number of predetermined response categories to which numbers are assigned” (Patton, 2002, p. 14) – predominantly involving quantity and quantifying (Grix, 2004). To reiterate this goal, quantitative methods generate and use numerical data in order to explain a particular phenomenon (Bryman, 1988; Muijs, 2004). Researchers develop concepts and measurement procedures such as structured observations, standardised tests, self-report questionnaires and attitude inventories to produce numerical information as an empirical representation of the phenomena. These measurement tools usually contain specific questions and responses developed in advance of a study (Creswell, 2012). Quantitative methods are, therefore, by nature highly structured.

Qualitative methods, on the other hand, concern meaning that is given by individuals to their experiences in the world and data are generated through interpretation of the quality and texture of experience rather than assigning numerical values (Grix, 2004; Willig, 2008). Data collected from qualitative methods are drawn from the “perspective of the people who are being studied” (Bryman, 1988, p. 61). The methods typically employed include interviews, documentary analysis, and participant observation as means of recording as much information as possible for the study, in the form of texts, images or other non-numerical information, but may include some numerical data. Instead of using specific questions, qualitative methods use more general questions. These general questions are often rather dynamic, changing and emerging during data collection (Creswell, 2012). Thus, in qualitative methods, data collection

provides rich and contextualised information for understanding the social phenomena (Bryman, 1988).

The form of data collected in quantitative and qualitative research determines the process for data analysis. Since quantitative methods gather numerical data, they employ mathematical-based methods, particularly statistics, in analysis (Blaikie, 2000; Muijs, 2004). These analysis methods generate various forms of numerical measures, which are used to describe the nature of the data, to determine associations between sets of data, and to establish causation, generalisation, and prediction (Blaikie, 2000; Bryman, 1988). Ultimately, quantitative methods enable researchers to test hypotheses and theories (Grix, 2004). Conversely, in qualitative data, text and image databases are analysed to describe the phenomenon of interest such as people, places or a community (Creswell, 2012). Instead of numerical measures, the qualitative database is described or represented in the form of themes or categories that carry interpreted meanings of the data and 'thick description' of the phenomenon (Grix, 2004). These themes or categories lead to the development of concepts and theories from the data (Bryman, 1988).

Although quantitative and qualitative methods have significant differences and strengths, some schools of thought consider that they are not mutually exclusive (Creswell, 2012; Kelle & Erzberger, 2004; Patton, 2002). Indeed any research methods, whether quantitative or qualitative in nature, are potentially applicable and appropriate to any paradigm (Guba & Lincoln, 1994). Quantitative and qualitative methods, which have originated from distinct philosophical foundations, inherit both their strengths and limitations (Maxwell, 1996). This flexibility in their use implies that methods are to be viewed as free from epistemological and ontological assumptions (Grix, 2004), and therefore, researchers from different paradigm beliefs may use the same research methods. Whatever the method is, it should be used according to the research questions and to the sources of data being collected (Grix, 2004; Patton, 2002).

Some researchers argue that quantitative and qualitative methods can be combined into a study – a mixed-methods approach. Proponents of this approach assert that there are several justifications for mixing the methods. The first justification is for meeting the purpose of *triangulation*¹, that is seeking convergence of different data sources to promote the credibility of the study (Bryman, 1988; Hesse-Biber, 2010). In other words, a combination of quantitative and qualitative methods in examining the same research problem provides sounder conclusions if mutual confirmation is shown from both methods. Second, combining methods is *complementary*, enabling the “researcher to gain a fuller understanding of the research problem and/or to clarify a given research result” (Hesse-Biber, 2010, p. 4). In this way, a combination of quantitative and qualitative methods enables a researcher to get a more general picture of a phenomenon such as an ethnographer might when carrying out a survey in order to gain insight into a community which cannot be readily obtained through qualitative methods (Bryman, 1988). Third, a combination of quantitative and qualitative methods can also be seen as a move from one phase to another in a research project (Bryman, 1988; Hesse-Biber, 2010). For example, statistical data collected from a quantitative method on students’ attitudes toward science can be used to shape an in-depth interview in further investigation into negative attitudes among secondary school students.

4.3.2 Selection of Research Methods for the Inquiry

The selection of research methods for this inquiry will be driven by the research questions, so that the research method selected provides the data or information required to answer the research questions (Grix, 2004; Willig, 2008). This inquiry deals with the meaning of students’ explanations about chemical phenomena, which provide insight into the nature of their mental models. Therefore, qualitative methods of data collection are considered the most suitable methods for providing rich and in-depth information about the students’

¹ Triangulation can be understood a means of checking the integrity of conclusion drawn from a study (Schwandt, 2007).

mental models. Mental models are personal and implicit in nature, so large amounts of information are likely to be required to describe these models fully.

Adopting quantitative approaches of collecting data in this study is also of potential interest but are not expected to enhance the inquiry into understanding students' mental models. The constitution of students' mental models about chemical reactions is ambivalent or indecisive, and this situation presents a great challenge when constructing a suitable instrument for accessing data about these mental models. It is expected that efforts to construct such instruments would involve a process of reification (treating something abstract as concrete), packaging, and ultimately distortion (Scott & Usher, 2011) because the construction of a quantitative instrument would be entirely based on the researcher's frame of reference rather than co-construction of meaning in generating required data.

Utilisation of other quantitative methods such as self-report questionnaires and paper-pencil tests could be considered disadvantageous to this inquiry because their administration would require construction of a large number of items in order to generate enough information about students' mental models, making them impractical. Even if, such instruments can be effectively designed, it would not ensure that students will provide enough detail in their responses. Furthermore, utilisation of self-report inventories does not allow for both researcher and research participants to seek clarification and elaboration on terms used for the questions and responses, which may lead to invalid interpretation of information. Additionally, getting students to answer questionnaires or test questions would probably not enable them to reflect on what they actually think, or to describe their mental models. The main goals of students within an 'examination' regime education system are to excel in the questionnaire or test rather than reveal what they actually believe, or express their own point of view.

There is no single best way to access students' mental models. According to the literature, mental models have been studied by methods including "problem

solving, verbal reports, drawing, categorisation and conceptual pattern representation” (Jonassen & Cho, 2008, p. 146). These methods typically involve interviews or interview-based activities. Although externalisation of mental models employs various techniques and strategies, most studies such as Adbo and Taber (2009), Borges and Gilbert (1999), Coll (1999), and Panagiotaki et al. (2009) have used interviewing as the basic method of data collection. Interviews offer researchers access to data that cannot be directly observed, allowing the researchers to develop an understanding of another person’s views (Patton, 2002). This capability is valuable in studies of mental models because mental models are reported to be complex, implicit and multi-faceted (Jonassen & Cho, 2008). The advantages of using interviews in mental model studies is that they are “a flexible tool for data collection, enabling multi-sensory channels to be used: verbal, non-verbal, spoken, and heard” (Cohen et al., 2007, p. 149). Methods, such as observations and self-reports, may not enable researchers to construct in-depth information about human cognitive processes and constructs such as their mental models.

4.4 Cross-sectional Study as Approach of Data Collection

This study seeks to establish an understanding of students’ mental models about chemical reactions based on their stage of education. Hence, it is a developmental study. There are various ways of conducting developmental studies such as longitudinal and cross-sectional/age studies (Abraham et al., 1994). Longitudinal studies gather data from a group of respondents and involves selective sampling of group members (also called a cohort study) or from the same individuals (also called a panel study) over an extended period (Cohen et al., 2007). In other words, a longitudinal study involves repeated measurement of the same group, sample or individuals over a period. In cross-sectional studies, the data collection occurs over a period but involves different samples of the population for each data collection conducted. These cross-sectional studies involve repeated measurement over a period of different groups or individuals. A special case of cross-sectional study is the cross-age study, in which parallel groups of different ages or educational stages are studied

from the population at a single point of time. A cross-age study “bears some characteristics of a longitudinal study, in that developments over age groups could be seen” (Cohen et al., 2007, p. 213).

Both approaches have their strengths and weaknesses. Longitudinal studies are useful for investigating causal relationships and allow inferences to be made by providing rich and accurate data, and tracing changes over time. On the other hand, longitudinal studies face problems in terms of feasibility and practicality because they can involve a long period, and there is a strong possibility of attrition. They also usually involve considerable funding (Cohen et al., 2007). Further threats to longitudinal studies include the danger that repeated measurements may result in contamination of results and the researcher presence in the study itself may influence the participant’s behaviour (Abraham et al., 1994; Cohen et al., 2007). In contrast, cross-sectional and cross-age studies may be easier to conduct. However, these approaches do not permit identification of causal relationships because they typically employ non-equivalent populations or different groups of subjects in the study.

Despite some limitations, cross-age studies have been useful in tracing students’ understanding of concepts, by providing insight into the role of instructional exposure that plays in students’ development of scientific concepts (Abraham et al., 1994). For example, Coll and Treagust (2003b) compared students’ mental models of metallic bonding among secondary school, undergraduate and post-graduate students and report that it is more prudent to introduce abstract concepts at higher levels of learning. In short, cross-age studies can provide information that is useful in curriculum development, including the content, and teaching and learning strategies (Driver, Leach, Scott, & Wood-Robinson, 1994). In this inquiry, a cross-age study was used, employing participants across different levels of schooling as shown in Table 4.1.

Table 4.1 Sample in the Cross-age Study

Level of Education	Student Level	Age	Assumed Acquired Chemistry Knowledge
Lower secondary	Form 1	13	Primary science
Upper Secondary	Form 4	16	Lower secondary science
Postsecondary	Form 6	17 or 18	Upper secondary chemistry
University	First year	19 or 20	Postsecondary or Matriculation college chemistry
University	Final year	22 or 23	Undergraduate chemistry

4.5 Qualitative Interviewing

Generally, an interview can be viewed as a way of getting information or perspectives from a person through engagement in an ‘interactional exchange of dialogue.’ Interviews can be conducted through one-to-one interaction, with individuals or focus groups, and in face-to-face situations or via the telephone or the Internet (Mason, 2002). Questions in interviews differ from surveys and questionnaires because they are posed by interviewer(s) and the responses are given by the interviewee(s) verbally.

Structured or closed quantitative interviews can be viewed as an alternative to self-report questionnaires (Mason, 2002). Since the questions and choice of response are pre-formulated and rigidly sequenced – they are a form of verbal questionnaire. The locus of control in the interview is mainly the questions, where the questions themselves function as the instruments, while the interviewer verbalises the questions and choices of responses. As in self-report questionnaires, a structured interview facilitates numerous questions, is less time consuming, and enables straight-forward data analysis (Patton, 2002). Despite these advantages, this technique of interview serves a similar function to questionnaires and poses the same limitations, that is inadequate at providing in-depth understanding of participants’ view. Moreover, the limited choice of responses requires interviewees to select their experiences and feelings to fit the questions, which can lead to distortion of meaning. Thus, a structured interview is deemed unsuitable for the present inquiry, which requires more than such just superficial information.

4.5.1 Variants of Qualitative Interviews

Different types of interviews in qualitative methods vary in terms of their structure or locus of control, the formulation of questions, purposes, underlying rules, and the epistemological assumptions that they are based on (Hopf, 2004; Scott & Usher, 2011).

Compared to structured interviews, other types of interviews are less structured in nature, and categorised as qualitative interviews (Cohen et al., 2007). Qualitative interviews tend to be informal in nature – a “conversation or discussion rather than a formal question and answer format” (Mason, 2002, p. 62). Although qualitative interviews are less structured, they commonly cover certain topics, agendas, issues, or themes which guide the conversational interaction between the interviewer and interviewee and a certain degree of control of the interview may be held by the participants (Scott & Usher, 2011). However, the role of interviewer is more important than in the structured interviews, because the interviewer is the main research instrument upon whom the quality of the interview largely depends (Patton, 2002; Yin, 2011).

Qualitative interviews come with various labels and can be known as clinical interviews, dilemma interviews, biographical interview, and so on (Hopf, 2004). Even so, qualitative interviews can be categorised roughly into the informal conversational interview, the interview guide approach, and the standardised open-ended interview (Patton, 2002). The informal conversational interview is the most open-ended and flexible approach. The direction and question of the interview are dependent on the current context and situation, with no predetermined agenda or topic, or even intention, in the dialogue. The locus of control of the conversational interview is at least equal between the interviewer and interviewee. In many cases, an informal conversational interview is conducted on several occasions with the same person, so the interviewer is normally in the setting for a long period in order to obtain more information. The questions and agenda of the conversation may change over time and develop from the previous interviews, to expand on the identified information.

The main strength of the informal conversational interview is its high flexibility, spontaneity and responsiveness to the individual and situational differences by enabling the interviewer to personalise the questions to suit the interviewee and the circumstances. This ability allows informal conversational interviews to provide more in-depth information compared to other qualitative interviews. However, despite the potentially in-depth information offered by this type of interview, it is time consuming since these interviews need to be done on many occasions and may require the interviewer to be same setting for long period in order to establish rapport with the interviewees. In addition, the data gathered may also be difficult to assemble and analyse because it is been generated from different questions. For this reason, informal conversational interviews were judged impractical for this inquiry.

The interview guide approach, also known as semi-structured interviews, is more structured than the previous qualitative interview since it lists certain general questions or issues to be explored in the interview (Grix, 2004; Mason, 2002; Patton, 2002). For this type of interview, in spite of flexibility for building a conversation, and wording and sequencing of the questions, the topics or themes that to be explored have been predetermined prior to the course of the interviews. The degree of structure provided in an interview guide serves the main strength of this interview that makes the data collection more systematic for each interviewee and increases the comprehensiveness of the data. This style of interview still remains fairly situational allowing personalisation of the questions, re-clarification, and follow up with any unexpected line of inquiry (Grix, 2004). However, the flexibility in formulation and sequence of questions can result in considerably different responses from participants, which may reduce comparability.

Standardised open-ended interviews may be viewed as similar to open-ended questionnaires, in that the wording and sequence of questions are determined in advance (Patton, 2002). The only flexibility offered in this interview is the responses given by the interviewee, but its great uniformity leads to more straightforward analysis. Consequently, a structured interview should reduce

interviewer effects and bias, especially when several interviewers are involved. Another advantage of a standardised open-ended interview is the time typically needed for the interview is minimised. Such advantages are similar to an open-ended self-report questionnaire, but a standardised open-ended interview allows some flexibility such as re-clarification of ambiguity in questions or responses by the interviewers. However, this degree of flexibility also demands that the researcher be more rigorous in developing the interview protocol, to ensure important information is not discounted or neglected. Even so, the nature of standardised wording in the questions may “limit the naturalness and relevance of questions and answers” (Patton, 2002, p. 349). This feature may incur ‘examination feeling’ among interviewees, especially students, leading to similar problems as in self-report tests.

In general, all of the qualitative interview styles have potential for providing the rich information needed to access students’ mental models by affording students the opportunity to express their perspectives in their own words allowing illumination of any ambiguity. In the current study, the interview guide approach or semi-structured interview was utilised to ensure access to students’ mental models of different aspect of chemical reactions, and to keep data gathering manageable for the researcher.

4.5.2 Interviewing Techniques

Any engagement in human interaction such as an oral presentation, speech, and especially teaching, requires certain techniques and procedures for it to be effective. In a research interview, there are various techniques that are recommended.

Since the main purpose of any kind of interview is to gain verbal information from a person, the most important aspect or component of an interview is the questions because the information that will be drawn from the interview depends on them (Bell, 1995). The ways questions are worded and asked influence the interviewee’s responses and a good question in a qualitative interview should “at a minimum, be open-ended, neutral, singular, and clear”

(Patton, 2002, p. 353). As a tool producing qualitative data, an interview should minimise predetermined responses by posing open-ended questions, so people are encouraged to answer in their own words when describing their views, feelings and experiences. Such questions should permit the interviewees “to take whatever direction and use whatever words they want to express what they have to say” (Patton, 2002, p. 354). Questions like “how important is education to you?” are considered leading questions since they encourage possible responses such as ‘very important’ or ‘not important’ (Seidman, 2006). Questions that lead to dichotomy responses should also be avoided. Another point, similar to the construction of questionnaires items, is that, each of the questions should be singular, avoiding the use of more than one verb or noun. This technique is to ensure that the interviewees will only provide responses to a single matter for each question.

Despite the high value of an interview, they may still fail to gather the desired information because an interview “is a social, interpersonal encounter, not merely a data collection exercise” (Cohen et al., 2007, p. 361). Thus, it is imperative for the interviewer to be able “to establish an appropriate atmosphere such that the participant can feel secure to talk freely” (Cohen et al., 2007, p. 361). One way to establish such an atmosphere, involves the interviewer building a good rapport with the interviewee by simply being respectful and displaying behaviours like being polite, friendly, non-threatening, and attentive. Cohen stressed that:

Rapport also requires the interviewer to communicate very clearly and positively the purpose, likely duration, nature and conduct and contents of the interview, to give the respondent the opportunity to ask questions, to be sensitive to any emotions in the respondent, to avoid giving any signs of annoyance, criticism or impatience, and to leave the respondent feeling better than, or at least no worse than, she or he felt at the start of the interview. (Cohen et al., 2007, p. 362)

It is vital to recognise that interviews for some people, especially young students, can be intimidating situations. Therefore, the interviewer should put the interviewees at ease by explaining the purpose of the interview, the procedure of the interview, how responses may be recorded, and their rights (Bell, 1995;

Cohen et al., 2007). This protocol also means that the interviewer's verbal and non-verbal actions should be non-judgemental or neutral, without indicating agreement or disagreement (Cohen et al., 2007; Patton, 2002). Being neutral in interviewing, especially with young people, is important because they "may seek affirmation from the [interviewer] that they are giving the 'right' answers, or they may try to work out what the [interviewer] wants in order to please the [interviewer]" rather than give their own point of view (Bell, 1995, p. 354).

Another way to make interviewees (especially students) feel at ease in an interview is by using visual and physical objects, "that provide a comfortable focus for conversation" to reveal their understandings of natural phenomena (Carr, 1996, p. 45). This technique can be traced from clinical interviews developed by Piaget (Carr, 1996; White & Gunstone, 1992), which were extensively developed in science education and have become known as either the Interview-About-Event (IAE) (Osborne & Freyberg, 1985; Schollum, 1981b, 1982) or Interview-About-Instances (IAI) (Bell & Osborne, 1981; Gilbert, Watts, & Osborne, 1985; Osborne & Gilbert, 1980). The Interview-About-Instances procedures use a set of visual stimuli such as diagrams and pictures, actual objects and phenomena, in 'probing' the understanding of focus ideas, which is usually related to scientific views such as animals, electricity, force, atoms and light (Carr, 1996; White & Gunstone, 1992). For example, instead of asking directly about the individuals' understanding of 'animal,' the interviewer may use pictures such as a duck, human, cat, trees, grasshopper, and spider to discuss the individuals' notion of animals. Interview-About-Events is similar, but uses some activities carried out together with interviewees. For example, an interviewer uses actual events such as melting an ice cube on a saucer, dissolution of salt in water, evaporation of ethanol on a plate, and a cold bottle that becomes wet in a warm room, to explore students' views about physical changes of matter.

4.5.3 Implication of Using Interviews in a Constructivist Methodology

Although the qualitative interview has the capability to provide rich information, there is the momentous issue of the 'translation interface' to consider since this is part of human communications (Figure 4.2).

Each person makes his or her own sense of the world, and can only use what he or she already knows (existing cognitive structure) to do this we will call this a "frame of reference." It follows that each person's frame of reference differentiates his/her world to different extents and integral to this is language-the meaning of words. Given this, there is an inbuilt uncertainty in any communication between two individuals. (Johnson & Gott, 1996, p. 563)

In any interactive communication, the translation interface (or the interpretation of the verbal communication) is 'traversed' twice (Figure 4.2), and each of the 'translations' or 'interpretations' may be inconsistent. The interviewee (child or student) may misinterpret the questions and respond according to the questions that the interviewer asks. Similarly, the interviewer could interpret the interviewee's responses differently even though both of them may be using the same words. In short, this is a situation where there could be a mismatch between the interviewer's and the interviewee's frame of reference, which leads to a 'finding' which best describes what the interviewees or students think the interviewer wanted to ask.

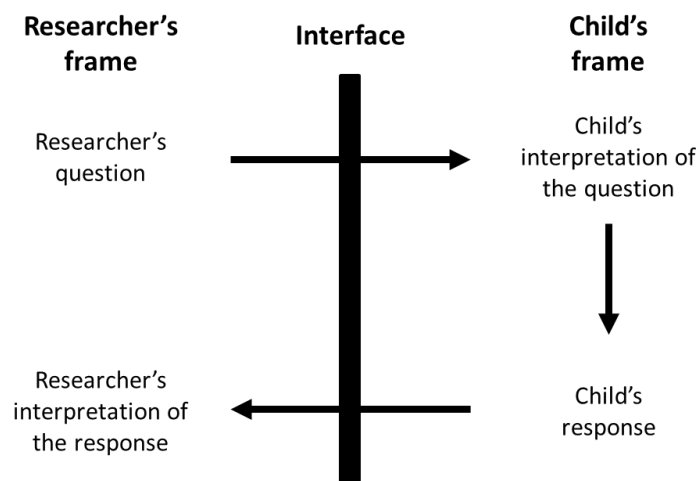


Figure 4.2 Translation Interface (After Johnson & Gott, 1996, p. 564)

These kind of ‘understandings’ or ‘findings’ cannot be considered a co-constructed meaning but rather like an excavation of facts based on the interviewer’s frame of reference (Mason, 2002). Such a situation in an interview can be minimised by establishing the ‘neutral ground’ in which “largely (but never completely) undistorted communication takes place between [interviewee] and [interviewer]” (Johnson & Gott, 1996, p. 565). In other words, the interviewee understands the meaning of the interviewer’s questions and the interviewer understands the meaning of the interviewee’s response.

Establishing neutral ground involves at least three components, which are shown in Figure 4.3 (Johnson & Gott, 1996). First, the prerequisite of neutral ground, is the utilisation of neutral tasks in the interview which implies that the tasks including objects or events and questions used are aligned to the interviewer’s and to the interviewee’s frames of references. This principle enunciates the avoidance of posing leading questions or the introduction of verbiage, jargon or ambiguous questions in the interviews which can result in distorted or misleading responses (Cohen et al., 2007; Patton, 2002).

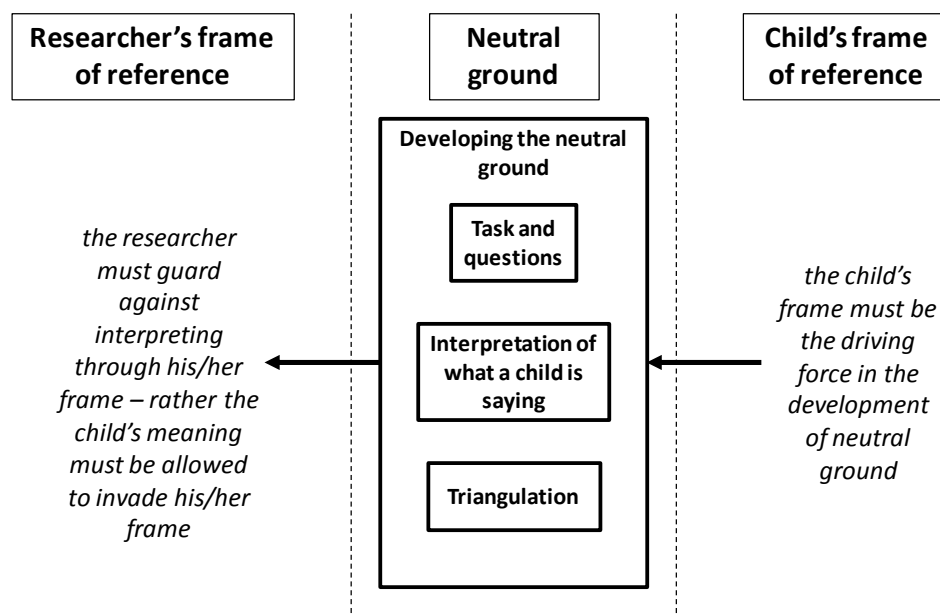


Figure 4.3 Developing the Neutral Ground (After Johnson & Gott, 1996, p. 568)

The second principle in establishing neutral ground is to make the interpretation on the neutral ground. This requirement means that the interpretation of the responses should be based on the interviewee's frames of references, where the interviewer needs to understand the terms used by the interviewee. It is emphasised that the interviewer "must guard against imposing meaning from his or her frame of framework" (Johnson & Gott, 1996, p. 566) which leads to the interviewer's meaning rather than the interviewee's meaning. For example, the word 'burn' may have different meaning and daily life applications among layperson interviewees in comparison to the scientific meaning, and should be interpreted based on their meaning rather than a scientific one. The third principle required in developing neutral ground is triangulation which "addresses not only the issue of reliability but also increases confidence in the validity of evidence" (Johnson & Gott, 1996, p. 567). Triangulation in an interview is necessary because even with neutral tasks and interpretation, the responses that are given by the interviewees may not reflect their actual understanding but rather 'instant invention.' This phenomenon can occur because interviewees may have no interest in the interview and they give what comes into their minds or they just invent answers that they do not genuinely believe in – a romancing response (Piaget, 1929). Therefore, interviewing should involve triangulating tasks where various instances of the same focus or theme are used, for example, using both endothermic and exothermic reactions in revealing students' views about change in energy in chemical reactions.

4.6 Development of Interview Protocol for the Inquiry

The current inquiry has adopted the semi-structured interview as its key data collection method (interview guide approach) with incorporation of Interview-About-Instances (IAI) techniques using chemical phenomena as a means for establishing the neutral ground. The development of the interview protocol for this inquiry required various stages, which included the determination of the interview themes or focus topics, selection of chemical phenomena to be used in the task, and the interview procedure.

4.6.1 Focus topic of the interview

Focus topics of the interview in this research were determined by basing them on the scientific descriptions of chemical reactions, the core subject in chemistry. According to Atkins (2005), chemistry includes nine central ideas: (1) matter is atomic, (2) elements display periodicity, (3) chemical bonds form when electrons pair, (4) molecular shape, (5) residual forces between molecules, (6) energy is conserved, (7) entropy tends to increase, (8) there are barriers to reaction, and (9) there are only four types of reaction that include the transfer of a proton; the transfer of electrons; the sharing of electrons; and the sharing of electron pairs. This suggestion indicates a need for emphasis on the structure of particles, changes of chemical structures, and the involvement of energy in the changes that should be grasped by students. A similar view also is expressed by Wade (2013), saying that:

If we truly want to understand a reaction, we must also know the mechanism, the step-by-step pathway from reactants to products. To know how well the reaction goes to products, we study its thermodynamics, the energetics of the reaction at equilibrium. ... To use a reaction in a realistic time period (and to keep the reaction from becoming violent), we study its kinetics, the variation of reaction rates with different conditions and concentrations of reagents. (Wade, 2013, p. 132)

Based on these views, chemical reactions (as well as physical changes) can be described or studied by way of various systems, namely *structures*, *kinetics*, and *energy* that are treated as the target systems for this current study.

An examination of the curriculum documents resulted in the identification of consensus models and the expected attributes related to the target systems of chemical reactions (Figure 4.4). For structure in chemical reactions, the corresponding consensus model is the particle model, which explains the change of chemical compositions and conservation of mass when chemical reactions occur. In chemical kinetics, the main consensus model identified, namely the collision model that explain the process of chemical reactions at the submicro level and the rate of reaction. The main components of collision theory are particle collisions and barrier to reaction, while, for the transition state model,

the components are activated complex and reaction mechanisms. When considering energy in chemical reactions, the thermodynamic model is identified as the main model for explaining energy change and spontaneity of chemical reactions, which includes conservation of energy, energy change, spontaneity, and reversibility as its key components.

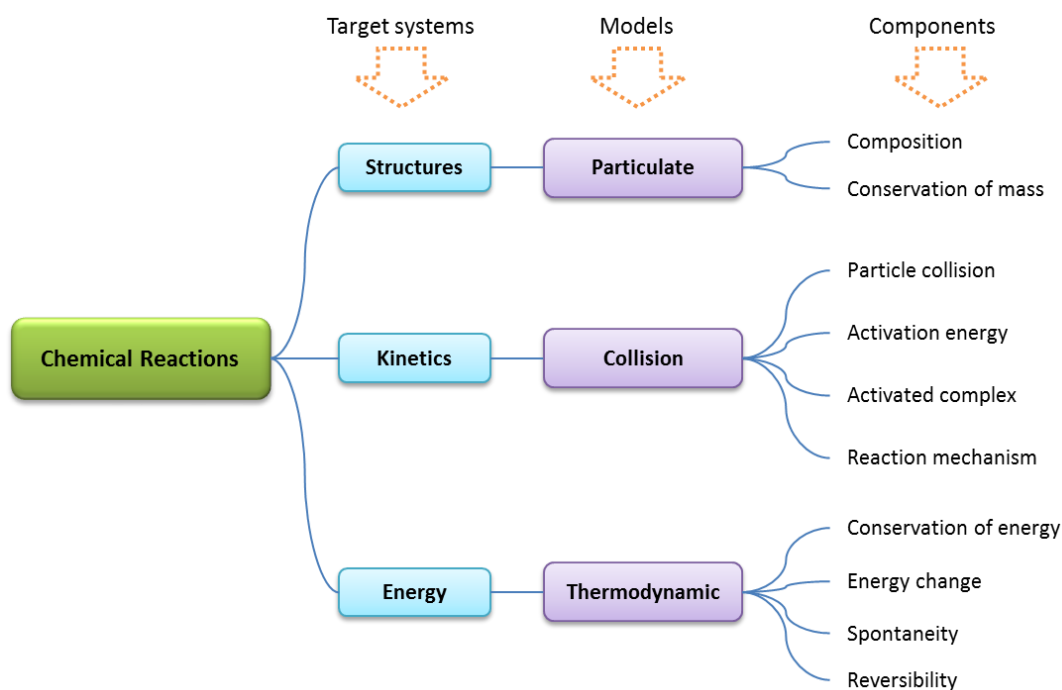


Figure 4.4 The Target Systems and Consensus Models of Chemical Reactions

In order to ascertain students' mental models of chemical reactions, the expected attributes of the components for each model according to the educational level of the students was developed (Table 4.2). The expected attributes for the components were developed through an examination of the Integrated Curriculum for Secondary School (KBSM) Science syllabus, the Malaysia High School Certificate (STPM) syllabus, and the university's academic prospectus. Consultation and cross-examination of the attributes was also conducted with teachers and lecturers of the respective educational levels.

Table 4.2 Expected Attributes of Model for Chemical Reactions According to Educational Level

Components	Primary School	Lower Secondary	Upper Secondary	Postsecondary	Undergraduate
Chemical composition	<ul style="list-style-type: none"> Iron rusts when air and water present 	<ul style="list-style-type: none"> A chemical reaction is a process of substance(s) into different form of chemical substances. 	<ul style="list-style-type: none"> A chemical reaction is a process of rearrangement of atomic composition of chemical substances to form different chemical substances. 	<ul style="list-style-type: none"> A chemical reaction is a process of rearrangement of atomic composition of chemical substances to form different chemical substances which involves change of chemical bonds. 	<ul style="list-style-type: none"> A chemical reaction is a process of rearrangement of atomic composition of chemical substances to form different chemical substances which involves change of chemical bonds.
Conservation of mass	<ul style="list-style-type: none"> Mass as a unit of quantity 	<ul style="list-style-type: none"> Mass as a unit of quantity 	<ul style="list-style-type: none"> Atoms are conserved in chemical reactions; therefore, mass is also conserved. 	<ul style="list-style-type: none"> Atoms are conserved in chemical reactions; therefore, mass is also conserved. 	<ul style="list-style-type: none"> In ordinary conditions, atoms are conserved in chemical reactions; therefore, mass is also conserved.
Particle collisions	Not available at this level.	<ul style="list-style-type: none"> Reactions occur at different rates. 	<ul style="list-style-type: none"> For a chemical reaction to occur, the reacting particles must collide with one another in the proper orientation and with sufficient energy. This collision is referred as an effective collision. Chance of an effective collision increases based on the frequency of collision which influenced by factors such as temperature, concentration, pressure, surface area and catalyst. 	<ul style="list-style-type: none"> For a chemical reaction to occur, the reacting particles must collide with one another. Molecular collision is affected by temperature, concentration, pressure and surface area. Only a small fraction of the collisions have sufficient energy to overcome a threshold energy called activation energy and proper molecular orientation of collision. This collision is referred as an effective collision. Catalysts provide a different pathway for the reaction, one with lower activation energy. 	<ul style="list-style-type: none"> For a chemical reaction to occur, the reacting particles must collide with one another. Molecular collision is affected by temperature, concentration, pressure and surface area. Only a small fraction of the collisions produce reactions that have sufficient energy to overcome a threshold energy called activation energy and proper molecular orientation of collision. This collision is referred as an effective collision. Catalysts provide a different pathway for the reaction, one with lower activation energy.

Table 4.2 Expected Attributes of Model for Chemical Reactions According to Educational Level (continued)

Components	Primary School	Lower Secondary	Upper Secondary	Postsecondary	Undergraduate
Barrier to reaction	Not available at this level.	Not available at this level.	<ul style="list-style-type: none"> Activation energy is the minimum energy in collision for particles to react. 	<ul style="list-style-type: none"> Activation energy is the minimum energy in collision for particles to react. 	<ul style="list-style-type: none"> Activation energy is the minimum energy in collision for particles to react.
Activated complex	Not available at this level.	Not available at this level.	Not available at this level.	<ul style="list-style-type: none"> In effective collision, a chemical species called as activated complex is formed before the formation of products happens. 	<ul style="list-style-type: none"> In effective collision, a chemical species called as activated complex is formed before the formation of products happens.
Reaction mechanism	Not available at this level.	Not available at this level.	Not available at this level.	Not available at this level.	<ul style="list-style-type: none"> Chemical reaction occur as a sequence of elementary reactions or elementary steps. This overall sequence is called the reaction mechanism. Chemical species or reaction intermediates are formed and consumed in elementary reactions.
Conservation of energy	<ul style="list-style-type: none"> Chemical energy can be transformed into other kind of energy. 	<ul style="list-style-type: none"> Energy is conserved. Energy can only be transformed, but neither can be created or destroyed. 	<ul style="list-style-type: none"> Energy is conserved. Energy can only be transformed, but neither can be created or destroyed. 	<ul style="list-style-type: none"> Energy is conserved. Energy can only be transformed, but neither can be created or destroyed. 	<ul style="list-style-type: none"> Energy is conserved. Energy can only be transformed, but neither can be created or destroyed.

Table 4.2 Expected Attributes of Model for Chemical Reactions According to Educational Level (continued)

Components	Primary School	Lower Secondary	Upper Secondary	Postsecondary	Undergraduate
Energy change	<ul style="list-style-type: none"> Heat gain and loss causes change in temperature of matter 	<ul style="list-style-type: none"> Change in state of matter involves absorption and release of heat 	<ul style="list-style-type: none"> Exothermic reactions release energy to the surroundings. <ul style="list-style-type: none"> The chemical energy of reactants is higher than the products. Therefore, the energy absorbed in bond breaking is lower than the energy given out in bond formation. This difference in chemical energy is transferred to the surroundings and observed as increase of temperature. Endothermic reactions absorb energy from the surroundings. <ul style="list-style-type: none"> The chemical energy of reactants is lower than the products. Therefore, the energy absorbed in bond breaking is higher than the energy given out in bond formation. 	<ul style="list-style-type: none"> Exothermic reactions release energy to the surroundings. <ul style="list-style-type: none"> The enthalpy of reactants is higher than the products. This difference in enthalpy is transferred to the surroundings and observed as increase of temperature. The energy absorbed in bond breaking is lower than the energy given out in bond formation. Endothermic reactions absorb heat energy from the surroundings. <ul style="list-style-type: none"> The enthalpy of reactants is lower than the products. This difference in enthalpy is transferred to the system and observed as decrease of temperature. The energy absorbed in bond breaking is higher than the energy given out in bond formation. 	<ul style="list-style-type: none"> Exothermic reactions release energy to the surroundings. <ul style="list-style-type: none"> The potential energy of reactants is higher than the products. This difference in potential energy is transferred to the surroundings and observed as increase of temperature. The internal energy of system decreases. The energy absorbed in bond breaking is lower than the heat energy given out in bond formation. Endothermic reactions absorb energy from the surroundings. <ul style="list-style-type: none"> The potential energy of reactants is lower than the products therefore This difference in potential energy is absorbed from the surroundings and observed as decrease of temperature. The internal energy of system increases. The energy absorbed in bond breaking is higher than the energy given out in bond formation

Table 4.2 Expected Attributes of Model for Chemical Reactions According to Educational Level (continued)

Components	Primary School	Lower Secondary	Upper Secondary	Postsecondary	Undergraduate
Spontaneity	Not available at this level.	Not available at this level.	Not available at this level.	<ul style="list-style-type: none"> Spontaneous electrochemical reactions are when the electromotive force (emf) of a chemical reaction is positive and result of energy release (especially electric energy). Non-spontaneous electrochemical reactions are when the electromotive force (emf) of the chemical reaction is negative and require energy (especially electric energy) to happen. The idea of entropy is not introduced. 	<ul style="list-style-type: none"> A spontaneous change of a system is one that occurs by itself under specified conditions, without a continuous input of energy from outside the system. For a non-spontaneous change to occur, the surroundings must supply the system with a continuous input of energy. Spontaneous reactions proceed in the direction that increases the entropy of the universe (a system plus surroundings). Exothermic reactions are spontaneous because energy released from the system results in a significant increase in entropy of the surroundings. Endothermic reactions are spontaneous because of a significant increase in entropy of the system. Spontaneous reaction at constant temperature and pressure, the Gibbs free energy of the system always decreases.
Reversibility of reactions	Not available at this level.	Not available at this level.	Not available at this level.	<ul style="list-style-type: none"> Chemical equilibrium is the state when the concentrations of reactants and products remain constant over time. The equilibrium mixture results because the reaction is reversible. Chemical equilibrium is a dynamic state in which forward and reverse reactions continue at equal rates so that there is no net conversion of reactants to products If a system is at equilibrium and the conditions are changed so that it is no longer at equilibrium, the system will react to reach a new equilibrium state in a way that partially counteracts the change. 	<ul style="list-style-type: none"> Chemical equilibrium is the state when the concentrations of reactants and products remain constant over time. The equilibrium mixture results because the reaction is reversible. Chemical equilibrium is a dynamic state in which forward and reverse reactions continue at equal rates so that there is no net conversion of reactants to products If a system is at equilibrium and the conditions are changed so that it is no longer at equilibrium, the system will react to reach a new equilibrium in a way that partially counteracts the change. For a system at equilibrium, the Gibbs free energy is zero. Chemical systems tend to achieve equilibrium because it is the lowest possible Gibbs free energy.

Focus topics for each component in the respective target systems are drawn (Table 4.3). Focus questions were then constructed based on the focus topics in where students were being asked to express their mental models.

4.6.2 Chemical Phenomena Used for the Task

To explore students' mental models of chemical reactions, examples of chemical phenomena were used as foci for conversation in the Interview-About-Instances (IAI) approach. This strategy also ensured that the interview builds on the students' frame of reference (Johnson & Gott, 1996). There were eight chemical phenomena used in the interview namely; (1) rusting, (2) ice melting, (3) dissolution of salt and sugar in water, (4) lead iodide precipitation, (5) zinc-acid reaction, (6) combustion of butane, (7) an endothermic reaction¹, and (8) the chromate-dichromate equilibrium (Table 4.4). These phenomena are considered simple and frequently encountered in students' everyday environment and classroom education.

Although it is desirable to get to know students' mental models for the target system of each chemical phenomenon, this procedure would be time consuming. In addition, not all of the chemical phenomena show obvious characteristics of each target system. Thus, each of the chemical phenomena had specified focus topics that the students were asked about corresponding to the target system (Table 4.5). In other words, students' expressions of their mental models are only performed for certain focus topics when being interviewed about a particular chemical phenomenon. For example, although the lead precipitation is a suitable example for discussing conservation of mass, it is not suitable to show the energy change in chemical reactions because the energy change is quite small and not that obvious.

¹ The example of endothermic reaction between barium hydroxide octahydrate and ammonium thiocyanate is used in Chemistry Form 5 textbook (Lim et al., 2006).

Table 4.3 Focus Topics Corresponding to Target Systems and Components

Target systems	Components	Focus topics	Focus questions	Anticipated responses
Structure	Composition	Notion of chemical reactions	What is a chemical reaction?	Explanation of their understanding of a chemical reaction and how it differs from physical change.
	Conservation of mass	Mass conservation in chemical reactions	Why does mass conserved in a chemical reaction?	Prediction and justification of mass change in closed system.
	Particle collision Reaction mechanism	Reaction at the particulate level	How does a chemical reaction happen at the submicro level?	Explanation about the process of chemical reactions at particulate level.
Energy	Barrier to reaction Activated complex	Rate of reaction	Why does a chemical reaction happen slowly or fast?	Prediction and justification of the progression or rate of reaction.
	Conservation energy Energy change	Change of energy in chemical reactions	Why does a chemical reaction release or absorb energy?	Explanation about change of temperature and energy in chemical reactions.
	Spontaneity	Driving force of chemical reactions	What makes a chemical reaction happen?	Explanation about the spontaneity of chemical reactions.
	Reversibility	Reversibility of chemical reactions	Why does a chemical reaction irreversible or reversible?	Explanation about reversibility and irreversibility of chemical reactions.

Table 4.4 Chemical Phenomena Used in the Interview-About-Instances (IAI)

Phenomenon	Chemical equation	Phenomenon Classification	Type of system	Rate of change	ΔH	ΔS	ΔG
Rusting	$4\text{Fe}(s) + 3\text{O}_2(g) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}(s)$	Redox	Open	Slow	-ve	+ve	-ve
Ice melting	$\text{H}_2\text{O}(s) \rightarrow \text{H}_2\text{O}(l)$	Melting	Open	Fast	+ve	+ve	-ve
Dissolution of salt and sugar in water	$\text{NaCl}(s) \rightarrow \text{NaCl}(aq)$	Dissolution	Open	Fast	-ve	+ve	-ve
Lead iodide precipitation	$\text{Pb}(\text{NO}_3)_2(aq) + 2\text{KI}(aq) \rightarrow \text{PbI}_2(s) + 2\text{KNO}_3(aq)$	Double displacement	Closed	Fast	-ve	+ve	-ve
Zinc-acid reaction	$\text{Zn}(s) + 2\text{HCl}(aq) \rightarrow \text{H}_2(g) + \text{ZnCl}_2(aq)$	Single displacement	Closed	Fast	-ve	+ve	-ve
Combustion of butane	$\text{C}_4\text{H}_{10}(g) + 6\text{O}_2(g) \rightarrow 4\text{CO}_2(g) + 4\text{H}_2\text{O}(g)$	Combustion	Open	Fast	-ve	+ve	-ve
An endothermic reaction	$\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(s) + 2\text{NH}_4\text{SCN}(s) \rightarrow \text{Ba}(\text{SCN})_2(s) + 2\text{NH}_3(g) + 10\text{H}_2\text{O}(l)$	Double displacement and acid-base	Open	Fast	+ve	+ve	-ve
Chromate-dichromate equilibrium	$\text{Cr}_2\text{O}_7^{2-}(aq) + 2\text{OH}^-(aq) \rightarrow 2\text{CrO}_4^{2-}(aq) + \text{H}_2\text{O}(l)$	Redox in equilibrium	Open	Fast			0

Table 4.5 Chemical Phenomena and the Focus Topic for the Interview-About-Instances (IAI)

Chemical phenomena	Focus Topics						
	Notion of chemical reaction	Conservation of mass in chemical reaction	Reaction at the particulate level	Rate of reaction	Change of energy in chemical reaction	Driving force of chemical reaction	Reversibility of chemical reaction
Rusting	✓						
Ice melting	✓						
Dissolution of salt and sugar in water	✓						
Lead iodide precipitation		✓					
Zinc-acid reaction		✓	✓	✓			
Combustion of butane			✓		✓	✓	✓
Endothermic reaction					✓	✓	✓
Chromate-dichromate equilibrium							✓

There are some other justifications for the selection of the chemical phenomena. First, the tasks that were selected not only enabled students to use their preferred mental models, but also more advanced models in order to explain the chemical reactions. The interviews contained some chemical phenomena that are not easily explained with simple understandings but require a scientific model. For example, the endothermic reaction was used to ensure students are prompted that spontaneity of a chemical reaction is not solely a consideration of energy release. Second, some of the chemical phenomena were used as non-examples which serve as within-methods triangulation (Denzin, 1970). Table 4.5 shows that each of the focus topics was discussed for at least two chemical phenomena. For instance, melting of ice and dissolution of salt and sugar, which are physical changes, were used to triangulate students' understanding of chemical reactions, to make sure they were really able to distinguish between chemical reactions and physical changes. Similarly, students' notions of energy change in chemical reactions were triangulated using both exothermic and endothermic reactions, and the chromate-dichromate equilibrium reaction was used to triangulate students' notion of reversibility in other chemical phenomena. Third, most of the chemical phenomena are considered familiar, not only because of students' formal learning but also in their daily life experiences, which students may have constructed some idea or mental models related to the chemical phenomena.

4.6.3 Interview Procedure

It is indispensable in the initial stage of the interview to create a non-threatening environment and to build rapport with the students (Bell & Osborne, 1981). The steps that were taken to establish rapport included the researcher's self-introduction and explanation of the purpose of the interview to the students. The students were told that the purpose of the interviews was to gain insight into their understanding about chemical reactions. They were assured of the confidentiality of the interview data and that the interviews were not an examination or test. To minimise any intimidating feeling of being evaluated, the interviews were conducted side-by-side rather than face-to-face. Students were

assured that the researcher was not seeking correct responses but was interested on their views and might ask for further clarification. Students were also notified that the interviews were being recorded, and permission to do so was obtained from them. Before the interview was conducted, students were told how the interviews were to be conducted, and they were informed of their rights to stop from continuing the interview or to withdraw their information.

The interview was guided by an interview protocol¹ (Appendix A). Students were encouraged to express their mental models of the target systems through their verbalisation of thoughts². Their attentions were focused in sequence on each of the selected chemical phenomenon, and they were asked to respond to questions on the designated focus topics corresponding to the target system. Students were also encouraged to draw diagrams to illustrate their understanding about the target system where necessary, but they were not compelled to do so.

The incorporation of Interview-About-Instances (IAI) technique in this study was quite different to the graphical cards first developed to explore students understanding of particular events (Carr, 1996). In this study, instead of using cards, still pictures of rusting, melting of ice, and dissolution of salt and sugar; and video clips of the lead iodide precipitation, zinc-acid reaction, combustion of butane, endothermic reaction, and chromate-dichromate equilibrium were used in the interview. As recommended by Gilbert et al. (1985), the still pictures and video clips were shown in sequence from simple ones finishing with more challenging chemical phenomena. The pictures and video clips were shown via a computer presentation (MS PowerPoint) and replayed upon students' request or when deemed necessary by the researcher. Chemical equations for the reactions were also shown in the computer presentation. At the end of the

¹ The interview protocol was developed in English and Malay. An expert of both languages has examined the consistency of the meaning of each question in the interview protocol.

² Most of the interview was conducted in Malay. However, some students preferred to respond in English or interchangeably with Malay.

interviews, students were thanked sincerely for their participation and contributions to the study.

Each of the interviews was entirely transcribed verbatim whenever possible before the next interview commences. This practice is considered beneficial because it enables an early stage of data analysis (Ezzy, 2002). It allows a form of reflection about interview sessions that helps the researcher to improve the following interview by emphasising techniques or actions that went well and avoiding unproductive actions.

4.7 Description of the Sample

A total of 67 students with various academic abilities were selected from secondary schools (Form 1 and Form 4)¹, post-secondary colleges (Form 6), and undergraduate university classes (first and final year) in west coast of Sabah, Malaysia. These groups of students were selected based on their assumed acquired knowledge in chemistry from their previous level of learning. For example, Form 1 students in lower secondary have just completed their primary schooling, and this experience is likely to be reflected in the level of scientific knowledge and skill they have acquired as a result of their learning experiences in primary science.

Table 4.6 shows students' pseudonyms according to their levels of education and the institution. All students were approached through administrator of the learning institutions involved. For Form 1, Form 4, Form 6 students, the school administrators usually assigned which class to be involved for the interview and got the students to volunteer (explained in detail in Section 4.10, page 172). On the other hand, the university students were approached through email and then face-to-face follow up.

¹ Students in Year 6, Form 3, and Form 5 are preparing for their national standard examination. For this reason, the Malaysia Ministry of Education does not allow any form of research conducted for these groups of students.

Table 4.6 Students' Levels of Education and Their Institutions

Learning Institution	Junior	Senior	Form 1	Form 4	Form 6	Total
University (B Ed)	UO017, UO019, UO021, UO023, UO024, UO025, UO026, UO027, UO028, UO029	UF007, UF008, UF009, UF010, UF011, UF012, UF013, UF014, UF015, UF016, UF018, UF020, UF022				23
University (B Sc)	UO064, UO065, UO069, UO070	UF060, UF061, UF062, UF063				8
ES1			SO054, SO055, SO056	SF051, SF052, SF053		6
NS1			SO033, SO035, SO036, SO037	SF038, SF039, SF040		7
NS2			SO044, SO045, SO046	SF041, SF042, SF043		6
NS3			SO075, SO076	SF072, SF073, SF074		5
NS4					SS057, SS058, SS059	3
NS5					SS067, SS068, SS071	3
NS6					SS030, SS031, SS032	3
NS7					SS047, SS048, SS049	3
Total	14	17	12	12	12	67

Note. UO = Junior University; UF = Senior University; SO = Form 1; SF = Form 4; SS = Form 6

Most of the Form 1 and Form 4 students were from the national schools (NS1, NS2, and NS3), which all are considered as high performing schools. Only 6 of them were from an elite school (ES1), which is a science specialist school that only offers science stream classes (meaning that only students who performed very well in their lower secondary are enrolled in this school). However, all the Form 6 students were from high performing national schools that offer Form 6 classes (NS4, NS5, NS6, and NS7). Both the Form 4 and Form 6 students were in science stream, which usually are those students with good grade in science. The university students were from a university in Sabah, enrolled in the bachelor programme in science education (majoring in chemistry) at the faculty of education and the chemical industry programme at the faculty of science. All of these students can be consider high achievers, since both of the programmes require good results in science subjects in the Malaysia High School Certificate (STPM) or in matriculation programme (see Section 1.3.2 on page 10). Both

groups of these undergraduate students had similar chemistry papers (most of the time taking the same paper together).

Form 1 students were 13 year olds of age, and they recently finished their primary schooling. They were expected to express a mental model of chemical reactions according to their learning in primary school science. In their primary school science, they were introduced to chemical phenomena such as change of physical state, acid and alkali, and rusting. Form 4 students (15 year olds) were those who have finished 3 years of lower secondary level education. At this stage, Form 4 students were exposed to a wider range of chemistry knowledge such as change of matter, minerals, and air in their lower secondary education. On the other hand, Form 6 students (18 year olds) are those who have finished their two years of secondary education where they have learned about basic chemistry concepts such as atomic structure, Periodic Table, chemical bonding, and various types of chemical reactions (see Table 1.1 on page 14 for details). There were two groups of university students involved in the interviews, that is junior and senior undergraduate students. The juniors are those who have completed their advanced level or postsecondary education, either from Form 6 or the matriculation programmes. At this stage, students were exposed to more advanced topics or models in chemistry (see Table 1.1 on page 14). The senior university students were in their fourth year of study, had completed most of the chemistry courses offered in university, comprising of more in-depth topics in the area of physical chemistry, inorganic chemistry, organic chemistry, chemical analysis, and other applied chemistry topics. These senior students were mostly completing their final year projects.

4.8 Approach to Data Analysis

There were two forms of data gathered in this study; the students' verbal utterances and the sketches that they drew in the interviews. All of the verbal utterances were fully transcribed, which served to familiarise the researcher with the content and students' generation of ideas about the data (Gibbs, 2007).

Each transcript¹ was read carefully several times and emerging patterns were noted. Initial observations and thoughts were also recorded for further analysis. In contrast, the sketches on papers were scanned into digital graphic form. Both transcriptions and digitalised sketches were compiled using NVIVO 9 software for analysis.

The process of data analysis as shown in Figure 4.5 was conducted using the data retrieval capability of NVivo 9. The first stage of data analysis was to reduce and manage the large amount of data. All of the transcriptions and sketches were coded according to the students' pseudonyms and educational levels. This stage was followed by topical coding, where the segments of the interview transcripts and sketches were coded according to the type of chemical phenomena and focus topics used in the interviews. With the code assignment based on students' information and focus topics, a form of inventories was generated in which students' responses from their verbal utterances and sketches were organised according to the focus topics. The compiled form of interview transcripts were then examined for statements and sketches that could be interpreted as evidence of students' ideas about the target systems that reflect the attributes of their mental models of chemical reactions. These expressions were summarised based on students' own language where possible, forming a type of conceptual inventories linked to the focus topics, and constituting the basic unit of analysis (Erickson, 1979). Using the conceptual inventory, the summarised expression of students' ideas about the target systems were further examined for similarities, repetitions, and differences, which were then coded into themes (see Appendix B) – a thematic coding (Auerbach & Silverstein, 2003; Guest, 2012). The themes were continually refined to adapt for redundancy and ambiguity. Transcripts and the conceptual inventories were also read again, and the units of students' expression were compared, removed, or regrouped where

¹ The transcriptions in Malay were translated into English only those that were used for the analysis. An expert of both language has examined the consistency of Malay transcription and the English translated transcription. However, the data analysis is carried based on the Malay language.

appropriate. The interview excerpts according to the thematic codes are given in Appendix C.

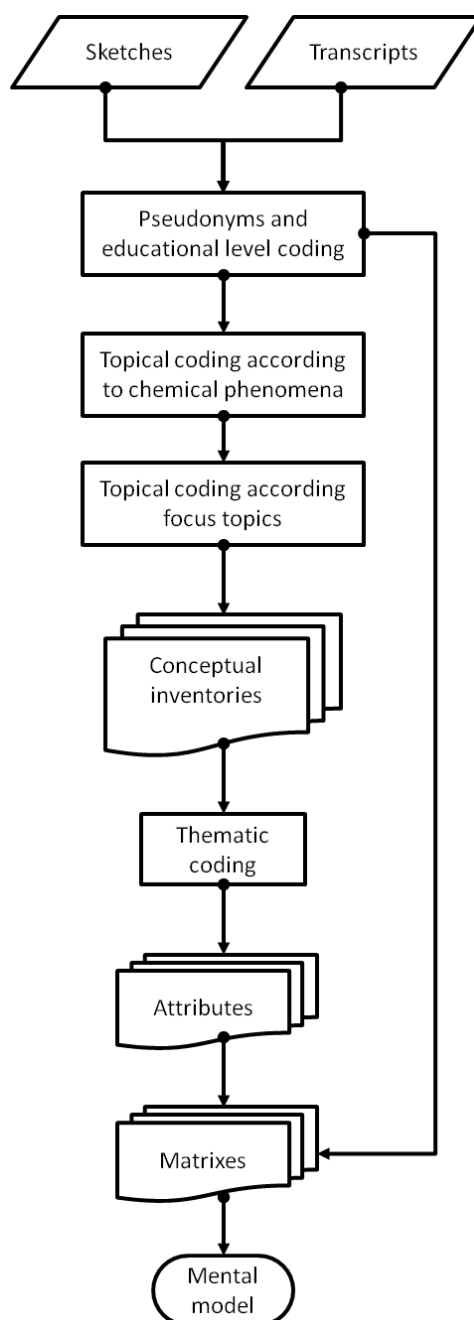


Figure 4.5 Overall Process of Data Analysis

The themes generated from the thematic analysis were considered as the attributes of students' mental models of the target systems. In order to identify students' mental models of the target systems for chemical reactions, matrixes were generated through tabulation of the thematic codes against each of the

students' pseudonyms codes (Appendix D). The matrixes were used to locate interconnections between attributes and construe students' mental models.

4.9 Trustworthiness of the Qualitative Inquiry

Conventional ways to examine the rigour or quality of research (especially positivist and postpositivist) are based on the internal validity, external validity, reliability, and objectivity of the study (Guba & Lincoln, 1989). Although, within the framework of logical positivism, these criteria are reasonable and appropriate, constructivists have suggested an important departure from the conventional paradigms and argued that the quality criteria can be translated into what is termed *trustworthiness* criteria (Guba & Lincoln, 1989). Trustworthiness criteria include credibility, transferability, dependability, and confirmability, which are considered parallel to conventional criteria.

4.9.1 Credibility

The credibility criterion is concerned with the similarity between findings and the constructed social realities and the reconstructions attributed to them. Instead of focusing on achieving the 'truth' about the reality, credibility in constructivist inquiry is more concerned with establishing the match between the constructed realities of the participants¹ and those realities as represented by the inquirer (Guba & Lincoln, 1989). Thus, to ensure credibility in a constructivist inquiry, the methods of data collection and analysis should ensure that the constructed reality is based on the participant' interpretation of the reality and is a true representation of their interpretation.

The credibility of an inquiry can be addressed through strategies such as prolonged engagement, persistent observation, peer debriefing, negative case analysis, progressive subjectivity, and member checking. Building rapport and trust with participants by prolonged engagement in the site of inquiry helps to uncover constructions, and understand the cultural context, overcoming the

¹ Underpinned by an assumption that participants can have full knowledge of their worlds (Scott & Usher, 2011).

effects of misinformation, or distortion. Persistent observation provides identification of characteristics and elements relevant to the inquiry. Peer debriefing with a disinterested peer or someone who has no contractual interest over the situation allows discussions of the progress of the inquiry and also helps the inquirer to understand his or her own position, values, and roles in the inquiry. Negative case analysis is “the process of revising working hypotheses in the light of hindsight, with an eye toward developing and refining a given hypothesis (or set of them) until it counts for all known cases” (Guba & Lincoln, 1989, pp. 237-238), and implies that the researcher/inquirer should not expect that all cases will fit the analysis. Progressive subjectivity ensures the credibility of constructivist inquiry by monitoring the researcher’s own developing construction that may otherwise interfere with the researcher’s attention to the construction offered by the participants. This practice alerts the researcher to his or her own construction, which cannot be given more affordance over anyone else’s, so that any construction that emerges from the inquiry must be a joint one. Finally, member checking, a crucial technique for establishing credibility, is a practice of negotiation with stakeholders in the representation of their construction, providing opportunities for validating their reality. This strategy enables participants to offer additional information to the inquiry and to “react to what has been presented as representing their construction” (Guba & Lincoln, 1989, p. 239).

Another effective way of enhancing credibility in a constructivist inquiry is through triangulation (Cohen et al., 2007; Patton, 2002; Stake, 2010). A triangulation is a process of “collecting information from a diverse range of individuals and settings, using a variety of methods” (Maxwell, 1996, p. 93). This strategy minimises the risk of systematic biases arising due to a specific method and provides corroborated evidence. Although the first impression of triangulation is may be that it is a form of confirmation and validation, it is also considered a form of differentiation (Stake, 2010). Triangulation is not just used to demonstrate that different methods yield the same results, but it is also used to identify “inconsistencies in findings across different kinds of data” that can be

illuminative and significant (Patton, 2002, p. 556). Thus, inconsistencies should not be viewed as diminishing the credibility of the inquiry but rather offering deeper insight about the relationship between the methods and phenomenon under study; either way, research can be improved with triangulation.

There are several kinds of triangulation, such as source triangulation, methodological triangulation, and investigator triangulation (Patton, 2002). Source triangulation involves comparing and crosschecking the consistency of information drawn from different types and levels of data sources using qualitative methods. The variety of types of data sources for triangulation may involve collection from a different time frame, space or situation, and person. Source triangulation may also involve more than one level of data analysis “namely the individual level, interactive level (groups), and the level of collectivities (organisational, cultural and societal)” (Cohen et al., 2007, p. 142). Investigator or analyst triangulation refers to multiple investigators/analysts for data collection or reviews of the findings. Triangulating observers or interviewers may help minimise potential biases of a single person in data collection and provides a means for assessing the consistency of obtained data (Patton, 2002). Analyst triangulation involves more than one person with independent analysts analysing the same qualitative data and comparing their results. Methodological triangulation, on the other hand, applies to multiple data collection methods or strategies typically mixing qualitative and quantitative styles of data collection in an inquiry (Neuman, 2006) – a between-methods triangulation. Methodological triangulation may also employ multiple strategies within the same methods, a within-method triangulation (Denzin, 1970). For example, a self-completion questionnaire may contain contrasting scales for measuring attitude.

4.9.2 Transferability

Transferability can be viewed as a parallel to external validity; the extent a finding is applicable in other situations or contexts. Instead of depending on the degree of representativeness of a study to a wider population, transferability of a

constructivist inquiry depends on the degree of similarity or matches of its salient conditions with other situations. However, the degree of transferability is relative, and is judged by the reader of the research findings rather than by the inquirer (Guba & Lincoln, 1989). Although the decision about the pertinence and relevance of a study lies entirely with the readers, they need to be provided with rich thick descriptions of the study by setting out all the working hypotheses and providing “an extensive and careful description of the time, the place, the context, the culture in which those hypotheses were found to be salient” (Guba & Lincoln, 1989, pp. 241-242). Providing “as complete a data base as humanly possible,” such as incorporating extensive but readable excerpts of verbatim transcripts and presentation of participants’ characteristics, is essential for readers to determine whether the research findings are transferable on the basis of shared characteristics between the study and their own situation. Such richness of data is recommended “to facilitate transferability judgements on the part of others” (Guba & Lincoln, 1989, p. 242).

4.9.3 Dependability and Confirmability

Dependability in constructivist inquiry is considered a match to reliability in the positivist paradigm. Dependability or reliability in constructivist enquiry should be regarded as a fit between the recorded data and what actually occurred in the natural setting of the inquiry (Cohen et al., 2007). Dependability is the degree of accuracy and comprehensiveness of the data (Bogdan & Biklen, 2007). Though positivist inquiry requires the application of the same methods throughout the data collection in order to ensure replicability of the result, this requirement is not applicable to constructivist naturalistic inquiries, which tend to include methodological changes and shifts because of a maturation of constructions. Such changes and shifts are argued to be the hallmark of maturing and successful inquiry, and “need to be both tracked and traceable” showing the development of the inquiry process and its rationale. This requirement means that the “data (construction, assertions, facts, and so on) can be tracked to their sources” (Guba & Lincoln, 1989, pp. 242-243).

Confirmability corresponds to the positivist criterion of objectivity and is concerned with “assuring the data, interpretations, and outcomes of inquiries are rooted in contexts” and are “not simply figments” of the inquirers’ mind (Guba & Lincoln, 1989, p. 243). This means of determining confirmability differs from the positivist paradigm where assurance of objectivity is achieved through disconnection from the inquirers’ values, biases, or political interests. The integrity of constructivist findings is rooted in the data itself. Respondent validation (or member checking) which involves making sure the raw data, the process used in the data analysis, and the interpretation are available for scrutiny, is a frequently used strategy to enhance both dependability and confirmability in constructivist inquiries (Cohen et al., 2007). Both dependability and confirmability of an inquiry can be further enhanced through an audit trail which explores the process of the inquiry, the extent of traceability, and documentation of the data, findings, and interpretations (Lincoln & Guba, 1985). According to Lincoln and Guba (1985, pp. 319-320), the audit trail can be provided in terms of various records or information, such as raw data, data reduction and analysis, data reconstructions and syntheses, field notes, and development data collection methods.

4.9.4 Measures to Enhance Trustworthiness

Credibility for this study was maintained through the strategies described in Section 4.9.1 on page 166. Although the interview data were gathered over a short period (about three months), several steps were taken to ensure prolonged engagement and persistent observation. Amongst the university students, the researcher was known, and most of them had been taught by him previously. Thus, the researcher was able to develop a good rapport and trust with the students, so they were willingly to participate in the interview. Building a non-threatening environment for the interview was also crucial, especially with the secondary school students with whom the researcher had no prior contact. In order to establish such environments in the interviews, several measures were taken including a self-introduction by the researcher and getting acquainted with the students, the researcher’s informal attire, an explanation of the purpose of

the interview, assurance of confidentiality of the interview data, a non-examination situation (the researcher and students sit side by side rather than face to face), and conducting the interview in a private space.

Negative case analysis was also employed in the study. Each interview was transcribed and read as soon as possible after completion, which enabled the researcher to reflect and continually examine the goal of the inquiry to understand students' mental models of chemical reactions. A pilot study was also carried out, not only as a practice for the researcher, but also it also as a test for the effectiveness of the interview protocol and its further development. As a result, parts of the interview protocol were changed such as the sequence of the chemical phenomena. These actions are considered consistent with the dynamic nature of constructivist inquiry, and improve the credibility of the interview data. Field notes were also compiled while interviews were in progress and being audio-recorded, and also during the process of transcribing the interviews. These field notes were used to assist the researcher in terms of identifying emerging patterns and to formulate probing questions.

Progressive subjectivity was more difficult to establish but the researcher continually examined his own constructions in relation with the research goal. These criteria were met through the researcher's reflections, listening back to the interview recording, reading the interview transcriptions, and examining if where and how the researcher had imposed his own point of view to the student participants before proceeding to the next interview. Member checking was also employed through participant validation of the raw data by inspection of interview transcripts. This last step not only improved the credibility, it also ensured that the data were recorded accurately, which also enhanced the dependability and confirmability criteria of the inquiry.

Multiple ways of triangulations were also employed in the inquiry to enhance credibility. Within-methods triangulation involved incorporating various types of chemical phenomena and non-examples in the interview protocol (see Section 4.6.2 on page 155). Students were also encouraged to further clarify their

responses through drawing. Source triangulation involved triangulation of various data sources including students' interview transcripts, students' sketches, curriculum documents, and cross-checked expected attributes of the target systems of chemical reactions (see Table 4.2 on page 151).

Besides employing participant validation to enhance the dependability of this study, several other actions were taken. A digital recorder was used during the interviews to ensure the accuracy of the recording of data and the transcribing was done by the researcher. Since the interviews were solely conducted by the researcher, skill in conducting interviews was crucial. In order to get initial skills for the interview, the pilot study was employed. Another factor considered was the possible instability of data collection that could jeopardise the dependability of the inquiry. This would be caused by the researcher's exhaustion or psychological stress from the intensity of the interviews process (Guba & Lincoln, 1989). To minimise such conditions, the interviews were limited to not more than two interviews a day and most were conducted on alternate days. Handling large amount of qualitative data may also affect the dependability of the data. This issue was addressed by the utilisation of NVIVO 9 computer software for qualitative data analysis that facilitated recording and tracking of the construction, assertions, annotations, reflections, and related information.

4.10 Ethical Considerations

According to Lodico, Spaulding, and Voegtler (2006), there are three important ethical issues to consider when conducting an educational research. Researchers need to make sure participants are fully informed when they consent to engage in the project, that all efforts are made to identify harm and mitigate the student participants from harm, and that participants' confidentiality is assured throughout the study. All of these considerations were covered in the ethics application, and approval was granted by the University of Waikato human research ethics committee.

Gaining access

Conducting educational research in Malaysia is governed by two main gatekeepers namely the Education Planning and Research Division (EPRD) in the Malaysian Ministry of Education, and the Economic Planning Unit (EPU) in the Prime Minister's Department. Application to conduct this study was made to the Economic Planning Unit (EPU) and this unit consulted with the Education Planning and Research Division (EPRD) before granting permission for data collection (Appendix E). Gaining access to students was achieved by seeking permission from the leadership of the institution where these students were studying (the school principals, the Deputy Vice-Chancellor and the deans) to explain the research and its processes.

When these authorities gave permission to conduct the research in their institutions, the informed consent form was given to them for signing (see Appendix G for schools and Appendix H for the university). To access the student participants, the institutions instructed their personnel such as the teacher, head of programme, or head of department to introduce the researcher to the student participants individually. After the introduction, the interview was explained to the student, and also the use of the data and confidentiality issues. The students were not coerced into participating and were provided with information for participants' (Appendix I).

Informed consent

The student participants had the interview procedures, confidentiality issues, and their rights explained to them. The informed consent form was given to them and to read and understand (Appendix I). If they agreed to participate in the interview, they were asked to sign the informed consent form without being coerced into participating. The time and place of the interview was determined after the students signed the informed consent form.

Confidentiality and participants' rights

Students were told that they had the right to decline to participate or to withdraw from the data collections process even after the interview. The

researcher's contact details (email, address, and telephone number) were also given to the students for them to refuse the use of the data collected up to two weeks after the interview was conducted if they so wished. Any data gathered from a student who later withdrew would be destroyed.

A summary of the interview was given to the students to check or change any content, and they had two weeks to make any changes or even to withdraw. This summary was confidential to the persons interviewed. Participants' identities were handled anonymously through the application of numerical code or pseudonyms.

4.11 Summary

This chapter has provided a description of the methodology and methods of the inquiry, building on the literature review in Chapter 2 and theoretical perspective in Chapter 3.

This chapter has discussed and scrutinised the major paradigms in research in terms of their ontological, epistemological, and methodological assumptions. This discussion has justify that adaptation of the constructivist paradigm on the basis that mental models are personal construct that cannot be directly measure and only be inferred from human interaction or communication. In order to provide rich information about mental model that co-constructed between participants and the researcher, qualitative data was considered to be more suitable for this study. This method adapted the semi-structured interviews, employing the Interview-About-Instances (IAI) approach in focusing various target systems of chemical reactions. Through the semi-structured interviews, students' mental models of chemical reactions were examined in term of three target systems (i.e., structures, kinetics, and energy). This study also seeks for understanding of students' mental models about chemical reactions according on their levels of education, which has adapted a cross-sectional study. This adaptation was justified based on the merits of its practicality and feasibility for the purpose of this study. In order to enhance the trustworthiness of this study,

several measures have been exercised, *inter alia*, negative case analysis, member checking, within-method triangulation, and audit trail. Ethical issues were also been taken into consideration by ensuring gatekeepers' permission, participants' informed consent and confidentiality.

The following Chapter 5 reports on the research findings concerning the attributes of students' mental models.

Chapter 5 Attributes of Students' Mental Models of Chemical Reactions

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This chapter provides an overall description of the research findings addressing the first research question, which is concerned with the nature of students' mental models. This chapter starts with an introduction about the attributes identified from the interviews. The attributes of students' mental models of chemical reactions for the three main target systems, that is structure, kinetics and energy, are presented in detail according to the focus topics. In this chapter, the attributes of students' mental models are presented in such a way to provide a general sense about the students' responses. The identification of types of mental models of chemical reactions and comparison of students mental models according to levels of education follow in subsequent chapters.

5.1 Introduction

The overall aim of this inquiry was to gain insights into students' mental models of chemical reactions. The attributes (or characteristics) of students' mental models were sought through their responses to the Interview-About-Instances (IAI) approach in order to address the first research question:

RQ1: What are the attributes of students' mental models of chemical reactions?

The attributes of students' mental models that were identified from students' responses to each of the focus topics are presented in the following sections according to the components of the target systems (Table 5.1). The percentages given for each emerging attribute (from the data analysis) presented in this inquiry reflects the proportion of all students that responded with the particular attribute when explaining the chemical phenomenon. These percentages did not necessarily add up to 100% since most of the time students could be categorised with more than one attribute.

Table 5.1 Focus Topics According to the Target Systems and Components

Target system	Components	Focus topics
Chemical structures	Composition	Notion of chemical reactions
	Conservation of mass	Mass conservation in chemical reactions
Chemical kinetics	Particle collision	Reaction at the particulate level
	Reaction mechanism	
	Barrier to reaction	Rate of reaction
	Activated complex	
Chemical energy	Conservation energy	Change of energy in chemical reactions
	Energy change	
	Spontaneity	Driving force of chemical reactions
	Reversibility	Reversibility of chemical reactions

5.2 Mental Model Attributes for Chemical Structures

The attributes of students' mental models in terms of the chemical structure component of chemical reactions were elicited from their response to the focus topics concerning the notion of chemical reactions and mass conservation of various chemical phenomena.

5.2.1 Notions of Chemical Reactions

To reveal students' notions of chemical reactions, they were presented in turn with three chemical phenomena: rusting, ice melting, and dissolution of sugar and salt (see Task 1, 2 and 3 in Appendix A on page 375). Subsequently, the students were asked to identify whether the phenomena were chemical reactions or physical changes and explain what they think happened in the events. Their responses are shown in Table 5.2. Most of the students easily

identified rusting as a chemical reaction, but about 60% ($n=40$) of the students considered that dissolution of salt and sugar to be a chemical reaction. Surprisingly, a fair number of the students (40%, $n=27$) also considered ice melting as a chemical reaction.

Table 5.2 Students' Classification of Chemical Phenomena

Chemical phenomenon	Chemical reaction		Non chemical reaction	
	<i>f</i>	% ^a	<i>f</i>	% ^a
Rusting	59	88	2	3
Ice melting	27	40	34	51
Salt and sugar dissolution	40	60	19	28

Note. Details may not add up to total due to some students gave more than one type of response or no response.

^aPercentage out of 67 students.

Table 5.3 shows students' responses to the focus topic of the notion of chemical reactions. Most of the students (70%, $n=47$) attributed chemical reactions as the *response to reacting agents* and about half of them viewed chemical reactions as the *formation of new substances or interaction between substances*. Only about 40% of the students possessed the attribute that a chemical reaction is a process involves *submicro changes*.

Table 5.3 Students' Responses About the Notion of Chemical Reactions

<i>What is a chemical reaction?</i>	<i>f</i>	% ^a
Expected natural occurrence	5	8
Change of chemical substances	14	21
Change in physical properties	20	30
Response to reacting agents	47	70
Interaction between substances	30	45
Formation of new substances	37	55
Submicro changes	26	39

Note. Details may not add up to total due to some students gave more than one type of response or no response.

^aPercentage out of 67 students.

Expected natural occurrence – Some 8% of the participants considered a chemical reaction to be a natural occurrence, happening without manipulation. In the thinking of these participants, the changes of substances, which happen in the surroundings such as rusting and ice melting are part of nature. “Natural” in Malay is “*lumrah*” which implies that a phenomenon is expected and meant to happen; therefore, it is not necessary to explain this.

What I know is that in our air, there is oxygen, everywhere, even here where we are sitting, except in vacuum. This thing is natural phenomenon in the world. It is like why chickens lay eggs. It is the same with iron rusting. The reason why it rusts is because it is exposed. (UF008)

Change of chemical substances – Students with this attribute considered a chemical reaction is evident when any change happens to any chemical substance. They also considered that any chemicals they know of, will undergo changes or chemical reactions. Ice melting (which is a physical change) is assumed to be a chemical reaction here purely because it undergoes some changes, which indicates a lack of understanding of the chemical change idea. This notion was not confined to novice students, but also present for some final year university students.

Substances change from one state to other state through a chemical reaction. ... The substance changes into a different form. But it is not necessary change in terms of its content. It changes. (UF015)

Change in physical properties – Some students presumed that any change is a chemical reaction, and looked for changes in the physical appearance of materials like such as physical state, colour, and density, all which they see as characteristics of chemical reactions. However, other students seemed aware that changes of physical properties are related to changes of chemical substances.

For chemical reactions, we know it when there is change in colour. We look at its colour change. Like the metal, we know it is silvery and after it is corrode, its colour changed to orange. So, one of the elements in the metal has been reduced. (UF060)

Response towards reaction agents – This type of response was found to be the most frequent (70%), and students explained chemical reactions or changes as something that happens to a substance as a result of some responses towards other chemical substances or other kind of agents such as the surroundings, air, heat, and light. These agents were assumed to be causing the chemical substances to change. In other words, the changes, regardless of whether they are physical changes or chemical changes, happen in the presence of or via exposure to the reaction agents.

[The iron is rusting. It is] caused by the acid rain. There is something causes it to happen. Chemical reaction is something that makes something change. It involves process depends on the changes. (SF040)

Interaction between substances – This idea involved more than one substance reacting, but neither of the reacting substances causes the reaction. Students perceived chemical reactions as obtaining the product from a certain ingredient – like a recipe used in the making of a product, more than one chemical substance is needed for the reaction to happen. Students using this notion were more likely to think of the dissolution of sugar and salt as a chemical reaction.

Iron which is rusting is a reaction between oxygen with iron. Oxidised. It is between a chemical with [other] chemical. Like just now, between oxygen and iron. Normally to me, there were two, like metal with something else. There is something reacting with something else. Not necessarily with something else. Maybe heat. (SF041)

In some instances, students described chemical reactions as the combining of substances to form a singular new chemical substance, which probably consists of a combination of the previous chemical substances. The word 'combine' or in Malay '*bergabung*,' is normally used to describe the chemical phenomena.

I think it is like something and with something that are combined. Is not only two, but maybe more. Is like being combined. It is still there but it is already combined with the other one. So, both mixes, but still there. (SF051)

Formation of new substances – A common idea about chemical reactions, especially among the senior university students, is the production of new substances, which are chemically different from the initial substances. Some junior students shared this notion, but saw it rather differently in terms of how the new substances are formed. Students at different levels of education seemed to understand that, in chemical reactions, the substances formed are new substances. The success of this notion in telling whether a change is a chemical reaction depends on the students understanding of the composition of chemical substances. However, the formation of new substances was described in different ways. Lower level students were more likely to describe the formation of the new substances at the macro level, where the formation of the new substance is merely a transformation from one substance to another. On the other hand, the senior students were more likely to explain the formation of new substances at both macro and submicro levels. At the submicro level, the senior students related the formation of new substances to change in chemical bonding, transfer of electrons, change of oxidation number, and chemical composition.

A chemical reaction is when either a compound or element is formed from its constituent elements ... [In ice melting] Only involve a change of state as in from water to ice or ice to water, I don't feel it is a chemical reaction, just change of state. A physical change. (SS030)

Students commonly failed to differentiate between chemical reactions and physical changes, when solely relying on this idea that new substances formed in chemical changes. Dissolution, for example, was considered as a chemical reaction, because some students assumed that a solution (or even heat energy) is a new product formed from combining sugar with water or salt with water.

When substances mixed together, something else, other substances produced. That is a reaction. We can see in terms of colour or colours of the new compound. Or, the other properties that can be observed or measured. ... [Ice melting] There is no new product. It is only the state is changed. For the one, salt and water, there are two substances mixed together, they will produce new substances. (UF007)

This attribute was not restricted to secondary school students; it was also held by senior university students. However, none of the Form 1 students thought of the formation of new substances as chemical events.

Submicro changes – Only about 40% of the students classified chemical phenomena in terms of changes that happened at the submicro level, examples of which included modification of chemical bonding, transfer of electron(s), change in oxidation state, and chemical compositions.

When a chemical reaction happen composition in the molecule changed, change in terms of its chemistry. It reacts with other substance and it will form new products. The previous composition is still there but it combines with other chemical to form new products. But, non-chemical reaction, it will maintain the same molecule; the composition is still the same. (UF016)

Some of these students who understand that chemical reactions involve changes at the submicro level, they also considered that dissolution of salt and sugar in water as a chemical reaction.

Salt and sugar. It is chemical reaction because there is change in terms of the initial structure of the substance. Maybe there is certain change happen, maybe change in the position between them. I feel that there is change in terms of its structural component. (UF022)

5.2.2 Conservation of Mass in Chemical Reactions

In Task 4 and Task 5 (Appendix A in page 375), students were asked to predict the change of mass in lead iodide precipitation and zinc-acid reactions. Table 5.4 presents the students' prediction of the mass change. A striking observation is that only 24% (n=16) predicted that the mass would remain the same for both chemical reactions, implying that they have grasped the principle of conservation of mass. In contrast, some 36% (n=24) predicted the mass of the mixtures of both reacting systems would either increase or decrease. This result indicates that the students who gave these responses did not assume the conservation of mass in a chemical reaction. Another 10% (n=7) predicted that the mass in lead iodide precipitation reaction will change, but would remain the same for the zinc-acid reaction. Interestingly, 19% (n=13) considered that the mass would

remain the same in the lead iodide precipitation reaction but the mass would decrease in the zinc-acid reaction.

Table 5.4 Mass Prediction in Chemical Reactions

Mass		Lead Iodide Precipitation							
		Change		Same		Uncertain		Total	
		<i>f</i>	% ^a	<i>F</i>	% ^a	<i>f</i>	% ^a	<i>f</i>	% ^a
Zinc-acid	Change	24	36	13	19	3	5	40	60
	Same	7	10	16	24	0	0	23	34
	Uncertain	3	5	1	2	0	0	4	6
	Total	34	51	30	45	3	5	67	100

^aPercentage out of 67 students.

There were five main assertions that students used in their justifications of their predictions about mass change as provided in Table 5.5. About 20-30% of the students can be considered to hold mass-density confusion, which means their judgement was influenced by the physical state and quantity of substances. About half of the students thought that a closed system would affect the conservation of mass. Only 13% of the students were able to say that the mass in the chemical reactions is conserved based on the rearrangement of atoms. This result is a clear indication that most students fail to recognise conservation of mass in chemical reactions because they did not link it to the concepts of mass and atom.

Table 5.5 Students Responses About Mass Conservation in Chemical Reactions

<i>Why does mass conserved in a chemical reaction?</i>	<i>f</i>	% ^a
Dependent on the physical state	18	27
More substances formed	17	25
Gas properties	15	22
Closed system	32	48
Rearrangement of atoms	9	13

Note. Details may not add up to total due to some students gave more than one type of response or no response.

^aPercentage out of 67 students.

Dependent on the physical state – This explanation attributes the change in mass to the physical state of matter of the product(s). Here, students considered that the formation of solid(s) in the lead iodide precipitation reaction contributes to an increase in the total mass of the reaction mixture. In contrast, the gas produced in the zinc-acid reaction will not contribute to an increase of mass because the gas is considered lighter than the liquid, which mean the overall mass will be less.

[The mass] decreases because it changes into gas. The gas is lighter than water. (SO076)

The mass will change because the zinc has dissolved. That's what makes [the mass] changed. I think so, because something in form of liquid is lighter. (SF040)

[The mass] increase because of the precipitation formation. The precipitation is solid. So, solid's [mass] is more than the liquid. (UF011)

More substances formed – In this explanation, the formation of new substances contributes to an increase of mass in the mixture. It seems here, students who expressed this attribute thought that the product in the reaction was a consequence of additional substances being formed without considering that the formation of products occurs as a result of reactants being used up. It seems that these students thought particles duplicate themselves to form the new substances. This construct may suggest that the mechanism of chemical reactions in this mental model is a transmutation process, where totally new substances are produced from the original substances.

It is caused from the mixing the new liquid, the new chemical. So, when mixing the new chemical, it can be said that [the substances] become more. Before that, the yellow thing was not there. After that, there is the new thing [formed]. Therefore, the weight increases. (SO037)

The air content becomes more. [When] the air becomes more, the weight becomes more. (SF074)

Gas properties – Some of the students, who recognised conservation of mass in the lead iodide precipitation reaction, believed that a gas cannot be weighed using a balance because the gas is too light, or that the gas is not on top of the

balance, or because of gas buoyancy. As a result of such thinking, students inferred that the total mass of the mixture decreases. Such beliefs were not confined to younger students but were held also by senior university students.

I believe it will change. Since the gas expands upward. I don't think the [balance] can detect the gas because, the [balance] depends on what was on it, right. So the gas is on top of the conical, in the balloon, so I don't think gas will affect. (UO069)

Closed system – By recognising that the chemical reactions were carried out in a closed system, about half of the students considered that the mass of the mixture would remain the same regardless of the formation of a precipitate or gas. Such students were most probably able to relate the mass of matter to the number atoms involved in the reaction.

The overall mass is the same because it is in a [closed] container. So, after the reaction, [the mass] must be the same. Nothing goes in. The mass must be the same. ... The number of particle is still the same. (SS032)

However, this relationship was not always the case because some students did not refer to the idea of particle in their prediction of mass change in the closed systems.

I think it is the same. ... Although they have different masses, after being in the container, the mass will be the same, even there is change in the chemical. ... It is because the air just goes up and it is not become more. There is nothing can come in or goes out. (SF039)

Rearrangement of atoms – Only 13% (n=9) of the students reasoned that the mass would remain the same, based on the notion that, in a chemical reaction, atoms are rearranged in make up any new product. Although new chemical substances were formed, they thought the atoms that were involved in the chemical reactions remained the same. This explanation is probably the best indication that some students had grasped the idea of atomic nature of matter and understood its relationship with macro properties.

[The mass is still the same] because of the elemental content is still the same. For example, in lead nitrate, its nitrate, it will use two nitrate ions, there are still two nitrate ions. So, its mass is not changes for the nitrate. Also with lead, before the reaction, it has one mole of lead, but after the reaction, it will not increase also. It exists in one mole of lead. The same with iodide, for iodide before the reaction, it has two moles of iodide ion, after the reaction, the iodide still two moles. (UF013)

5.2.3 Attributes for Chemical Structures

Students' mental models in terms of change in chemical structures were examined through their responses regarding their idea of chemical reactions and the conservation of mass. The prevalent observation of students' mental models of these concepts was that about 70% of the students viewed chemical reactions as a process of *response to reacting agents*. Their assumption was that a chemical reaction is a response of reactants towards agents acting on them. On the other hand, 45% of the students perceived chemical as *interaction of new substances*. With these attributes in their mental models, students seemed to fail to distinguish between chemical reactions and physical changes. About 55% of the students recognised that chemical reactions results in change of chemical substance by the *formation of new substances*. However, only 40% of the students (mostly from Form 6 and the university) assumed that chemical reactions involve *submicro changes* such as change in chemical composition, oxidation state, and chemical structures.

In terms of conservation of mass, students predicted and reasoned that change of mass in chemical reactions based mainly on the macro level. For example, the students predicted that the change of mass was *dependent on the physical state* (27%) or influenced by the *gas properties* (22%) or reasoned that the mass increase because of *more substances formed* (25%), and the chemical systems are closed systems (48%). Only 13% reasoned the conservation of mass based on the particulate nature of matter by explaining that mass is conserved because, in closed chemical reactions, the atoms in reactants are rearranged to form the products.

5.3 Mental Model Attributes for Chemical Kinetics

The chemical kinetics features of students' mental models were examined using students' responses to the focus topics that concerned the reaction at the particulate level and rate of reaction (see Table 5.1 on page 178).

5.3.1 Reactions at the Particulate Level

To investigate students' mental models of chemical reactions related to chemical kinetics, students were asked to describe the process of the reaction for the zinc-acid reaction (Task 5) and combustion (Task 6) at the submicro level¹. The students' responses to this focus topic are shown in Table 5.6. These responses indicate that students offered more explanations in the case of the zinc-acid reaction, compared to the combustion reaction, especially in terms of chemical bonding. Consistent with students' predictions and explanations about the rate of reaction, the application of the kinetic theory of particles and chemical bonding was limited. However, about a quarter of the students (37%, n=25) thought that a chemical reaction involves a rearrangement of the atomic components of chemical substances in the zinc-acid reaction.

Collisions of particles – About 20% of the students mentioned the collisions of particles when explaining the process of chemical reactions at the particulate level, similar to their explanation about the rate of reaction.

I imagine zinc as a simple sphere, and hydrogen chloride as another sets sphere. So these two will undergo collisions, and meantime transfer of electrons will occur. Oxygen molecules will collide with these butane molecules. (SS030)

¹ Attributes for chemical kinetics were also drawn from other chemical reactions used in the interviews. Some excerpts shown here also taken from other than these chemical reactions.

Table 5.6 Students' Responses About Reaction at the Particulate Level

<i>How do reactions happen at the particulate level?</i>	Zinc-acid		Combustion	
	<i>f</i>	% ^a	<i>f</i>	% ^a
Collisions of particles	15	22	13	19
Activation energy	4	6	4	6
Metastable species	0	0	1	2
Octet approach	3	5	0	0
Redox	4	6	1	2
Bond breaking-formation	11	16	19	28
Transfer of electrons	17	25	0	0
Attraction between charges	9	13	0	0
Intermediates	10	15	5	8
Mechanistic approach	5	8	5	8
Transmutation	1	2	0	0
Internal arrangement	9	13	0	0
Atoms rearrangement	25	37	10	15

Note. Details may not add up to total due to some students gave more than one type of response or no response.

^aPercentage out of 67 students.

Activation energy – Some students thought that chemical reactions are influenced by the activation energy, and that energy is needed to overcome an energy barrier.

This butane has a certain flash point or activation energy. If the activation energy can be provided by the spark, produce by flint as the highly energetic, some of this energy initiates the reaction with oxygen. Therefore, the combustion happened. (SS030)

In the aqueous, the HCl will collide with zinc. When energy is enough, the activation energy, HCl will break to H and Cl. (SS032)

Metastable species – One student mentioned a kind of chemical species similar to an activated complex, which is formed first, then it decomposes into the reaction products.

Butane and oxygen in the reaction will temporary combine first, and later on they will break up to form the carbon dioxide and water. (UF016)

Octet approach – In this explanation, formation of the products was mimicked by the formation of a compound from its elements. Electron transfer happens as described in the octet rule.

Cl is the one receiving the electron, that's why it is attracted to each other. Cl, for it to achieve stable noble electron configuration, it needs one extra electron, ... because it is a halogen, so it receives one electron. So, this one zinc, one zinc can donate two electrons. So, it will involve one chlorine, one chloride, so it will become zinc two. (UF014)

Bond breaking-formation – In this case, the chemical reactions were explained on the basis of bond breaking and bond formation. The molecules of the reactants undergo bond breaking, and then bond formation, which results in the formation of new product molecules.

The C-H bond or C-C bond will break. Therefore, leaving behind free C or H as intermediates, as it does this oxygen also may break or may not break, and ... it will all break, and form with these free atoms, and therefore, forming the products and the process release heat. (SS030)

Redox – Here, chemical reactions were simply described as change in the oxidation state of the substances.

This [process] is an auto-oxidation. As long as it is exposed to air which contain water vapour and oxygen gas, it start oxidation process whereby the Fe atom will become Fe three plus. Right, if it is a metal ion, iron metal oxide, let say FeO, mean Fe two plus auto-oxidation will also occur because the reduction potential of Fe three plus is much more stable than Fe two plus. So, oxidation occurs. (UO064)

Transfer of electrons – In this construct, chemical reactions were explained as a process of manipulation of electrons, either transferred or received by atoms. Normally this notion was accompanied by the redox explanation of chemical reactions.

A redox reaction happened here. It involves the oxidation and the reduction processes. The iron has been oxidise because of exposure to air. So, oxidation occurred. And reduction occurs the same time due to oxygen and the substance. So, there's a transfer of electrons. (UF062)

Zinc undergoes reduction, by releasing its electron. The electron received by the chloride ion to form the chloride. Received by this chloride to form this $[\text{ZnCl}_2]$. (SS031)

Intermediates – Chemical reactions here were explained by the formation of intermediates or other chemical species during the process of the reactions before the formation of products.

Oxygen molecules will collide with these butane molecules. Bonds will break, the CH bond or CC bond will break. Therefore, leaving behind free C or H as intermediates. (SS030)

When zinc is added into HCl, Zn will ionise forming two plus. After that, it is surrounded with the other ions. The positive ions and negative ions will attract to each other. So, it will form this one $[\text{ZnCl}_2]$. (UF011)

Attraction between charges – Chemical reactions in this view, involved the attraction between charged particles to form the product.

Maybe, zinc is negative, and hydrogen is positive, and the attraction of the hydrogen is stronger than Cl, the zinc attracts the chlorine atom. (UF018)

Mechanistic approach – Students with this understanding described chemical reactions carefully in more detail, through a process of bond breaking, transfer of electrons and bond formation, in which there were considerations of the transfer of electrons towards a suitable recipient and attraction between charged species.

The H plus and Cl. ... when zinc is added, zinc will react with Cl. ... [Zinc] will release two electrons. So, zinc, will become zinc two plus. Adding two electrons and zinc two plus will move to stabilise the chloride. So, zinc chloride is produced. Since H plus has less electrons, to stabilise it, H plus will accept two electrons. And two H plus, will need two electrons and produce hydrogen gas. (UF013)

When C2, I mean C radical and oxygen atom come together, so they will start their bonding formation, whereby they form a C double O, and then for H two O also form a single bond O. ... First, what happens is the CC bond and the CH bond, is going to change into radical, whereby it is a homolytic fission. ... And then, when the oxygen comes in, we have oxygen here, and then it forms the double bond by joining here, double bond, and then, this joining here. (UO064)

Transmutation – Only one student (Form 1) stated explicitly that atoms change into a different kind of atoms.

May be, acid hydrochloric separates the atom in zinc ... To create hydrogen gas. Because, what I have learn, or observed in some part of my lesson, ... atoms break up, or they form more atoms, and combine to create a new atom or multiply the atom. (SO033)

This idea about chemical reactions is not dissimilar to that held by most of the lower secondary school students, who were unable to explain how chemical reactions happen at the submicro level. They said that chemical substances change into a different kind of chemical substances (see page 182 and 185).

Internal arrangement – Lower secondary school students typically, explained the chemical reaction between zinc and hydrochloric similar to what happen during changes of physical state. This understanding indicates that students at this stage were still unable to differentiate between chemical reactions and physical changes.

The particles will become gas. When it is mixed [metal and acid], it becomes active and flies here and there. It will move randomly and gather energy to become gas. (SF038)

Atom rearrangement – With this attribute, students explained that atoms in the reactants are rearranged in terms of how they are bonded with other atoms. Chemical reactions here were described as the rearrangement of atomic constituent of the reactants, which results in the formation of new substances with new atomic composition.

Butane has carbon and hydrogen. So, carbon will combine with oxygen to form carbon dioxide and H will mix with oxygen to form water. (SF043)

Zinc has one atom, and hydrochloric acid has hydrogen and chloride. When they are mixed up, zinc will combine with chloride and hydrogen will be released to the air. (UF018)

5.3.2 Rate of Reaction

To access the students' mental models further about the process of a chemical reaction, students were asked to predict the rate of reaction in a zinc-acid reaction (Task 5) as the reaction takes place at room temperature and then when it was heated. Table 5.7 shows the students predictions about the rate of reaction for both situations. Some 76% (n=51) of the students predicted the reaction would become slower as it proceeds, and quite a large proportion, 87% (n=58), predicted that the reaction would become faster when it is heated. Only 69% (n=46) correctly predicted both situations.

There was a variety of ways students predicted the speed of reaction (see Table 5.8). Most of the students (63%, n=42) rationalised the rate of reaction based on quantity dependency. Only 20% of the students thought that rate of reaction depends on the rate of collisions of reacting particles. The role of energy in the rate of reaction also varied. Some 19% of the students considered that energy initiates the chemical reactions. Remarkably, only 5% (n=3) of the students related the rate of reaction to the activation energy with similar small numbers having views related to *probability of reactions* and *sites of reaction*.

Table 5.7 Students Prediction of Rate of Reaction

Rate of reaction		As it takes place									
		Slower		Faster		Constant		Not asked or no responses		Total	
								<i>f</i>	% ^a		
If it is heated	Slower	1	2	0	0	0	0	0	0	1	2
	Faster	46	69	4	6	3	5	5	8	58	87
	Constant	0	0	1	2	0	0	0	0	1	2
	Not asked or no responses	4	6	1	2	0	0	2	3	7	10
	Total	51	76	6	9	3	5	7	10	67	100

^aPercentage out of 67 students.

Table 5.8 Students' Responses About the Rate of Reaction

<i>Why does the chemical reaction happen slowly or rapidly?</i>	As it takes place				If it is heated			
	Slower		Faster		Slower		Faster	
	<i>f</i>	% ^a	<i>f</i>	% ^a	<i>f</i>	% ^a	<i>F</i>	% ^a
Quantity dependent	42	63	0	0	0	0	1	2
Collisions of particles	13	19	0	0	0	0	19	28
Probability for reactions	2	3	0	0	0	0	2	3
Site of reactions	2	3	0	0	0	0	1	2
Activation energy	0	0	0	0	0	0	3	5
Movement of particles	0	0	0	0	0	0	30	45
Energy initiates reactions	0	0	0	0	0	0	13	19
Energy as a catalyst	0	0	0	0	0	0	6	9
Heat effects as in physical change	0	0	0	0	0	0	5	8

Note. Details may not add up to total due to some students gave more than one type of response or no response.

^aPercentage out of 67 students.

Quantity dependent – Some 63% (n=42) of the students across lower secondary schools students and the older students justified their prediction about the rate of reaction as depending on the quantity of the reactants. This explanation is probably the easiest way to predict the rate of a reaction since it does not require any understanding of particle collision or much chemistry knowledge. The basic understanding required is that the quantity of products only depends on the quantity of reactants.

You have this amount of reactant; you can produce a certain amount of product. So, the lesser you have, the less product you can get. So, as far I concern, mathematically saying, it's slower. Let say the time is equal to zero within this period, you have a larger amount of reactant. As time go by, let say, six to seven [second], between this period maybe most of the reactant gone right [changed into products]. Let say it less than forty percent left, so you have lesser product being formed. (UO069)

Collisions of particles – Only 19% (n=13) of the students used the collisions of particles theory when explaining the rate of reaction as the reaction progress. In their explanation, the rate of collisions depends on the quantity of reactants, i.e.,

when there are more reactants, the more collisions happen; therefore more reactions happen.

Once zinc and chloride ions form the new product, the ions and zinc become lesser. For them to react, they need to collide. So, when the reactant becomes lesser, the collision also becomes lesser, as well as the effective collision. Therefore, the chemical reaction also become lesser, and the rate of reaction also become slower. (UF016)

Interestingly, the use of rate of collision in predicting the rate of reaction when the chemical system is heated, increases to 28% (n=19).

If we heat the mixture up, therefore, the rate of reaction will increase. As the particle, zinc and hydrochloric acid particles will have more energy. Therefore, they move at higher velocity. When they do so, they can hit [collide] each other more often, and this increases of rate collision. And then, the rate of effective collision will increase. (SS030)

Probability for reactions – Only a modest number of students (3%, n=2) went further with their collision explanations by including the notion of probability and treating chemical reactions in probabilistic terms.

For example, there are twenty-four atoms. First, [the reaction is] fast because of high probability for the reaction to occur. So, after a period, more and more atoms are been used. So, the probability becomes lower, so the rate [of reaction] becomes lower. (UF014)

When heat is provided, the molecules will vibrate more frequently, so the chance of collisions is more. (UF061)

Sites of reaction – Here, the students explained that the rate of reaction depends on the surface area of the substances where the reactions occur.

If the salt is in powder form, it will dissolve faster because its total surface area compare to the cube because its total surface is more. The surface that reaction occurs. That's why it is faster, for the salt. For the sugar cube, this is the only surface [i.e., lesser surface area] it has to provide. So, it is slower than this one. (UF014)

Some students related the site of reactions to the correct orientation of collisions.

The surfaces where they are contacting become lesser when the substance becomes lesser. When the surface of area is bigger, the correct orientation of collisions between ions is easier. (UF020)

Activation energy – Similar to the notion of particle collisions, the concept of activation energy only emerged when heating was involved in the reaction. However, only 5% (n=3) mentioned activation energy when explaining the heat or temperature effect on rate of reaction.

According to the collision theory, for the product to form, they must overcome a certain amount of energy first. This energy is called activation energy. If the reactants do not have enough energy to overcome the activation energy, the product will not be formed. The energy enables them to overcome the activation energy. (UO026)

Movement of particles – As shown in Table 5.7, 87% (n=58) of the students were able to predict the increase of rate of reaction when heating is involved. About 28% (n=19) related this prediction to collisions of particles, and some predicted the rate of reaction based on the movement of particles increasing when a higher temperature is applied. In this explanation, the reaction becomes faster just because the movement of particles becomes faster.

I think the [reaction of zinc and hydrochloric acid], higher the temperature, more rapid the movement become. I think, because it is moving faster due to the temperature when we heat it up. The particles vibrate faster. And [then the] particles move even further. (SF052)

Energy initiates reactions – Quite a noticeable proportion of the students (19%, n=13) justified the chemical reactions occurring faster when heated, because of heating provides “energy to do work or move” allowing the chemical substances to react.

Heating the mixture. Maybe the reaction becomes faster. I feel it becomes faster because the particles have more energy to work. (UF012)

When we add heat into the matter, into the compound, so the atomic bonding will become loose. So, they have more energy to move. Therefore, they will break more easily from their partners, and then combine to [others to form] a new one. (UF063)

Similar views can be traced back to the previous explanation, mentioning the need of a spark in combustion of butane (see page 198).

Energy as a catalyst – Ideas about the nature of the energy involved in the rate of reaction seemed to vary with some students considering it as a catalyst, where a catalyst was understood to be something that makes reactions take place faster.

It [zinc-acid reaction] will become faster. ... the temperature [heat] is a catalyst that make it faster to make the product.
(SS067)

Similar to their explanation of the need for a spark in the combustion of butane, some students considered that the heat energy from the spark acts as the catalyst of the combustion process.

The spark is the catalyst of the flames. I think when the spark is not present, so there is no catalyst yet, and the activation energy is high. That's why it is hard to burn. But when the catalyst exist, the [butane gas] burns. (UO021)

Heat effects as physical change – Here, the formation of hydrogen gas in zinc-acid reaction was explained in a similar way to how matter changes state, even though most of these students recognised that the transformation of matter (Task 4) shown to them was a chemical reaction.

[The reaction will be] faster because, at some point it promotes the formation of gas. After all, gas only occurs at a higher temperature. So, having higher temperature, it would promote the production of gas. I meant to say that gas has tendency coming out faster when the temperature is increased.
(UO069)

The focus on the rate of reaction was also explored by students reasoning the need of spark in the combustion of butane in Task 6. As presented in Table 5.9, several categories of students' responses were similar to their responses about the rate of reaction in zinc-acid reaction in Table 5.8 on page 194.

Table 5.9 Students' Explanation of the Need of a Spark in Combustion

<i>Why do you think the spark is needed for the combustion to happen?</i>	<i>f</i>	<i>%^a</i>
Energy initiates reactions	36	54
Energy as a part of reactions	17	25
Activation energy	9	13
Energy as a catalyst	1	2
To lower the activation energy	2	3

Note. Details may not add up to total due to some students gave more than one type of response or no response.

^aPercentage out of 67 students.

Energy initiates reactions – Some 54% (n=36) of the students assumed that the spark in the gas lighter provides the heat which is needed for a certain process in the combustion of butane. The spark is needed to begin a process that includes formation of the flame by breaking bonds to provide energy for the reactants to react and start the reaction. The students, however, did not view the spark as a reactant.

[Energy is needed] to break the bonds between butanes, and CH or CC, so that they can react with oxygen to form carbon dioxide and water. If the energy can break the bond between them, butane will combine with oxygen. (SS047)

Similar to their responses about the effect of heat on the rate of zinc-acid reaction, students with this view thought that chemical substances need the energy (or heat energy from the spark) to make them start to react, or undergo changes.

[The spark is needed to] start the reaction. It provides heat that starts the reaction. With the spark, the heat makes the reaction happened, these two, oxygen and butane. (SF041)

The spark causes it [the butane gas] to react. It makes the reaction or burning to happen. So, when there is spark, butane will gain the energy and then the reaction will occur. Maybe the butane at first has not enough energy, so when there is spark, it supplies heat energy to butane. So, butane gained energy, and it will burn. (SS032)

Energy as a part of reactions – 25% (n=17) of the students considered the heat energy provided from the spark to be one of the reactants and that combustion will only happen when all the 'components' for combustion are present. In other words, the spark or heat is actually one of the reacting substances. Therefore, without the spark, the reaction will not happen.

Because, in the theory of combustion to happen, it needs to have the in the presence of three components, which is the oxygen, fuel and heat. The spark, act as a heat, and the butane is the fuel. So, I think will, it happens in the presence of the three components. (SS047)

Activation energy – Only 13% (n=9) of the students (Form 6 and the university) were able to relate the spark to the energy barrier in chemical reactions.

In my view, butane has a certain flash point or activation energy. If the activation energy can be provided by the spark, produced by the flint in highly energetic, some of this energy initiates the reaction with oxygen. ... [For other chemical reaction] the initial activation energy is not high. So, even at room condition, they can undergo some form of reaction. (SS030)

Energy as a catalyst – Some students used this scientific idea in a slightly different fashion to their explanation of energy as a catalyst in the zinc-acid reaction. Here, a junior university student assumed that spark or heat as a catalyst that promotes the process of combustion.

[Spark in combustion of butane is needed] The spark is the catalyst of the flames. But what I think, when the spark is not present, there no catalyst yet, the activation energy is still high. That's why it is hard to burn. (UO021)

To lower the activation energy – Some Form 6 and university students thought that the activation energy can be lowered by heat energy which they treated as a catalyst; some kind of chemical substance that influences the magnitude of activation energy.

When there is spark as the catalyst, the activation energy become lower and makes it burns. It is because there is a catalyst, so the activation energy is lowered down. So the reaction becomes faster. (UO021)

5.3.3 Attributes for Chemical Kinetics

Consistent with the previous findings in this study, students especially those from lower secondary schools did not offer acceptable explanations about how chemical reactions happen at the submicro level. Fewer than a quarter of the students (mostly Form 6 and the university students) held attributes related to the idea of the particulate nature of matter such as *collisions of particles*, *atoms rearrangement*, *bond breaking-formation*, and formation of *intermediates*. These students were also found to use the particulate/kinetic theory in predicting the rate of reaction. Conversely, students from the lower secondary level relied on their intuitive thinking by reasoning that rate of reaction is *quantity dependent*, that is the more of the reactants present, the faster the reaction is and vice versa. This reasoning is closely related to their thinking of reaction as a *response to reacting agents*.

5.4 Mental Model Attributes for Chemical Energy

In order to elicit students' mental models with regard to energy change in chemical reactions, they were asked to explain the nature of combustion (Task 6) as an exothermic reaction, and then why temperature decreases in endothermic reaction between barium hydroxide octahydrate and ammonium thiocyanate (Task 7).

5.4.1 Change of Energy in Chemical Reactions

Table 5.10 shows the distribution of students' explanations of energy change for both the exothermic and endothermic reaction.

Change of physical state – Some explained the change of temperature in chemical reactions similarly to the in temperature change in the associated with changes of physical state of matter. For example, students associated the release of heat energy with the change of state from liquid to gas and solid to liquid.

When the ice releases energy, it also releases heat that will cause the ice to change into water. ... Butane. It is in liquid form, but when the reaction between the liquid and the spark, it changes into gas and at the same time it also releases heat. (SF039)

It liquefies the solid into liquid. Since the change is from solid to liquid, it needs heat energy. ... the energy is already been used to form the liquid. (SF043)

Table 5.10 Students' Responses about Change of Energy in Chemical Reactions

<i>Why does a chemical reaction release or absorb energy?</i>	Combustion of butane		Endothermic reaction	
	<i>f</i>	% ^a	<i>f</i>	% ^a
Change of physical state	2	3	8	12
Change in form of energy	19	28	0	0
Heat as a reactant or product	18	27	13	19
Energy content	16	24	13	19
Enthalpy of formation comparison	9	13	2	3
Energy gain and loss	2	3	32	48
Energy transfer	32	48	21	31
Net energy transfers	5	8	9	13
Energy transfer in chemical bonding	8	12	10	15
Reverse energy transfer in chemical bonding	7	10	5	8

Note. Details may not add up to total due to some students gave more than one type of response or no response.

^aPercentage out of 67 students.

Change in form of energy – Heat energy in the combustion reaction was explained by a change or transformation of the form of energy, this is from kinetic energy to heat energy or chemical energy to heat energy. About 28% (n=19) of the students did not link the exothermic nature of combustion with the change in the internal energy of the chemical system.

Chemical energy [changes] into heat energy. (SS059)

Energy change – chemical energy [changes] into heat energy and light energy. Chemical energy from butane and oxygen, after the fire is formed, there is light energy and we feel hot because of the heat energy. (UF010)

Heat as a reactant or product – Some students also seemed to think that the heat energy is either a product or reactant in chemical reactions. Combustion

was thought to be hot because the reaction produces heat as one of its products, while, in the endothermic reaction, heat is considered 'used' in the reaction (i.e. it is a reactant).

Fire is hot. Maybe because chemical reactions also produce energy. (SF041)

Disappeared. It has lesser heat. So, it is cold. Because [the heat] reacts with barium and ammonium. The heat is a part of the substances. (SF053)

Heat is formed from the combination of the fuel and oxygen and then fire is produced. [And] this [endothermic reaction], it absorbed the heat and after that combines with other substances. (UF010)

This view is similar to the students' views of *energy as a part of reactions*, where they assumed that the spark to be one of the components for combustion (see page 199).

Energy content – Heat energy was also considered by some students, to be something that can be 'contained' in substances. In the combustion of butane, the reaction is hot because butane is understood to be a source of heat energy. Butane as a fuel is translated directly in Malay as "fire substance" or "*bahan api*" which suggests that butane contains heat energy. Most young students explained the heat in combustion as energy that had been released or produced from "fire substance," butane. In the endothermic reaction between barium hydroxide octahydrate and ammonium thiocyanate, the temperature drop was explained as loss of heat energy from the surroundings since the reaction causes the heat to be contained in the product.

Heat comes from the flame. Heat, because flame has heat energy and also light energy. (SF053)

When it is in solid form, it's like certain temperature [or heat] trap inside the solid. And when it turns into liquid [the temperature] is released. (SS071)

The temperature goes down because the energy content is absorbed to become the energy content of barium thiocyanate. Before the reaction happen, the energy content for barium hydroxide and ammonium thiocyanate is lower. ... After the reaction, the energy content for barium thiocyanate is higher. (UF013)

Energy of formation comparison – Here the energy change in chemical reactions was explained by comparing the energy of the formation of the reactants and products. If the energy required for the formation of reactants is more than the energy required to form the products, the reaction will result in excess of energy, which is released to the surroundings.

To my understanding, the bond energy in the reactants is higher than the energy of bond formation in the products. What I mean is the energy required in formation of the reactant compounds is higher than the energy required in the formation of the products. So, energy is released. There is an excess of energy. So, the excess is given off as heat energy. Because the energy of the product is higher than the reactant, so it takes in energy from outside to form its compound. (SS032)

[For the endothermic reaction] Initially the energy acquired to form the bonding of the reactant is less. But when it forms the product, it needs more energy, so it takes in energy from outside. (SS032)

Energy gain and loss – In this view, temperature change in the chemical reactions was explained by the gain or loss of heat energy, similar to the notion of heat conduction. Increase in temperature was caused by the heat energy being conducted from higher temperature to a lower energy area. Students used this idea to explain why combustion is hot (3%, n=2) and also for the drop of temperature in the endothermic reaction (48%, n=32). In combustion, heat is reasoned to be 'conducted' into the flame, which makes it hot while heat in the endothermic reaction is reasoned to be released out to the surroundings, resulting in a loss of heat energy from the chemical mixture and subsequently a drop in temperature.

When you heat a substance, and leave it at room temperature, the surroundings will become hotter. The heat is absorbed to the surroundings. (SO033)

I think this combustion is endothermic. ... Fire is hot so, butane absorbs the heat from surroundings to produce hot fire. (UO065)

Energy transfer – In another view, energy transfer in chemical reactions was seen as either release or absorption of energy. In the exothermic reaction, energy is released to the surroundings, and in the endothermic reaction, energy

is absorbed from the surroundings. These students stated that combustion is exothermic since it releases energy to the surroundings. This explanation is similar to that for the endothermic reaction where the energy is understood to have been absorbed from the surroundings resulting in the drop of temperature. Such students did not discuss the relation between energy and chemical bonding.

Exothermic is a process of releasing of heat. ... Combustion releases heat, so it is exothermic. Releases heat to the surroundings. So, the temperature of the surroundings increases. (SS031)

To me, this [endothermic] reaction causes the temperature drops. When a reaction absorbs heat, it is called endothermic [reaction]. Endothermic reaction absorbs heat from the surroundings causes the temperature drops. The one just now [the combustion] that releases heat is an exothermic [reaction]. (UF007)

Net energy transfers – Less than 20% of the students explained the change of temperature in the chemical reactions as due to the net energy change that resulted from release and absorption of energy. In the exothermic reaction, they believed that more energy is released compared to the energy absorbed, while, in the endothermic reaction, more energy is absorbed than released.

To my point of view, [butane] undergoes homolytic fission, [and this] absorbs energy. Then, one of [carbon and hydrogen atom] start to form CO two and also H two O; heat energy is then released to the surroundings. [In the reaction between barium hydroxide octahydrate and ammonium thiocyanate], when aqua [is broken off], they take in energy. But after the reaction, the energy that they absorb already is released again.

(UO064)

Only 16% (n=11) of the students correctly explained chemical reactions in terms of both energy release and absorption and that the change of energy as indicated the temperature change, is actually the *net* energy being transferred from and into the chemical system. These students explained exothermic reaction as resulting in more energy released for the bond formation process, compared to the energy absorbed during bond breaking.

The heat that is released will be significantly higher than the heat that is absorbed ... [In the reaction between barium hydroxide octahydrate and ammonium thiocyanate], based the drop of temperature, we can imply that the energy required to break the bonds is significantly higher than the energy required to form [or] reform the bonds. The total energy will be higher as they have absorbed more energy than they've released. (SS030)

Energy transfer in chemical bonding – About 31% of the participants attempted to relate the energy change in chemical reactions to chemical bonding. However, not all accurately described the energy change and the process of breaking and formation of bonds. One cohort of students considered only breaking or formation of bond when explaining the energy change in chemical reactions. For example, in the endothermic reaction, the only energy transfer, in their view, is from the absorption of energy from the surroundings for bond breaking. Some students got confused with the absorption of energy in bonding. They considered that energy is needed for the formation of products, and therefore, energy is absorbed from the surroundings. While, in combustion, energy is released from the butane since it is a big molecule, and in the chemical reaction, it seems to be broken into smaller molecules; water and carbon dioxide.

When carbon dioxide formed, it will release heat. That's mean when this reaction happens, this reaction is exothermic process, and will release heat when carbon dioxide is formed. [For the formation of] the bonds, the heat is released. [The heat is] from the formation of the bond between the carbon dioxide molecules, and also water. (SS047)

Heat is absorbed for breaking the bonds. Looking at the barium hydroxide octahydrate, [there is bond breaking]. So, it needs energy to break the bonds. This reaction absorbs heat, so the surroundings becomes cold. The energy has been absorbed [for bond breaking]. (UF014)

Reverse energy transfer in chemical bonding – Students displaying this attribute in their explanation assumed bond breaking releases heat and bond formation absorbs heat.

This is because of the breaking of bonds. When butane turning into carbon dioxide and water, from a big compound, butane breaks into smaller compounds. So, energy is released and that's why it is hot. (SS032)

When the barium hydroxide want to bond with ammonium thiocyanate, it needs energy. The energy is absorbed from the surroundings to form the bond. So, that's why the temperature is negative. (UF015)

5.4.2 Driving Force of Chemical Reactions

In Tasks 6 and 7, students were asked to say what makes chemical reactions happen. Students also were asked to explain why metal corrosion in Task 1 happened. Table 5.11 shows how students explained why reaction happens or continues to occur. Most of the responses centred on the idea that chemical reactions are cause-and-effect processes. Less than 20% of the students related chemical reactions to achieving a state of stability, and only 6% considered that chemical reactions are energy driven.

Table 5.11 Students' Responses About the Driving Force of Chemical Reactions

<i>What make chemical reactions happen?</i>	<i>F</i>	<i>%^a</i>
Reactions naturally happen	6	9
Presence of reactants	17	25
Reacting agents	14	21
Reactive agents	16	24
Stability driven	12	18
Electrostatic charges	3	5
Electronegativity differences	2	3
Energy driven	4	6

Note. Details may not add up to total due to some students gave more than one type of response or no response.

^aPercentage out of 67 students.

Reactions naturally happen – Occurrences of chemical reactions here were considered by students holding this view to be natural events or something that is meant to happen. For example, iron should rust because it is in its nature to rust.

The nature of the chemicals that meant to react in such way. (SS030)

The nature of ferum [iron]. Because ferum is a metal, right. So, when it is mixed with oxygen, of course it will corrode. Naturally. (UO017)

Presence of reactants – Here, reactions were considered to rely on the presence of the reactants. This is similar to the notion of an ingredient in cooking. When all of the required ingredients are present in the mixture, it is expected to undergo some chemical reactions. Additionally, with this notion students explained the continuity of the combustion reaction and the endothermic reaction as the result of availability of the reacting substances. However, neither of the reactants were considered as the cause of the changes.

Spark, then it continues to burn. When there is more gas, it will continue. It won't stop until the gas is finished. (SF038)

Rusting actually needs the balance of both. It needs the metal, water and air. ... [The combustion] continues to happen because there are still substances present. When there is none, there is no reaction. (SF040)

Reacting agents – Some 21% (n=14) of the students thought the presence of agents such as heat, rain, and the environment cause the reaction to occur, and continue to happen.

When the spark started the reaction, the heat is there already. The heat energy will continue to be there. So, it doesn't need the spark anymore. Self-sustained. As long as the gas supply is maintained [the combustion continues to happen]. (SF041)

The surface of the iron is exposed to the surroundings like rain, water, and the surroundings, that's what causes the iron rust. The element in iron metal reacts with the element in the water and oxygen. The oxygen makes the iron undergoes reduction. (UF007)

Reactive agents – This idea is quite similar to that above, but the causal agent present in the chemical system was based on the reactivity of the reactant. About 24% (n=16) of the students here explained that whether or not a chemical reaction is to occur depends on the reactivity series. For example, zinc is considered a reactive metal, and therefore, reaction will happen.

Zinc is basically a quite reactive metal. So, when it is in contact with an acid, definitely it will react vigorously. As you can see the reaction occurs just now, there are bubbles formed. There is the hydrogen [gas formed]. (UF062)

It [is something about] reactivity. Maybe barium has higher reactivity, it will take the thiocyanate [ions]. (UF011)

Stability driven – Some 18% (n=12) of the students assumed that occurrence of chemical reactions are driven by the tendency of reactants to form more stable chemical compounds or products.

Maybe, it is stability. The reactant is more reactive turning into something not reactive, in a stable form. The products are more stable. But if it is not stable, why does it happen like that. It has to be stable. (SS032)

The zinc will discard its electron so that it is more stable. Cl will need one electron for it to be stable. For zinc and chloride to be stable, both them will combine. There are two of chloride atoms that combine with zinc. They will form zinc chloride. The H, it only needs one electron. So, H and H need one and one, so they will combine, so that they are more stable. To achieve stability. (UF011)

Electrostatic charges – Another explanation considered that formation of the products was determined by the presence of stronger electrostatic forces between certain chemical species.

I think due to the charge inside the chemicals. Like, the positive charge, the cation will react with the anion to form other new products. (SS047)

Barium ... with the thiocyanate. It will react. It has some kind of attraction that make them break the bond. (UF008)

[The reaction happens] Because lead is two plus. It is positive, and this one [the iodide ion] is negative. (UF011)

Electronegativity differences – Only 3% of the students assumed that electronegativity drives chemical reactions to happen. This notion seems similar to how electronegativity is used to determine the type of chemical bonding. However, these students considered electronegativity to be an indication of a tendency towards bond formation, which is a difference in electronegativity of chemical substances.

The differences in electronegativity between this two are so great, that they are able to continue the reaction, despite the environment [or] condition being actually counter-productive. A decrease of temperature will obviously cause a decrease of rate of reaction, however, the rate of reaction still continue, in fact accelerate despite the decrease in temperature. (SS030)

Zinc reacts with hydrochloric acid. Since these two substances are not stable, they will react to each other to form more stable compound. This is also influenced by the differences in electronegativity. (UO023)

Energy driven – About 6% of the students related the tendency of a chemical reaction occurring to the role of energy. Some considered that lowering of energy is preferable.

We have two ligands; the thiocyanate and OH. [Not sure which] one will lead to a lower d-d transition energy field. ... But there is going to be a change of ligand because, one of them going to be more preferable because this result in a lower d-d transition [energy]. (UO064)

Others assumed that a chemical reaction occurs when the energy of the chemical reaction is sufficient for it to happen, or to overcome the activation energy.

The energy that is stored within the chemical is already enough to initiate the reaction, almost spontaneous between the two. (SS030)

In this case, there are butane and oxygen presence, and the spark for the energy, and achieving the activation energy, only then the reaction can occur. (UF008)

5.4.3 Reversibility of Chemical Reactions

Eliciting students' views concerned with the reversibility of a chemical reaction is another important step in understanding the attributes of students' mental models of chemical reactions. Table 5.12 shows students' responses when explaining the reversibility of chemical phenomena shown in Task 6, Task 7, and Task 8. Interestingly, about 40% of the students considered that chemical reactions are reversible through a different set of conditions. However, 21% of students seemed to make the assumption that chemical processes are irreversible.

Table 5.12 Students' Responses About the Reversibility of Chemical Reactions

<i>Why do chemical reactions are irreversible or reversible?</i>	<i>f</i>	<i>%^a</i>
Irreversibility presumption	14	21
Physical state	6	9
Matter is not conserved	14	21
Through a different set of conditions	27	40
Stability factors	14	21
Chemical structure factors	15	22
Energy factors	12	18
Equilibrium system	8	12

Note. Details may not add up to total due to some students gave more than one type of response or no response.

^aPercentage out of 67 students.

Irreversibility presumption – 21% of the students indicated that they believe that it is somehow unnatural or difficult to reverse a process¹.

The liquid inside the lighter is natural, from the seabed. Formed millions of years ago. So, it cannot be formed back. (SO076)

When something had happened [cannot be undone]. It's like when a baby is born, how to unborn the baby? So, it is hard. (UO021)

Physical state – Some students considered that reversibility (or otherwise) depends on the physical state of the product. When the state of the product is different from the reactants, students considered the reaction irreversible.

The state of the products are already different. So, even we mix the two, they will not turn to butane. (UF060)

Why [chromate-dichromate reaction] is reversible? It is reversible, because it is still the same thing. The same state of matter. Still in form of liquid; it did not change into solid. It is still aqueous [solution]. (UF012)

Matter is not conserved – About 21% of the students seemed to think that there are components in the reactants that were somehow lost, therefore, it is impossible to get the reactants back.

¹ Malay proverb "rice has turned into congee" (*nasi sudah menjadi bubur*) is commonly used to indicate that what has happened cannot be undone.

When butane is added with oxygen, I think [carbon dioxide and water] are just the by-products. So, when [even] you mix carbon dioxide and water, heat up, I think it won't [turn into] the initial component, like butane and oxygen. (SO033)

When [butane] is combined with heat, oxygen and hydrogen are been used up, what's left is carbon and water. So, if [carbon and water] are mixed, [the initial substances] cannot be [reproduced] because, some parts of the butane are already been used up. (SF053)

Through a different set of conditions – A fair number of students (40%, n=27) considered that chemical reactions can be reversible if suitable conditions are provided. For example, for the combustion of butane, some students thought that butane can be obtained through a certain process.

Yes [we can get the butane back] through a different kind of reaction. (SF039)

It is possible [to reverse the reaction]. For carbon dioxide to turn back to oxygen, it needs photosynthesis process. Plants use carbon dioxide in photosynthesis, and it produces oxygen. (UO019)

When explaining the chemical phenomenon in Task 8 (chromate-dichromate equilibrium), some students considered that the change of colour was due to different processes of chemical reactions, which then enabled the reaction to be reversed.

Maybe it involves the response of the two chemicals. The first chemical turns it into by-product [chromate – yellow], and the other chemical turns it back into the initial chemical [dichromate – orange]. (SO033)

Stability factors – Some 21% (n=14) of the students assumed that the reversibility/irreversibility of a chemical reaction depends on the stability of the products. When a chemical reaction is irreversible, it is assumed that the products are more stable compare to the reactants. Therefore, it is not possible for the more stable products to revert to the less stable reactants.

The new substance, iron trioxide, is a stable chemical. It will react when exposed to air to form rust, which is more stable. The rust is more stable. (UF013)

The water and carbon dioxide are more stable in its form. To turn them back to butane, it will require a lot of energy. So, that's my opinion why it is hard to be turned back. (UF020)

For a reversible reaction, reactants and products were assumed to have similar stability.

I think they [chromate and dichromate] are almost the same in terms of stability. If they are not, it cannot be change easily. The stability of chromate and dichromate ions are almost the same. (UF016)

Chemical structure factors – Some of the students (22%, n=15) reasoned that the reversibility of chemical reactions was somehow based on the chemical structures of reactants and products. They considered that a chemical reaction is irreversible when the chemical structures of the products are totally different from the original reactants.

If [a reaction] that is reversible, the bonds are not broken completely. So, it can form back to the original substances. But for this one [combustion reaction], it is completely broken. It is completely broken, forming into these new ones [carbon dioxide and water]. (UO028)

Butane only consist of two different elements [carbon and hydrogen], whereas these two [carbon dioxide and water] are already in total different elements. (SS030)

A chemical reaction was, however, considered reversible if the chemical structures or composition of reactants and products are similar.

[This chromate-dichromate reaction] is reversible because it is still [the same]. [Both chromate and dichromate], Cr Cr still has O O. It is just differ in terms of oxidation number. (UF009)

Some other students believed that the strength of chemical bonds was a factor in the irreversibility of chemical reactions. To these students, if the chemical bonds in the products are stronger than in the reactants, a reverse reaction is not likely.

[Carbon dioxide] is probably more stable because breaking a double bond is harder than breaking a single bond. So, in this case, [carbon dioxide] is stable, oxygen has two hydrogen, this one is can be considered more stable. (UO069)

Energy factors – Irreversibility in chemical reactions was rationalised by some on the basis of the energy required to reverse the chemical reactions. Some 18% (n=12) of the students assumed that more energy is required to reverse a chemical reaction. One of the reasons given for the reverse reaction requiring more energy, was that the stability of the product was greater than the reactants.

Water and carbon dioxide are more stable in their form. To turn them back to butane will require a lot of energy. So, that's my opinion why it is hard to be turned back. (UF020)

Another reason given was that the activation energy of the reverse reaction is much higher than the forward reaction, and therefore, would not occur.

The activation energy [for the forward reaction] is easy to be overcome to become the product. But when changing back from product to reactants it has to go through a higher activation energy. (UF016)

For a reversible reaction, it was considered that both forward and reverse reactions have similar magnitude of activation energies than for the reverse reaction.

The activation energy [of forward and backward reaction] is [about the same]. So, it is easier to shift it [back to dichromate]. (UF013)

Equilibrium system – Only 12% (n=8) of the students were able to recognise the reaction as an equilibrium system. Here, change of colour in the chromate-dichromate reaction was explained based on Le Châtelier's Principle.

When dichromate ion was added with hydroxide ion, the basicity of the solution increases, thus shift the ionic change of the dichromate ion into chromate ion. So when added with more HCl, it becomes dichromate ion back. (UO063)

5.4.4 Attributes for Chemical Energy

In general, there were few descriptions of energy change in chemical reactions in students' explanations about the exothermic combustion reaction and the endothermic reaction between barium hydroxide octahydrate and ammonium

thiocyanate. First, energy was perceived as contained within chemical substances and energy change in chemical reactions was due to the change of *energy content* or *enthalpy of formation*. Those students who hold the idea of *energy content* considered that a reaction is exothermic because of the reactants contain high energy, and a reaction is endothermic because the *energy content* of the chemical substances has become lower. Other students explained that energy change is based on the comparison between *enthalpy of formation* of the reactants and products. Secondly, energy change in chemical reactions was based on the idea of the transformation of energy that includes the attributes *change in form of energy* and *heat as a reactant or product*. Students holding these views perceived that energy is transformed from one form to another or is part of the reactants or products. Thirdly, energy was considered to be transferred between a chemical system and the surroundings. About half of the students thought that an endothermic reaction loses its energy to the surroundings and exothermic reaction gains energy from the surroundings. Only about half of the students said that energy was being transferred – in exothermic reaction, energy is transferred from the chemical system into the surroundings, but for endothermic reaction, energy is absorbed from the surroundings into the chemical system. Although these students recognised energy transfer in chemical reactions, only a small number of students were found to relate it to bond breaking and/or formation.

In terms of spontaneity of reactions, most students did not relate this property to the energy change in chemical reactions. Most students were found to use causal agents as the determining factor of spontaneity or the reversibility of chemical reactions such as the *presence of reactants*, *reacting agents*, and *reactive agents*. Some students also thought that chemical reactions are reversible *through a different set of conditions* with suitable agents or situations. Other students especially from Form 6 and the university considered that chemical reactions are *stability driven* because reactants undergo a chemical reaction to form more stable products, and it is irreversible since the stable products are unlikely to revert to its unstable forms.

5.5 Summary

The attributes of students' mental models from three aspects of their understanding of chemical reactions: structures, kinetics, and energy were presented in this chapter. Basically, the attributes were either built upon the particulate/kinetic theory of matter or non-particulate nature of matter, and students used these theories in explaining the phenomena of chemical reactions, conservation of mass, and the reactions at the particulate level. Energy change was considered as change in the energy contents of chemical substances, transformation in the form of energy or transfer of energy. An important feature for students' mental models of chemical reactions was the causal agentive attribute, which seems to be considered as the impetus for chemical reactions, determining spontaneity and the reversibility of a chemical system instead of attributing it to the idea of entropy.

The following chapter identifies and characterises the types of mental models of chemical reactions.

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Chapter 6 presents the types of students' mental models and their characteristics based on the attributes that were presented in the previous chapter. It begins with descriptions of how the classification of the mental models was developed followed by detailed descriptions of each mental model type in relation to chemical structures, kinetics, and energy. This chapter ends with a summary of the key characteristics of each mental model types.

6.1 Classification of Mental Models of Chemical Reactions

This inquiry also sought to understand students' mental models of chemical reactions by addressing the second research question,

RQ2: Do students' mental models of chemical reactions differ and in what way?

To assist with identification of different types of students' mental models, the attributes of these models were classified into three different categories, namely *initial*, *synthetic*, and *scientific* as shown in Table 6.1. The initial attributes are students' ideas or constructs related to a component in a given target system of

chemical reactions, which were not based on any scientific view about chemical reactions. Conversely, scientific attributes are students' ideas which seem to be based on scientific knowledge, and which are considered consistent with scientific views. Finally, synthetic attributes are students' ideas, which seem to be based on the scientific idea but include some erroneous assumptions or ideas (i.e., the alternative conceptions).

This attributes-based classification identified three distinct mental models of chemical reactions expressed by students. The first type of mental model called Model A, is considered mainly non-particulate, with an absence of the kinetic theory of particles and chemical bonding. Model A mainly consisted of the *initial* attributes for all of the target systems of chemical reactions. The second type of mental model, Model B was based either on the attributes related to the kinetic theory of particles or attributes related to chemical bonding. This type of mental model consisted of a mixture of initial, synthetic, and scientific attributes. Finally, Model C was identified as a mental model type comprising attributes related to both kinetic theory of particles and chemical bonding, which were considered consistent with the scientific views of chemical reactions.

Although students' mental models were categorised into different types, it is interesting that some of the attributes were common to all types of the mental models. For example, in terms of students' understanding of chemical reactions, almost all of the attributes were present in all types of mental model (see Table 6.2). The obvious differences between Model A and Model C were the absence of the attribute, *submicro changes* in Model A and that of *expected natural occurrence* in Model C. In the conservation of mass component, most of the initial and synthetic attributes were identified in all types of mental model. However, the dominant attribute held by students was identified as the *closed system*, which occurred mostly in Model B and Model C. The only clear distinction between Model A and Model B compared with Model C was the presence of the *rearrangement of atoms* attribute in Model C.

Table 6.1 Classification of Students' Mental Models Attributes of Chemical Reactions

Component	Initial attributes	Synthetic attributes	Scientific attributes
Composition	<ul style="list-style-type: none"> • Expected natural occurrence • Change of chemical substances • Change in physical properties 	<ul style="list-style-type: none"> • Response to reacting agents • Formation of new substances • Interaction between substances 	<ul style="list-style-type: none"> • Submicro changes
Conservation of mass	<ul style="list-style-type: none"> • Dependent on the physical state • More substances formed • Gas properties 	<ul style="list-style-type: none"> • Closed system 	<ul style="list-style-type: none"> • Rearrangement of atoms
Particle collision	<ul style="list-style-type: none"> • Internal arrangement 	<ul style="list-style-type: none"> • Movement of particles 	<ul style="list-style-type: none"> • Collisions of particles • Sites of reaction • Probability for reactions
Barrier to reaction	<ul style="list-style-type: none"> • Energy initiates reactions 	<ul style="list-style-type: none"> • To lower the activation energy • Energy as catalyst • Energy as a part of reactions 	<ul style="list-style-type: none"> • Activation energy
Activated complex			<ul style="list-style-type: none"> • Metastable species
Reaction mechanism	<ul style="list-style-type: none"> • Transmutation 	<ul style="list-style-type: none"> • Quantity dependent • Octet approach 	<ul style="list-style-type: none"> • Atoms rearrangement • Bond breaking-formation • Transfer of electrons • Redox • Attraction between charges • Intermediate • Mechanistic approach
Conservation of energy	<ul style="list-style-type: none"> • Heat gain and loss • Change in the form of energy 	<ul style="list-style-type: none"> • Energy content 	<ul style="list-style-type: none"> • Net energy transfers
Energy change	<ul style="list-style-type: none"> • Change of physical state • Heat as a reactant or product 	<ul style="list-style-type: none"> • Energy transfer • Reverse energy transfer in chemical bonding 	<ul style="list-style-type: none"> • Enthalpy of formation comparison • Energy transfer in chemical bonding
Spontaneity	<ul style="list-style-type: none"> • Reaction naturally happens 	<ul style="list-style-type: none"> • Presence of reactants • Reacting agents 	<ul style="list-style-type: none"> • Reactive reactants • Stability driven • Electrostatic charges • Electronegativity differences • Energy driven
Reversibility	<ul style="list-style-type: none"> • Irreversibility presumption • Physical state • Matter is not conserved 	<ul style="list-style-type: none"> • Through a different set of conditions 	<ul style="list-style-type: none"> • Stability factors • Chemical structure factors • Energy factors • Equilibrium system

Table 6.2 Distribution of Students for Attributes of Chemical Structures According to Types of Mental Models

Component	Attributes	A (n=25)		B (n=15)		C (n=27)		Total (n=67)	
		<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%
Composition	Expected natural occurrence ^a	3	12	2	13	0	0	5	7
	Change of chemical substances ^a	9	36	0	0	5	19	14	21
	Change in physical properties ^a	3	12	5	33	12	44	20	30
	Response to reacting agents ^b	21	84	10	67	16	59	47	70
	Formation of new substances ^b	6	24	10	67	21	78	37	55
	Interaction between substances ^b	9	36	7	47	14	52	30	45
	Submicro changes ^c	0	0	7	47	19	70	26	39
Conservation of mass	Dependent on the physical state ^a	8	32	4	27	6	22	18	27
	More substances formed ^a	10	40	3	20	4	15	17	25
	Gas properties ^a	3	12	3	20	9	33	15	22
	Closed system ^b	7	28	8	53	17	63	32	48
	Rearrangement of atoms ^c	1	4	1	7	7	26	9	13

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

The greatest distinction between the types of mental models was observed in those attributes related to chemical kinetics (Table 6.3). For the particle collision component, Model A consisted mainly of the initial attributes *internal arrangement* and *movement of particles*, while Model C mainly comprised *movement of particles*, *collisions of particles*, *site of reactions*, and *probability for reactions* attributes. For the barrier to reaction component, Model A did not contain the idea of *activation energy* as Model C does, and was dominated by the attributes of *energy initiates reactions* or *energy as a part of reactions*. Model B partially consisted of scientific attributes (*collisions of particles*) along with synthetic attributes such as *energy as catalyst*, and *energy as a part of reactions*. Another clear distinction between Model A and Model B compared with Model C was also shown in the reaction mechanism component. Model C consisted largely of attributes that are consistent with scientific views such as *atoms rearrangement*, *bond breaking-formation*, and *transfer of electrons*. On the other hand, the main attribute in Model A is *quantity dependent*, while Model B mainly contains *atoms rearrangement*.

Table 6.3 Distribution of Students for Attributes of Chemical Kinetics According to Types of Mental Models

Component	Attributes	A (n=25)		B (n=15)		C (n=27)		Total (n=67)	
		<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%
Particle collision	Internal arrangement ^a	8	32	1	7	0	0	9	13
	Movement of particles ^b	5	20	6	40	20	74	31	46
	Collisions of particles ^c	0	0	5	33	27	100	32	48
	Site of reactions ^c	0	0	0	0	5	19	5	7
	Probability for reactions ^c	0	0	0	0	6	22	6	9
Barrier to reaction	Energy initiates reactions ^a	17	68	9	60	15	56	41	61
	To lower the activation energy ^b	0	0	0	0	2	7	2	3
	Energy as catalyst ^b	0	0	5	33	1	4	6	9
	Energy as a part of reactions ^b	10	40	3	20	4	15	17	25
	Activation energy ^c	1	4	2	13	13	48	16	24
Activated complex	Metastable species ^c	0	0	0	0	1	4	1	1
Reaction mechanism	Transmutation ^a	1	4	0	0	0	0	1	1
	Quantity dependent ^b	17	68	10	67	25	93	52	78
	Octet approach ^b	0	0	0	0	3	11	3	4
	Atoms rearrangement ^c	2	8	11	73	17	63	30	45
	Bond breaking-formation ^c	0	0	5	33	19	70	24	36
	Transfer of electrons ^c	0	0	2	13	17	63	19	28
	Redox ^c	0	0	0	0	5	19	5	7
	Attraction between charges ^c	0	0	3	20	7	26	10	15
	Intermediates ^c	0	0	2	13	10	37	12	18
	Mechanistic approach ^c	0	0	0	0	8	30	8	12

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

In terms of chemical energy, the differences between the types of mental models can also be identified in all of the components (Table 6.4). In the conservation of energy component, Model A is characterised by the *heat gain and loss* attribute, while, Model C can be characterised by the *net energy transfer* attribute. In the component of energy change, Model A mainly consisted of either *change of physical state* and *heat as part of reaction* attributes. Model B and Model C, on the other hand, can be characterised by *energy transfer* and *energy transfer in chemical bonding* attributes.

Table 6.4 Distribution of Students for Attributes Chemical Energy Component According to Types of Mental Models

Component	Attributes	A (n=25)		B (n=15)		C (n=27)		Total (n=67)	
		<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%
Conservation of energy	Heat gain and loss ^a	17	68	5	33	10	37	32	48
	Change in form of energy ^a	10	40	7	47	9	33	26	39
	Energy content ^b	12	48	4	27	11	41	27	40
	Net energy transfers ^c	0	0	0	0	11	41	11	16
Energy change	Change of physical state ^a	5	20	1	7	2	7	8	12
	Heat as a reactant or product ^a	7	28	5	33	7	26	19	28
	Energy transfer ^b	3	12	7	47	24	89	34	51
	Reverse energy transfer ^b	0	0	4	27	8	30	12	18
	Enthalpy of formation comparison ^c	0	0	0	0	9	33	9	13
	Energy transfer in chemical bonding ^c	0	0	3	20	12	44	15	22
	Nature of the reactant ^a	2	8	3	20	1	4	6	9
	Presence of reactants ^b	7	28	4	27	5	19	16	24
Spontaneity	Reacting agents ^b	3	12	4	27	7	26	14	21
	Reactive agents ^c	0	0	3	20	13	48	16	24
	Stability driven ^c	0	0	2	13	10	37	12	18
	Electrostatic charges ^c	0	0	1	7	2	7	3	4
	Electronegativity differences ^c	0	0	1	7	1	4	2	3
	Energy driven ^c	0	0	1	7	3	11	4	6
	Irreversibility presumption ^a	8	32	4	27	2	7	14	21
	Physical state ^a	3	12	1	7	2	7	6	9
Reversibility	Matter is not conserved ^a	8	32	1	7	5	19	14	21
	Through a different set of conditions ^b	10	40	3	20	14	52	27	40
	Stability factors ^c	0	0	4	27	10	37	14	21
	Chemical structure factors ^c	1	4	6	40	8	30	15	22
	Energy factors ^c	0	0	1	7	11	41	12	18
	Equilibrium system ^c	0	0	1	7	7	26	8	12

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

Spontaneity, on the other hand, is a vague component for all of the mental models especially Model A and Model B with less than 50% of students' mental models containing this component (see Table 6.4). In other words, the spontaneity component of Model A and Model B was less developed and likely to be a non-attribute for Model A and Model B as students were unable to explain chemical spontaneity in terms of stability and energy. However, the *presence of reactants* and *reacting agents*, are the main attributes of some of mental models categorised as Model A and Model B. For Model C, this spontaneity component mainly consisted of *reactive agents* and *stability driven* attributes but less than 50% of students had these attributes. In the case of the reversibility component (see Table 6.4), *irreversibility presumptions* and *matter is not conserved* attributes are present in some 30% of Model A and Model B. Less than 40% of Model C comprised the *stability factors*, *chemical structure factors*,

energy factors, and *equilibrium system attributes*. All mental model types did not indicate the idea of entropy or dispersal of energy and mass in explaining chemical spontaneity and reversibility.

Each type of mental model was then further divided into different subtypes based on their attributes in the energy target system. The identification of subtypes of mental models was done in order to provide further insights into the relationship between the attributes within each type of mental models. There were at least three patterns that emerged for each type of mental model. One group of mental models mainly consisted of the attribute that energy change in chemical reactions is due to *energy transfer* (i.e., energy is either absorbed or released). On the other hand, a handful of students' mental models recognised that the energy change is due to *net* energy transfer, meaning they realised that both energy absorption and release happen in chemical reactions. The third group of mental models explained the energy in chemical reactions is based on things other than energy transfer.

Using this added classification, Model A was divided into five subtypes namely A1, A2, A3, A4, and A5; Model B divided to two subtypes; B1 and B2; and Model C into three subtypes; C1, C2 and C3. These subtypes provide a detailed picture of students' mental models that emerged from the rich data in this study. Table 6.5 shows an overview of each mental model subtype identified from the attribute classification. Each type and subtype of mental model is described in turn in the following sections.

Table 6.5 Type of Students' Mental Models of Chemical Reactions

Model	Description	Subtypes	Description
A	Chemical reactions are mainly described as the response of chemical substances towards other reacting agents such as other chemical substances, heat energy, air and surroundings. Reactions are described at the macro level. Energy change in chemical reactions is based on energy gain-loss reasoning. Reaction is driven by the reactants.	A1	Energy transfer.
		A2	Heat gain and loss reasoning. Reaction is driven by reacting agents.
		A3	Heat gain and loss reasoning.
		A4	Energy change unexplained.
		A5	Unclassifiable.
B	Chemical reactions are sometimes described as changes happen at the submicro level. The process of chemical reactions is described based on either kinetic theory of particles or chemical bonding. Energy change in chemical reactions is based on the idea that energy transfer occurs between a chemical system and the surroundings. Chemical reactions are driven by various non-energy based factors.	B1	Only attributes based on chemical bonding are used in explaining the process of chemical reactions. Energy change is mainly based on change in the form of energy and energy transfer.
		B2	Only attributes based on the kinetic theory of particles are used in explaining the process of chemical reactions. Energy change is described as heat gain and loss reasoning.
C	Chemical reactions are described as changes happen at the submicro level. Reactions based on kinetic theory of particles and chemical bonding. Energy change in chemical reactions is explained as two ways energy transfer between a chemical system and the surroundings. Transfers of energy are due to the breaking and formation of chemical bonds. Change of temperature is related to the net energy transfer. Chemical reactions are driven by various factors.	C1	Mainly consistent with the description of the main type.
		C2	Inconsistent in terms of energy change.
		C3	Inconsistent in terms of energy change. Energy change based on energy transfer and energy gain-loss attributes.

6.2 Model A of Chemical Reactions

A significant proportion of the participants (25/67) expressed mental models that were classified as the Model A of chemical reactions, and this category includes most of the Form 4 and Form 1 students.

6.2.1 Chemical Structure Characteristics of Model A

Composition

Model A described chemical reactions occurring mainly as a response of chemical substances (see Table 6.6) towards other chemical substances or other agents such as the surroundings; air, heat, and light. These agents were assumed to be

causing the chemical substances (or the reactants) to change. For example, consider the following interview excerpts:

SO040 : For the metal corrosion, [the metal] is rusting. Caused by acid rain.
 I : Okay.
 SO040 : Although it is a weak acid, does not give any effects on our skin, but it affecting [the metal]. Let me explain more about the rusting process. It happens when there are water and air.
 ...
 I : For the metal corrosion, the rust. How did it formed?
 SO040 : It is formed because of ... I don't know, but just giving my opinion. The acid rain will combine, filling in the empty spaces. Although [the iron metal] is compact but maybe it [acid rain] gives impacts.
 ...
 I : Why do you say all of these are chemical reactions?
 SO040 : Because this chemical as we know interacts with our surroundings. There is something causes it to happen.

Table 6.6 Distribution of Students for Attributes in Chemical Structures According to Model A and its Subtypes

Component	Attribute	A1	A2	A3	A4	A5	A
		(n=3)	(n=4)	(n=13)	(n=5)	(n=1)	(n=25)
Composition	Expected natural occurrence ^a	1	0	2	0	0	3
	Change of chemical substances ^a	1	0	6	1	0	8
	Change in physical properties ^a	0	0	2	1	0	3
	Response to reacting agents ^b	2	3	10	5	0	20
	Formation of new substances ^b	1	2	3	0	0	6
	Interaction between substances ^b	1	3	5	0	0	9
	Submicro changes ^c	0	0	0	0	0	0
Conservation of mass	Dependent on the physical state ^a	0	2	5	0	0	7
	More substances formed ^a	2	2	4	2	0	10
	Gas properties ^a	0	0	2	1	0	3
	Closed system ^b	1	0	4	1	0	6
	Rearrangement of atoms ^c	0	0	1	0	0	1

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

A specific subtype of Model A, Subtype A3, recognised that chemical reactions are more than a response of chemical substances to other agents, by considering that chemical reactions are any chemical substances that undergo changes. This definition implies that anything that is thought to be a chemical substance and has changes happen to it, for whatever reason, is considered to be undergoing chemical reactions. Model Subtype A3 students normally failed to differentiate the melting of ice and dissolution of sugar and salt from chemical reaction, as can be seen below.

I : Why do you think all of these are chemical reactions?
 SF043 : This one [metal corrosion] involves oxygen. And some other thing. I forgot. But it needs oxygen for rusting.
 I : The ice?
 SF043 : Ice, because it absorbs heat. It is also one of a chemical process. For this one, it dissolves. It is a mixing of solvent and solute to form a solution.
 ...
 I : Meaning that, a chemical reaction is anything that involves ...
 SF043 : Changes.
 I : Any kind of changes?
 SF043 : Yes.
 I : To the substances.
 SF043 : Yes. Because everything is chemical. It involves chemistry.

Conservation of mass

In terms of conservation of mass (refer to Table 6.6), Model A relied on macro level attributes, and infers that change of mass in chemical reactions depends on the physical states and amount of the reaction products.

I : As you see just now, he weighs it with the stopper and all of them. The weight is one five eight point two. After the reaction [lead nitrate and potassium iodide], [i.e.,] after the changes happened, do you think the mass will increase or decrease or remain the same?
 SF074 : Maybe it increases.
 I : Increases. Why do you think it increases?
 SF074 : Because, at first it is in a form of liquid. From liquid to solid, become harder. So, the mass increases.

I : If we put the whole mixture, the conical flask, and the balloon on top of a scale, and let say the initial weight is one six seven gram. What do you think the weight will be after the reaction completed?
 SO033 : I guess the weight will increase because in our lesson, gas has weight. So, when it produces hydrogen gas, I guess it will increase in weight.

Only some students using this mental model were able to recognise that mass remains constant in a closed system, but they mostly reasoned that there was no loss or addition of material in the chemical reactions.

I : The initial mass is one five eight point two gram. Okay, this is before the reaction, and after the reaction, [that is] the formation of the yellow stuff, what do you think will happen to the mass or the weight? Do you think it increase or otherwise?
 SF052 : I think it stays the same. Yes, I think.
 I : Why?
 SF052 : Because ... volume ... I think the volume doesn't change. The volume doesn't change because the person didn't put something else. It's in the

same place. He just shakes it. And [yes], it won't change. I think it stays the same. the volume. The weight [or] the mass.

I : Can you explain further?

SF052 : [laughing] Mm. Because ah ... that's why I said, the volume doesn't change, because from the beginning lead nitrate and potassium iodide. They just combine together to produce lead iodide and potassium nitrate. So, I think the mass is still the same.

6.2.2 Chemical Kinetic Characteristics of Model A

Particle collision and reaction mechanism

In relation to these two components, Model A is characterised by the lack of any attributes based on the kinetic theory of particles and chemical bonding (see Table 6.7).

Table 6.7 Distribution of Students for Attributes in Chemical Kinetics According to Model A and its Subtypes

Component	Attribute	A1 (n=3)	A2 (n=4)	A3 (n=13)	A4 (n=5)	A5 (n=1)	A (n=25)
Particle collision	Internal arrangement ^a	1	2	4	1	0	8
	Movement of particles ^b	1	1	2	1	0	5
	Collisions of particles ^c	0	0	0	0	0	0
	Site of reactions ^c	0	0	0	0	0	0
	Probability for reactions ^c	0	0	0	0	0	0
Barrier to reaction	Energy initiates reactions ^a	3	3	6	3	1	16
	To lower the activation energy ^b	0	0	0	0	0	0
	Energy as catalyst ^b	0	0	0	0	0	0
	Energy as a part of reactions ^b	3	1	4	1	1	10
	Activation energy ^c	0	0	1	0	0	1
Activated complex	Metastable species ^c	0	0	0	0	0	0
Reaction mechanism	Transmutation ^a	0	0	1	0	0	1
	Quantity dependent ^b	2	2	9	3	0	16
	Octet approach ^b	0	0	0	0	0	0
	Atoms rearrangement ^c	0	0	1	1	0	2
	Bond breaking-formation ^c	0	0	0	0	0	0
	Transfer of electrons ^c	0	0	0	0	0	0
	Redox ^c	0	0	0	0	0	0
	Attraction between charges ^c	0	0	0	0	0	0
	Intermediate ^c	0	0	0	0	0	0
	Mechanistic approach ^c	0	0	0	0	0	0

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

Students who held Model A described chemical reactions mainly based on *internal arrangement* and *movement of particles*. Although apparently possessing both of these attributes, their mental models of chemical reactions may not be based on particle model of matter, since these students explained

the reaction between zinc and hydrochloric acid as physical change. As shown in the excerpts below, the students merely used the word 'particle' that was used by the researcher.

I : Okay. Can you imagine the particle of the zinc and the hydrochloric acid react together and change into hydrogen gas and zinc chloride.
 SF052 : You mean when they are mixed together.
 I : Yes ... in form of particles.
 SF052 : Ah ... I think the particles become, more moving faster because the state is changing from solid to gas. So, I think the particle move more randomly. So, that's why we can see, kind of full of bubble, producing hydrogen gas.
 I : But how do the particles, the zinc particle, the hydrochloric acid react together?
 SF052 : They react to together?
 I : Can you imagine how the particles react?
 SF052 : You mean when the zinc is put into the hydrochloric acid?
 I : Yes. The particles. What happens to the particles during the reaction?
 SF052 : You mean the movement?
 I : Yes ... may be the movement, what happened to them?
 SF052 : I think the movement become rapid, causing it change the state, to gas and liquid.

I : Can you imagine how zinc and HCl particles react?
 SF053 : The particles?
 I : Yes.
 SF053 : Ah ... when the zinc reacts with hydrochloric acid, it will move very fast, and change into gas.

Students with Model A also tended to explain the rate of reaction based on a reaction-quantity relationship (*quantity dependent* attribute), that is the rate of product formation is solely determined by the quantity of the reactants or the reacting agent – the less the reactants the slower the reaction.

I : Do you think the reaction will slow down or become faster?
 SO033 : Slow down.
 I : Why?
 SO033 : Because the chemical inside will be used up eventually.
 I : So when it's used up, the initial substances used up, is that why the reaction become slower?
 SO033 : Mm [yes]. Because in a chemical reaction, it needs all of the components. When one of the components is used up, no reaction can be form [or occurred].

Barrier to reaction

Model A also was characterised by the absence of the idea of an energy barrier in chemical reactions. Instead of recognising that a certain energy level needs to be achieved in order for a chemical reaction to occur, energy was considered to be required in the reaction because it is a part or 'ingredient' of the reaction itself.

I : So, why do you think the spark is needed [for the combustion to start]?
 SO033 : I think the fire wouldn't start without the spark. And it is also won't start without oxygen because the oxygen is needed. As an example, when there is oil burning, you should not pour water into it, but we just cover it, so that, the flame burns up the oxygen to produce carbon dioxide. And when the oxygen content is lower, the flame will die out.

Similarly, when describing the rate of reaction, the 'amount' of energy was thought to influence the rate of reaction since energy is part of the reaction – the more energy the faster the reaction.

I : Will this reaction become slower? What do you think?
 SF038 : Maybe its force, its energy gradually reducing.
 I : Reducing. Okay. If we heat it up?
 SF038 : If it's hot, maybe it [i.e., the rate of reaction] will increase.
 I : Faster?
 SF038 : Yes.
 I : Why does it become faster when we heat it up?
 SF038 : Normally when it's hot, the particles will absorb the heat and gain more energy. More energy.

6.2.3 Chemical Energy Characteristics of Model A***Conservation and change of energy***

The energy characteristics of Model A as is summarised in **Error! Reference source not found.** It shows that students' explanations of the energy change in chemical reactions were based on the *heat gain and loss* reasoning. This reasoning concludes that something containing heat will be hot and if it has less heat, it will be cold. In other words, whether something is hot or cold, depends on the heat energy that is contained in it.

I : Why is fire hot?
 SF053 : Because it has heat energy.
 I : What has heat energy?

SF053 : The butane.

I : Why is it hot? Why is combustion hot?

SF038 : [silent]

I : Do you have any idea why?

SF038 : Reaction normally absorbs heat, right. So, when it absorbs heat, the thing will be hot as well.

Table 6.8 Distribution of Students for Attributes in Chemical Energy According to Model A and its Subtypes

Component	Attribute	A1	A2	A3	A4	A5	A
		(n=3)	(n=4)	(n=13)	(n=5)	(n=1)	(n=25)
Conservation of energy	Heat gain and loss ^a	0	4	12	0	0	16
	Change in form of energy ^a	1	1	5	2	0	9
	Energy content ^b	2	2	4	4	0	12
	Net energy transfers ^c	0	0	0	0	0	0
Energy change	Change of physical state ^a	2	0	1	1	1	5
	Heat as a reactant or product ^a	1	1	3	1	0	6
	Energy transfer ^b	3	0	0	0	0	3
	Reverse energy transfer ^b	0	0	0	0	0	0
	Enthalpy of formation comparison ^c	0	0	0	0	0	0
	Energy transfer in chemical bonding ^c	0	0	0	0	0	0
Spontaneity	Nature of the reactant ^a	0	0	2	0	0	2
	Presence of reactants ^b	2	3	1	1	0	7
	Reacting agents ^b	0	3	0	0	0	3
	Reactive agents ^c	0	0	0	0	0	0
	Stability driven ^c	0	0	0	0	0	0
	Electrostatic charges ^c	0	0	0	0	0	0
	Electronegativity differences ^c	0	0	0	0	0	0
	Energy driven ^c	0	0	0	0	0	0
Reversibility	Irreversibility presumption ^a	0	0	5	2	0	7
	Physical state ^a	0	1	1	1	0	3
	Matter is not conserved ^a	1	3	2	1	0	7
	Through a different set of conditions ^b	3	1	4	2	0	10
	Stability factors ^c	0	0	0	0	0	0
	Chemical structure factors ^c	0	1	0	0	0	1
	Energy factors ^c	0	0	0	0	0	0
	Equilibrium system ^c	0	0	0	0	0	0

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

Thus, Model A seemed not to relate the energy change that happens during the chemical reactions with change that happens within the chemical system, particularly in chemical bonding. With Model A, a 'hot reaction' was explained as being due to the energy that the reacting substances have or contain, while, in a 'cold reaction,' the heat of the reacting substances is lost to the surroundings.

I : Why does it [endothermic reaction] become cold?

SO033 : May be because it expels heat, from the surroundings.

I : What do you mean expel?
 SO033 : It absorbs heat.
 I : What do you actually want to say? Is it absorb or expel?
 SO033 : No. It absorbs heat. I think it absorbs heat.
 I : Where does the heat absorb to?
 SO033 : It absorbs to the surroundings.
 I : What do you mean?
 SO033 : In our lesson, we didn't learn much about freezing, but we learned about heat. When you heat an object and leave it at the room temperature, the heat will be absorbed to the surroundings.

Spontaneity and reversibility

Students' explained why chemical reactions happen in Model A by the presence of essential ingredients. For a reaction to occur, which includes the reacting substances, the agent and also heat energy need to be present. This model appeared to mimic the process of cooking – where the intended dish can be prepared by mixing the ingredients and the heating. With this mental model, students explained the continuity of chemical reactions as a result of the presence of reacting substances and a reacting agent(s).

I : Why did the reaction continue?
 SF043 : Because the component is still there.

I : Why does it continue to burn?
 SO056 : It won't stop until it finishes.
 I : Until it finishes. When it finished then it will stop, isn't it. Why is it like that?
 SO056 : Because, it's just like the oil [or fuel]. Because, when the oil [or fuel] finish, it also stop.
 I : Why is it like that?
 SO056 : Because there is nothing to burn.

A similar idea, within Model A saw heat energy as a reacting component in addition to the chemical substances. Therefore, chemical reactions particularly combustion, will only start to occur when heat is present along with the reactants.

I : Why do you think we need the spark?
 SO033 : We need the spark to light up the fuel. The fuel inside the canister.
 I : The spark starts the fire?
 SO033 : I think the fire wouldn't start without the spark. And it also won't start without oxygen because the oxygen is needed. As an example, when there is oil burning, you should not pour water into it, but we just cover it, so that the flame burns up the oxygen to produce carbon dioxide.

And when the oxygen content is lower, the flame will die out. And carbon dioxide will be produced.

In Model A, chemical reactions were assumed to be an irreversible process. However, it was deemed possible to reverse a process albeit through a different procedure.

I : If we mix the carbon dioxide and water again, do you think we can get butane and oxygen back?
 SF052 : I'm not really sure, but I think, carbon dioxide, we can but [it is] not that easy. We can do something like experiment to separate both elements.
 I : May it requires ...
 SF052 : Requires a precise process.
 I : Why do you think that once the reaction happened, is very hard for us to get the initial materials back?
 SF052 : Because it's already mixed together. ... So, it's hard to separate something that has been mixed together.

Model A did not incorporate the concept of an energy barrier nor the spontaneity of chemical reactions. However, in Model A, energy was assumed to play agentic roles that determines the rate and occurrence of chemical reactions.

6.2.4 Representing Model A

Model A can be simplified based on analysis of the attributes and this simplification is shown in Figure 6.1 (page 234). The diagram illustrates that in Model A, a chemical reaction is seen as a response of a chemical substance towards a reacting agent(s), which includes other substances, energy, air, and surroundings to form 'transmuted' chemical substances. From examination of the attributes of Model A (shown in Table 6.5) in relation to the barriers to reaction, reaction mechanism, spontaneity, and reversibility components, it can be construed that this mental model was based on the causal agentic assumption. This mental model provided plausible explanations for spontaneity (i.e., the reaction happens because agents are present) and rate of reaction which is dependent on the presence of the agents (i.e., the more agents available, the faster the reaction); and the reversibility of chemical reactions or any chemical phenomena, depends on the availability of suitable agents. Energy

change was based on the *heat gain and loss* reasoning with absorption of energy by the reaction system resulting in an increase of temperature and release of energy resulting in drop of temperature, however, this is not necessarily relating energy/temperature change with chemical reactions. This view of energy change is represented with the diamond shape in Figure 6.1 indicating the energy is either gained or lost. The dashed line of the system indicates that there is no clear border between the system (i.e., the chemical reactions and the surroundings for Model A).

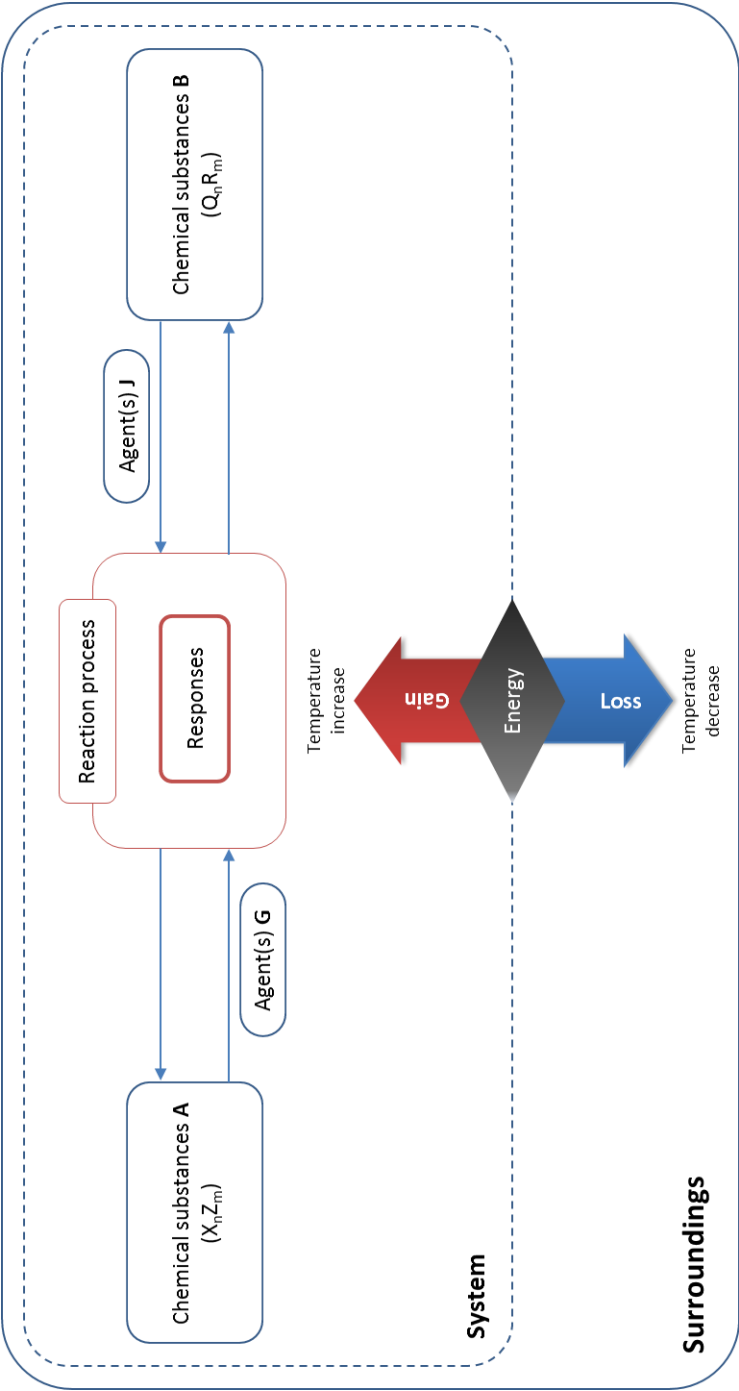


Figure 6.1 Model A of Chemical Reactions

6.3 Model B of Chemical Reactions

The proportion of students with Model B is quite small with only 15/67 falling into this category, most from the higher level of education.

6.3.1 Chemical Structure Characteristics of Model B

Composition

Attributes of Model B for the chemical structures are summarised in Table 6.9. Model B, also saw chemical reactions as a *response to reacting agents*, but in addition, chemical reactions were perceived by the holders of this mental model to be a process of producing new substances. Recognition of the formation of new substances in chemical reactions is far more prevalent in Model B, which distinguishes it from Model A.

I : How do you know this is a chemical reaction?
 UO023 : Chemical reactions is something like A plus B, and they will produce something new. So, the rust is the new product, from the reaction between metal, water and oxygen.
 I : Is the dissolution of salt and sugar a chemical reaction?
 UO023 : We say that a chemical reaction when it produces new substance. But, maybe salt and sugar will not react.

Table 6.9 Distribution of Students for Attributes in Chemical Structures According to Model B and its Subtypes

Component	Attribute	B1	B2	B
		(n=10)	(n=5)	(n=15)
Composition	Expected natural occurrence ^a	2	0	2
	Change of chemical substances ^a	1	0	0
	Change in physical properties ^a	2	3	5
	Response to reacting agents ^b	7	4	10
	Formation of new substances ^b	6	4	10
	Interaction between substances ^b	6	1	7
	Submicro changes ^c	4	3	7
Conservation of mass	Dependent on the physical state ^a	4	1	4
	More substances formed ^a	2	1	3
	Gas properties ^a	1	2	3
	Closed system ^b	6	3	8
	Rearrangement of atoms ^c	0	1	1

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

Model B also considered chemical reactions as the interaction of chemical substances (Table 6.9) including at least two chemical substances.

I : Okay. From these three pictures, which of them that you consider as a chemical reaction?
 SF041 : Chemical reaction. This [one, the metal corrosion/rusting].
 I : That's all?
 SF041 : Yes. I think, the metal corrosion.
 I : Why?
 SF041 : Because, it's between one chemical with other chemical. Like just now, between oxygen and iron.
 I : What it is important for a process that you can say it is a chemical reaction?
 SF041 : Normally to me, there are two things [i.e., chemical substances], such as metal with something else. There is something reacting with something else.

In some cases, students with Model B recognised that chemical reactions involve *submicro changes* such as change in chemical bonding and oxidation state.

I : What makes you think this process [i.e., metal corrosion] is a chemical reaction?
 UF063 : [By the] definition itself, when a chemical reaction happened, it creates new bonding of matter. That's mean a new molecular formula is formed. It is only occurred in metal corrosion but not in the other two pictures.

Conservation of mass

As with Model A, Model B seemed to rely on macro attributes such as physical state, quantity of substances, and open/closed system in predicting change of mass in chemical reactions.

I : Before the reaction, when we weigh everything, the initial mass is one five eight point two. Do you think the mass will change after the reaction?
 SS049 : Can I see [the video clip] again.
 I : Sure.
 SS049 : I think the mass will change.
 I : Why?
 SS049 : Because the elements have been displaced. So, I think the mass will change.
 I : Will it decrease or increase?
 SS049 : Increase.
 I : Why do you think so?
 SS049 : I have the feeling that lead iodide is heavier than lead nitrate. That's why.
 ...
 I : Before the reaction, we weigh everything; the balloon, the conical flask, the solution and metal, and weighs one six seven. Then, we let it reacts. After the reaction, what is the mass will be?

SS049 : I think the mass will decrease.
 I : Why do you think so?
 SS049 : Because hydrogen gas already has been released in the reaction. Hydrogen gas has been released. I still think it decreases. Because the mass of gas is lesser than the mass of liquid. That's why. Like this, change to hydrogen gas, so this one, the mass decrease.

6.3.2 Chemical Kinetic Characteristics of Model B

Particle collision and reaction mechanism

The main distinction between Model B and Model A for these components, is that the former described the process of chemical reactions at the particulate level (see Table 6.10).

Table 6.10 Distribution of Students for Attributes in Chemical Kinetics According to Model B and its Subtypes

Component	Attribute	B1	B2	B
		(n=10)	(n=5)	(n=15)
Particle collision	Internal arrangement ^a	0	1	1
	Movement of particles ^b	4	2	6
	Collisions of particles ^c	0	5	5
	Site of reactions ^c	0	0	0
	Probability for reactions ^c	0	0	0
Barrier to reaction	Energy initiates reactions ^a	7	3	9
	To lower the activation energy ^b	0	0	0
	Energy as catalyst ^b	3	2	5
	Energy as a part of reactions ^b	1	2	3
	Activation energy ^c	1	1	2
Activated complex	Metastable species ^c	0	0	0
Reaction mechanism	Transmutation ^a	0	0	0
	Quantity dependent ^b	7	4	10
	Octet approach ^b	0	0	0
	Atoms rearrangement ^c	8	3	11
	Bond breaking-formation ^c	5	0	5
	Transfer of electrons ^c	2	0	2
	Redox ^c	0	0	0
	Attraction between charges ^c	3	0	3
	Intermediate ^c	2	0	2
	Mechanistic approach ^c	0	0	0

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

Chemical reactions in Model B were considered to be a process of rearrangement of atoms in forming new substances, but without explicit reference to bond breaking and formation – merely rearranging atoms into different constituent molecules as shown in Figure 6.2.

- I : Can you imagine how butane and oxygen particles interact together to form carbon dioxide?
- UF007 : Oh. Its particles ...
- I : How the processes happen?
- UF007 : Er ... we do it in form of ... we draw butane molecule. It has carbons [see Figure 6.2], butane reacts with oxygen.
- I : O₂
- UF007 : If we do this ... er ... O₂ double bond. So, C ... it will ... its atoms will react with O₂ to produce We ignore the number of atoms. CH ... CO₂ ... this carbon will react with this, CO₂ so ... CO₂ and it will produce CO₂ and also water. Okay ... atoms ... carbon will react with water but there is eight of it. There's 13 ... 13 more molecules oxygen that will react with every other carbons in butane. It will produce carbon dioxide and the hydrogen will react with oxygen to produce water.

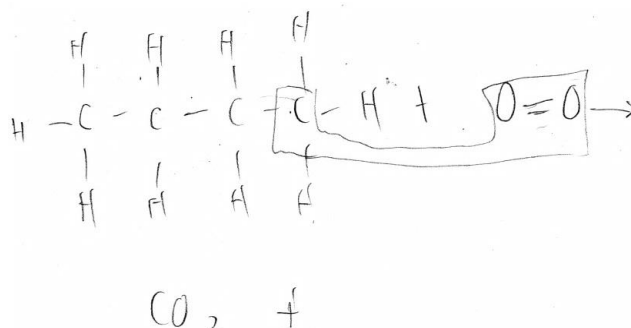


Figure 6.2 Drawing by Student UF007, Illustrating the Rearrangement of Atoms in the Combustion of Butane

Only Model Subtype B1 regarded chemical reactions involving chemical bonding.

- I : Can you imagine how butane and oxygen particles react together? What happen to the particles? Can you imagine it?
- SS049 : I think it is similar to [the zinc-acid reaction].
- I : You think so.
- SS049 : [It] undergoes the breaking of bonds.
- I : What will happen when zinc is mixed with the HCl?
- UF008 : When zinc is mixed with the HCl, chlorine will react with zinc. Chlorine will react with zinc. The bond will be broken. There are two chlorines, so it is easier to react. Zinc can hold two. Hydrogen, it turns into ions, but doesn't exist in single atom. H plus with H plus will become one [see Figure 6.3].
- I : Molecule?
- UF008 : One hydrogen molecule.

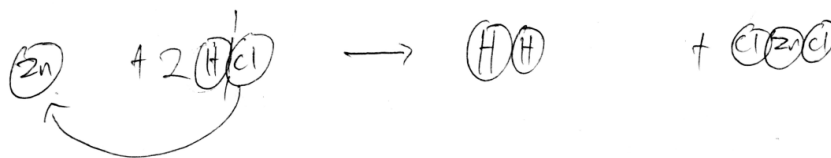


Figure 6.3 Drawing by Student UF008 Illustrating the Reaction Between Zinc and Hydrochloric Acid

Model Subtype B2 related the rearrangement of atoms in chemical reactions to the kinetic theory of particles, particularly the collisions of particles.

- I : How do zinc atoms react with HCl? What actually happen to zinc and HCl until it becomes the products?
- UO023 : Based on the kinetic theory, the particles will collide, and new product will be formed when there is effective collision. So, zinc and hydrochloric acid particles will collide and producing new products.
- ...
- UO023 : As you can see here, it needs two moles. So two moles of hydrochloric acid combine with zinc. When they collide, two chlorine atoms will combine with zinc. The hydrogen will form to hydrogen gas. Something like that.
- I : Can you show diagrams or particle model or whatever that suitable to describe how the process happen?
- UO023 : For example zinc ... [see Figure 6.4] ... I use circle. It is easy.
- I : How about the HCl?
- UO023 : HCl is like this. Two chlorines should react with one zinc. Effective collision, meaning that these two combine, and two hydrogen will be released forming hydrogen molecule [see Figure 6.4].



Figure 6.4 Drawing by Student UO023, Illustrating the Reaction Between Zn and HCl

Barrier to reaction

Similar to Model A, Mental B viewed chemical reactions without the notion of an energy barrier. In this mental model type, energy was considered necessary for initiating chemical reaction, without necessarily being involved further after reaction has begun. This necessity for energy to start the reaction is similar to the sense in Model A that energy was a part of the reaction and needed as an ingredient for reaction.

- I : Why do you think, for this process (the combustion), it has to be with the spark?
- SF041 : The spark, it got to, it starts the reaction between the gas and oxygen.
- I : Can you tell me a bit more about “the start”?
- SF041 : To start the reaction. Because just now, it provides heat, right. Because heating starts the reaction. With the spark, the heat makes the reaction happened, these two, oxygen and butane.
- I : Why is the spark needed for it to burn?
- SS057 : Because it needs heat energy that mix with the oxygen, so that it produces the flame.

However, in a few cases these students with that Model Subtype B2 extended this idea about the energy in reaction to the activation energy, but only after prompting:

- I : What is the spark actually for?
- UO023 : The spark is to ignite the butane gas.
- I : What do you mean ignite?
- UO023 : To ignite the butane, it needs heat from the spark and oxygen. The butane gas cannot burn by itself. It needs spark to ignite.
- I : Why does it won't burn by itself?
- UO023 : Because it needs a suitable temperature. But I don't know much about heat. The spark causes the butane gas to ignite. So, we can say that the spark helps butane gas to undergo combustion.
- I : Can you relate this with the activation energy?
- UO023 : Butane and oxygen, when they react, the flame will be produced. So, spark makes the butane and oxygen to reach the activation energy, as a helper.

6.3.3 Chemical Energy Characteristics of Model B**Conservation and change of energy**

Model Subtype B1 offered more explanation about energy changes compared with Model Subtype B2 (see Table 6.11), through the attributes *energy transfer*

and *heat as a reactant or product*. However, there were no consistent or systematic explanations as to how energy change in chemical reactions occurs.

Table 6.11 Distribution of Students for Attributes in Chemical Energy According to Model B and its Subtypes

Component	Attribute	B1	B2	B
		(n=10)	(n=5)	(n=15)
Conservation of energy	Heat gain and loss ^a	3	3	5
	Change in form of energy ^a	6	2	7
	Energy content ^b	4	0	4
	Net energy transfers ^c	0	0	0
Energy change	Change of physical state ^a	1	0	1
	Heat as a reactant or product ^a	5	1	6
	Energy transfer ^b	5	2	7
	Reverse energy transfer ^b	4	0	4
	Enthalpy of formation comparison ^c	0	0	0
	Energy transfer in chemical bonding ^c	3	0	3
Spontaneity	Nature of the reactant ^a	3	0	3
	Presence of reactants ^b	4	1	4
	Reacting agents ^b	4	0	4
	Reactive agents ^c	3	0	3
	Stability driven ^c	1	1	2
	Electrostatic charges ^c	1	0	1
	Electronegativity differences ^c	0	1	1
	Energy driven ^c	1	0	1
Reversibility	Irreversibility presumption ^a	4	1	4
	Physical state ^a	1	0	1
	Matter is not conserved ^a	2	0	1
	Through a different set of conditions ^b	2	1	3
	Stability factors ^c	2	2	4
	Chemical structure factors ^c	4	2	6
	Energy factors ^c	0	1	1
	Equilibrium system ^c	1	0	1

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

Model Subtype B1 only hints at the idea that the energy change has something to do with either breaking or forming of bonds. The energy transfer in this model subtype was in one direction, which is the energy is either released or absorbed.

I : How does the reaction form heat? How does the reaction produce the heat?

SS049 : Oh! Because of the bonds. Yes. Because of butane and oxygen, they have a reaction over there, that will cause carbon dioxide and water, in fact, the breaking or forming of bonds cause heat.

I : Both processes?

SS049 : Actually only ... exothermic. Actually very confused about that part. Ah ... breaking forms heat.

I : Breaking forms heat?
 SS049 : Yeaaaa. Eh ... no. Breaking ... [laughing] Okay Ump ... this one over there, don't know whether breaking or forming.
 I : But you know that in every reaction there breaking and formation of bonding. So, either of these one will ...
 SS049 : Absorb or release heat.
 I : Absorb or release heat.
 SS049 : Oh! No. It releasing heat. Yes. So, it is, breaking of bonds, release heat. Yes. That one. A bond breaks, that's why release heat. That's why we can feel hot. Yes.
 ...
 I : Why does it become cold?
 SS049 : Breaking of bond.
 I : Okay. Breaking of bond.
 SS049 : Yes.
 I : In this reaction, only breaking of bond?
 SS049 : [silent] Kind of, mostly breaking of bonds. The barium thiocyanate is displaced but I think mostly breaking of bonds, compared to forming. That's why the temperature ... I think is because if you break, then you for, right. So, at least the temperature will maintain. But, only break, temperature drop and if only form, the temperature will increase. Yes.
 I : So, the, where's the heat goes? Used up?
 SS049 : [silent] The heat is released to the surroundings.
 I : What do you mean by that actually?
 SS049 : Like it is diffused out to the surroundings area. I think.

In some responses, energy change occurred in chemical reactions, it seems, simply as the transformation of energy from one type to another.

I : Do you think there is a change in energy?
 UF010 : Energy change. Chemical energy, heat energy and light energy. Chemical energy form butane and oxygen, after that the fire is formed, there is light energy, and we feel hot because, there is heat energy.

Spontaneity and reversibility

In another similarity to Model A, Model B lacked explanations of spontaneity and reversibility of chemical reactions. Model Subtype B1 considered that a chemical reaction is controlled and/or caused by reacting agents.

I : To your opinion, what make the reaction [i.e., rusting] tend to happen? Like the rusting, whenever we leave it outside, it will get rusted?
 UF007 : It [i.e., the rusting reaction] is influenced by the substances itself. Like the iron, when it is added with water, it will rust. But when it is in contact with other element like oil element, it will not rust. Because it depends on what substance that it is reacting with.

Students with this mental model seemed to be comfortable with this idea even without prompting. For example, students see air and water as the causes of rusting, while, sunlight and air are causes of melting.

I : If we compare this [ice melting] and the previous one [rusting], is this process a chemical reaction?
 UF010 : I think air and ... like just now air and water. This one, air also one of the agent of reaction.
 I : For this one, ice changing into ... [water]
 UF010 : If it is placed under the sun and to air, so the sun and air become the agent of reaction change.

Most students with Model B were only able to identify the reacting agents, in chemical reactions, but some students seemed to think that chemical reactions are caused by *reactive agents* that are chemical species with higher chemical reactivity in the reactivity series, which is somewhat consistent with the scientific view of chemical reactions.

I : How do you imagine the reaction occurs at the particulate level?
 UF063 : Imagine how they occur?
 I : Yes.
 UF063 : How should I imagine it? This thing has been studied through molecular orbital. So to imagine is quite difficult. We know it, zinc has higher reactivity compare to hydrogen, so when it is reacting with a more reactive substance. I mean, in this case, zinc has higher reactivity compare to hydrogen, so when we add it into acid hydrochloric they will displaces the position of hydrogen. The zinc will combine with chloride and then leaving hydrogen alone, forming diatomic bond diatomic atom.

In Model B, it was also thought that heat energy initiates the combustion of butane. This understanding is consistent with the view of heat energy as an important reacting agent for reaction and necessary for 'starting' chemical reactions.

I : Why do you think the spark is needed?
 UO065 : The need of spark is to initiate the reaction. So, like the equation shown the butane and the oxygen. Oxygen is presence, but without the help from the other thing such as the spark, the reaction is impossible to occur. We have the two elements there, but we have to do something to make sure the reaction to occur.

I : What is the spark actually for?
 UO023 : The spark is to ignite the butane gas.

I : What do you mean ignite?
 UO023 : To ignite the butane, it needs heat from the spark and oxygen. The butane gas cannot burn by itself. It needs a spark to ignite.
 I : Why does it won't burn itself?
 UO023 : Because it needs a suitable temperature. But I don't know how much heat. The spark causes the butane gas to ignite. So, we can say that the spark helps butane gas to undergo combustion.

Holders of Model B also assumed that chemical reactions are irreversible.

I : Do you think if we mix the carbon dioxide and water again, we can get butane and oxygen back?
 UO065 : I think it is impossible. Because any organic compound if we burn with oxygen, we will get carbon dioxide and water, so the reaction is irreversible.
 I : Mhuh.
 UO065 : Because any organic compound if we burn with oxygen, we will get the carbon dioxide and water, so the reaction is irreversible.
 I : So why do you think the reaction is irreversible or what make the reaction irreversible?
 UO065 : Because the organic compound when we heat it up, it gives carbon dioxide and water, right. But when we mix carbon dioxide and water, it doesn't give us the specific [substances] like it doesn't give what we want [i.e., butane]. I think it's slightly impossible.

The irreversibility of chemical reactions was reasoned by students on the basis of *chemical structure factors*. Stronger chemical bonds are formed in products compared to reactants, and this outcome prevents the chemical reaction from reversing. The reversible reaction in the chromate-dichromate equilibrium was explained on the basis that the products containing weaker chemical bonds.

I : Why do you think we cannot get the reactants [butane and oxygen] from the product?
 SS049 : I think the atoms, like the elements are already bonded very strongly, because it gone through the combustion process. That's why. Cannot be separated back.
 ...
 I : Now, it is from orange to yellow, then yellow to orange. And it is yellow again. So, why do you think the reaction is like this?
 SS049 : Mmm. Because ... I think the ... ump ... the hydrogen ion and the hydroxide ion, yes. Is like ump ... original is the dichromate, so when ah ... the alkali (the base) sodium hydroxide is added, it produces [chromate and the water].
 I : Do you think this is a reversible reaction?
 SS049 : Yes. It is.
 I : Do you have any idea why this reaction is reversible?

SS049 : Because, the dissociation isn't very strong, I mean the bond is not very strong.
 I : You mean both are not strong?
 SS049 : No. the chromate ion.
 I : Okay. That's why it goes ...
 SS049 : Yes. Go back, just with the help with the acid and alkali.

6.3.4 Representing Model B

Model B can also be simplified based on analysis of the attributes in Figure 6.5 (page 246). Model B described chemical reactions as *submicro changes* through a process of *rearrangement of atoms*. In Model Subtype B1, it was observed that the notion of particle collision is not prevalent (indicated by the faded box and arrow in Figure 6.5), and the reaction at the particulate level was mainly described through a process of bond breaking and formation. However, this process does did have a clear relation with the energy change in chemical reactions. The change of energy was rather inconsistent, but it is mainly described as transformation of one form of energy into another form (indicated by the connected circular arrows), and energy transfer (indicated by the diamond shape). Similar to Model A, this mental model viewed the role of reacting agents as important, especially heat energy as an initiator or driving force of chemical reactions. It was presumed that chemical reactions are irreversible, since the chemical bonds formed in products of the reaction are stronger than the reactants. It was then reasoned that in a reversible reaction, the chemical bond formed in the products must be weaker than those in the reactants.

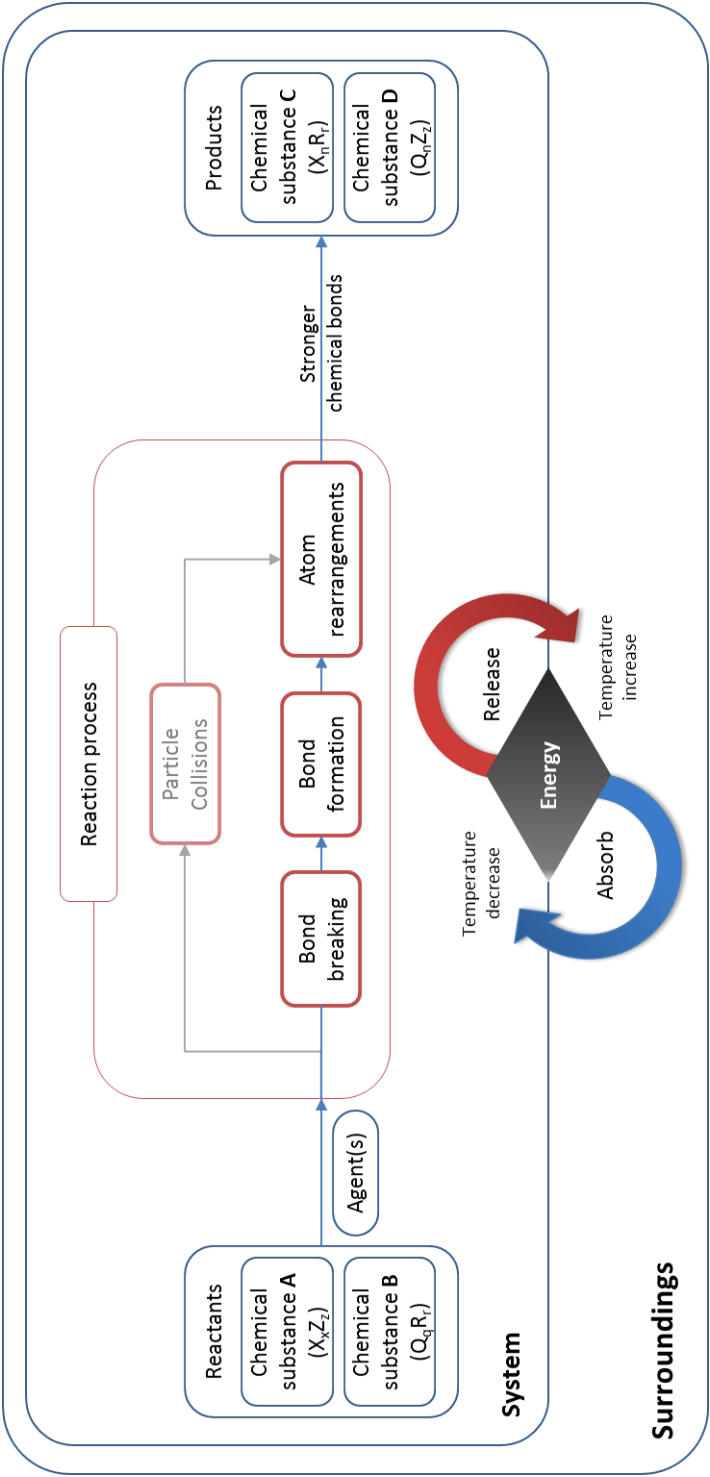


Figure 6.5 Model B of Chemical Reactions

6.4 Model C of Chemical Reactions

The proportion of students that expressed Model C was 40% (27/67) about the same proportion as for Model A. Most students holding this mental model come from university and about half of the Form 6 students. There was none from Form 4 and Form 1.

6.4.1 Chemical Structure Characteristics of Model C

Composition

A key feature of Model C is the emerging importance that the idea of *submicro changes* takes in describing and explaining chemical reactions. Although Model C contained the same attributes as Model B such as the *response of reacting agents* and *formation of new substances*, the explanation of chemical reactions in Model C also considered the *submicro changes* that including change in chemical compositions change in oxidation state, and chemical bonding (Table 6.12). The most important and distinguishing characteristic in Model C was that the explanations were overall more coherent compared to the other types of mental models. Model C integrated all the attributes in a more meaningful way, as illustrated in the quotes below, where the student sees rusting as a process involving interaction between iron, water and oxygen to produce the rust, which is a different chemical substance, iron oxide.

- I : Based on this picture, can you explain what you think about the change or changes that happened here?
- UF013 : Rusting has taken places, on top of the iron or metal. And it will corrode the metal's surface.
- I : Can you explain me more about the rusting?
- UF013 : Rusting happened when there is water and oxygen.
- I : Is the rust is air and water, or else? What's the rust actually?
- UF013 : Rust is actually a type of chemical with new formula of molecule, different from the metal.
- I : Where does it come from?
- UF013 : It is from ah ... the reaction between iron, oxygen and water. And produces a new substance that is the iron oxide. Or iron hydroxide.
- I : How do you know or why do you consider this process as a chemical reaction?
- UF013 : Because initially, the metal exists as atoms. Exist as metal atoms. But, after this reaction, a new substance formed. The formation of the new chemical substance, different from the metal atom. It exists as a type of ion.

Table 6.12 Distribution of Students for Attributes in Chemical Structures According to Model C and its Subtypes

Component	Attribute	C1	C2	C3	C
		(n=10)	(n=4)	(n=13)	(n=27)
Composition	Expected natural occurrence ^a	0	0	0	0
	Change of chemical substances ^a	2	0	3	5
	Change in physical properties ^a	4	2	6	12
	Response to reacting agents ^b	5	3	8	16
	Formation of new substances ^b	9	4	8	21
	Interaction between substances ^b	5	1	8	14
	Submicro changes ^c	6	4	9	19
Conservation of mass	Dependent on the physical state ^a	2	0	4	6
	More substances formed ^a	0	1	3	4
	Gas properties ^a	4	1	4	9
	Closed system ^b	8	2	7	17
	Rearrangement of atoms ^c	4	1	2	7

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

And in the example below, a holder of Model C described chemical reactions as a process that involves change of oxidation state, electron transfer, and also energy transfer.

I : I show you these three pictures here. In your point of view, what happen to the substances, or what happen to the material in these three pictures?

UF062 : First, this is a metal corrosion. Basically, a redox reaction happened here. It involves oxidation and reduction process. The iron has been oxidised because of exposure to air. So, there is an oxidation occurred. And reduction occurred the same time, due to oxygen and the substance. And also, there's a transfer of electrons.

...

I : So, which of these phenomena that you consider as chemical reactions?

UF062 : Mm ... chemical reactions, basically the first one.

I : The first one only?

UF062 : The first [metal corrosion] and the third [mixing salt and sugar into water].

I : The third one. So, what made you think that?

UF062 : When you talking about chemical reactions, there are bonds formed, and bonds are broken at the same time, therefore, heat is released, and heat is also absorbed. Therefore, it is considered as a chemical reaction.

Conservation of Mass

Consistent with the other mental models, Model C was limited when it comes to predicting conservation of mass and relied on macro level attributes such as the

physical states and quantity. Most of the time, this mental model predicted the final mass of a reaction mixture based on the *closed system* attributes.

- I : Before the reaction the mass is 158.2. After the reaction formation of the yellow stuff, do you think the mass will change.
- SS030 : The mass is constant. This is a closed system.
- I : How does the closed system affect the mass?
- SS030 : If this is not a closed system, masses of any type, associated with gas, liquid or solid might escape or they may enter inside, whereby changing the final mass.
- I : How about the formation of lead iodide, doesn't it affect the mass?
- SS030 : No. It won't. The formation this or that, is only involve its prior reactants. It does not rely on any other sources. All of the products in the form of solid or aqueous inside closed container which preventing anything to escape.

Only 7/27 students with this mental model used the *rearrangement of atoms* when reasoning the change of mass.

- I : If we take the mixture and the apparatus and weigh it as 158.2 gram, and after the reaction, we weigh them again. To your opinion, will the mass change or otherwise?
- UF013 : The mass will be the same. It is still the same.
- I : Can you explain why does it stay the same?
- UF013 : Because, before the reaction happens, the weights of both of the chemicals remain the same after the reaction. The ions just exchange their places. There is no new chemical is added. They just exchange their place.
- I : Can you explain further?
- UF013 : The elemental content is still the same. For example, in lead nitrate, its nitrate, it will use two nitrate ions. There are still two nitrate ions. So, its mass is not changed, for the nitrate. Also with the lead, the lead before the reaction, it has one mole of lead, but even after the reaction, it will not increase [or decrease]. It exists in one mole of lead. The same with iodide, for iodide before the reaction, it has two moles of iodide ion, after the reaction, the iodide still two moles.

6.4.2 Chemical Kinetic Characteristics of Model C

Particle collision and reaction mechanism

The most distinctive feature of Model C was the integration of the kinetic theory of particles with chemical bonding when explaining the process of chemical reactions at the submicro level (see Table 6.13).

Table 6.13 Distribution of Students for Attributes in Chemical Kinetics According to Model A and its Subtypes

Component	Attribute	C1	C2	C3	C
		(n=10)	(n=4)	(n=13)	(n=27)
Particle collision	Internal arrangement ^a	0	0	0	0
	Movement of particles ^b	5	4	11	20
	Collisions of particles ^c	10	4	13	27
	Site of reactions ^c	1	0	4	5
	Probability for reactions ^c	4	1	1	6
Barrier to reaction	Energy initiates reactions ^a	8	1	6	15
	To lower the activation energy ^b	1	0	1	2
	Energy as catalyst ^b	0	0	1	1
	Energy as a part of reactions ^b	2	0	2	4
	Activation energy ^c	6	3	4	13
Activated complex	Metastable species ^c	0	1	0	1
Reaction mechanism	Transmutation ^a	0	0	0	0
	Quantity dependent ^b	9	4	12	25
	Octet approach ^b	1	0	2	3
	Atoms rearrangement ^c	5	2	10	17
	Bond breaking-formation ^c	9	4	6	19
	Transfer of electrons ^c	7	4	6	17
	Redox ^c	2	1	2	5
	Attraction between charges ^c	2	1	4	7
	Intermediate ^c	4	1	5	10
	Mechanistic approach ^c	4	2	2	8

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

Unlike Model B, where students were inclined to choose just one of the attributes, students with Model C seemed to identify that collision between particles leads to bond breaking and bond formation as shown in this explanation for a zinc-acid reaction.

- I : If you imagine the zinc atoms and hydrochloric acid, may be the molecules or ions, can you imagine how they are together to form [the products]?
- SS030 : Yes, that how imagine this reaction are form molecules colliding each other.
- I : Can you show me by drawing how zinc and HCl reacting or interacting to each other? What kind of changes undergoes to them?
- SS030 : Okay. First of all, I imagine zinc as a simple sphere, and hydrogen chloride as another sphere. So these two, will undergo collision, and meantime electron transfer will occur, so hydrogen will transfer two of these, transfers over electron from zinc. There by, by rising ... no, no, ... zinc will take in electron, no wait, zinc will donate electrons, thereby forcing H become H plus. Cl minus combines with zinc to form zinc chloride. [drawing Figure 6.6]
- I : Where's the electron goes?

SS030 : Electron will be ... no, no wait. Ah ... [correcting himself with the drawing] Okay. Wait. Sorry. These electrons will go here, fill up the loop hole, neutralise the charges [of the H of HCl], forming H_2 . Meantime, zinc will combine with Cl, which now considered as free. Because hydrogen which attach to it is neutralised, to form zinc chloride.

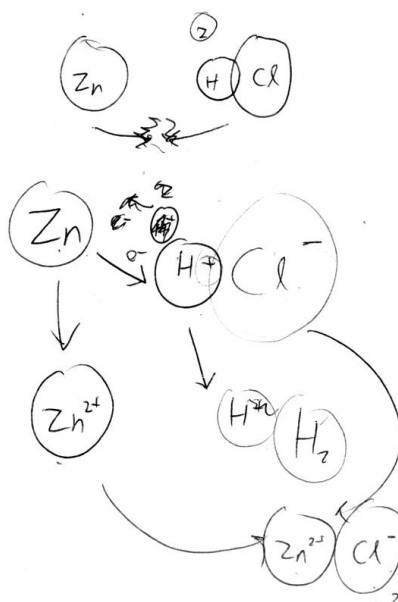


Figure 6.6 Drawing by Respondent SS030 Illustrating the Reaction Between Zn and HCl

In a similar manner, the need for a spark in the combustion of butane to cause the collisions between the reacting molecules, was thought to result in alteration of chemical bonds.

I : Why do we need the heat?

UO069 : I would say because it might be for the breaking. For the bonding, the breaking of bond. Because when the gas goes up, right, the gas contained in this butane but if you don't have anything to break the bond, to let the oxygen does its work, the reaction doesn't occur as how the reaction show here. It is needed to break the bonds, because as you say just now, without spark, the gas on its own, the gas will be the original butane.

I : You need the heat to ...

UO069 : You need heat to break it down. That's what I think.

I : To break the bond?

UO069 : Mm ... or maybe for even the oxygen to have enough energy to collide in and react. Because reaction actually, but is not only one sided, it can always be two sided, if you promote this one, it can collide in of cause and bond and form the product as well. Or you can break bond here

[referring to the C-C bond], making the oxygen easy to go in. It's two way.

Barrier to reaction

Model C was also found to share similar attributes with other types of mental models when referring to the barrier to reaction idea especially describing energy that initiate chemical reactions.

I : Why will the reaction only occur when there is a spark?
 UF018 : Maybe to activate it.
 I : To activate?
 UF018 : To activate the hydrocarbon gas so that it reacts with oxygen in the air. After that it produces fire.
 I : But this reaction [lead iodide precipitation] does not need to be heated. It will start to react immediately after mixing without doing anything else.
 UF018 : Because it can't react by itself. It needs something to cause the reaction for it to happen. To my point of view, because of the bonding in butane is stronger. So it needs help from the spark to produce the product. The flame is just by-product of the reaction.

However, what distinguished this model from the previous mental models is the extension of the idea to do with initiating roles of energy in chemical reactions to the concept of *activation energy*. For Model A and Model B, energy in chemical reactions was assumed to be a reacting agent and/or a part of component of reactions. However, Model C has extended the need of energy in chemical reactions to the idea that we need to achieve a certain required energy – that is the activation energy, in order to for the chemical reactions to proceed. Additionally, this attribute was also found associated with the *collisions of particles* attribute.

I : We have an empty gas lighter and this with gas.
 UF061 : Yes.
 I : This empty one with spark but no burning happened. This one, spark then it burn.
 UF061 : I think the spark is still burning but because not it is enough because as you know burning something like burning candle, something like that. You need the substance, you need the oxygen, and one more. I forgot the last one [laugh]. Then only the burning process can be sustained. Actually the first part is still burning, but due to the lack of substance or something like that, maybe you can say here is the butane. So, the lack of butane will add to the burning, because it cannot sustain the triangle

[fire triangle], less butane, the most important thing, the burning. The third thing is the ignition.

I : Ignition.

UF061 : We need oxygen, you need the burning substance, the fuel and the ignition.

I : In this case, why do you think the reaction occur or proceed once it happened? Like this, when it's burning, it burns until the gas finish.

UF061 : Because I think the spark provides something like the activation energy. My teacher told me ignition point is just like the activation energy. The spark provides the energy that compensated the activation energy, and then it will start burning.

In addition, students holding Model C seemed to integrate the attributes in particle collision component (*collisions of particles, site of reactions, and probability for reactions*) with the consideration of 'correct orientation' and 'effective collision.'

I : What will happen if we increase the concentration of HCl?

UO026 : Increase the concentration of the HCl?

I : With the zinc remain the same.

UO026 : The reaction will become faster.

I : Why?

UO026 : Because when the concentration of HCl is increased, that means the reactant, zinc reacts with more HCl. Therefore, the reaction becomes faster. According to the collision theory, for the product to be formed, they must overcome a certain energy first. This energy is called activation energy. If the reactants do not have enough energy to overcome the activation energy, the product will not be formed. And for a product to form, the collision must be in a correct orientation. If it is a wrong orientation, the product will not be formed also. In conclusion, for the product to be formed, the collision must be in a correct orientation and the energy must be able to overcome the activation energy.

I : What will happen if the mixture [zinc and acid] is being heated?

UF014 : If it is being heated, so heat is provided, that means the kinetic energy is increased. So, more collision will happen, and if more collision happened, the probability of effective collision is higher.

I : What do you mean by effective collision?

UF014 : For example, zinc. Zinc collide with H, but it is not suitable. Not effective. But if zinc and chloride, yes. It is suitable. So, it is an effective collision. It will able to produce something.

I : Are all collisions, effective collisions?

UF014 : No. Some collisions are not effective. For example, this zinc collide with H, that's not effective. And then, if zinc collides with chloride, there is collision, something is formed, transferred, and reaction. So, that's called as an effective collision.

I : If we increase the concentration of HCl?

UF014 : If the concentration of HCl is increase, [the reaction] is faster. Meaning that we increase the number of particles. So, more particles, the higher probability of effective collisions. So, it is faster, the rate of the reaction. Faster.

6.4.3 Chemical Energy Characteristics of Model C

There were also some variations in Model C around the component of energy change in chemical reactions, and these differences were used to identify subtypes C1, C2, and C3.

Table 6.14 Distribution of Students for Attributes in Chemical Energy According to Model C and its Subtypes

Component	Attribute	C1	C2	C3	C
		(n=10)	(n=4)	(n=13)	(n=27)
Conservation of energy	Heat gain and loss ^a	0	2	8	10
	Change in form of energy ^a	5	1	3	9
	Energy content ^b	4	2	5	11
	Net energy transfers ^c	8	3	0	11
Energy change	Change of physical state ^a	0	0	2	2
	Heat as a reactant or product ^a	0	2	5	7
	Energy transfer ^b	8	4	12	24
	Reverse energy transfer ^b	5	0	3	8
	Enthalpy of formation comparison ^c	5	1	3	9
	Energy transfer in chemical bonding ^c	8	4	0	12
Spontaneity	Nature of the reactant ^a	1	0	0	1
	Presence of reactants ^b	1	1	3	5
	Reacting agents ^b	4	1	2	7
	Reactive agents ^c	4	2	7	13
	Stability driven ^c	4	2	4	10
	Electrostatic charges ^c	1	0	1	2
	Electronegativity differences ^c	1	0	0	1
	Energy driven ^c	2	1	0	3
Reversibility	Irreversibility presumption ^a	0	1	1	2
	Physical state ^a	0	0	2	2
	Matter is not conserved ^a	2	1	2	5
	Through a different set of conditions ^b	4	3	7	14
	Stability factors ^c	5	1	4	10
	Chemical structure factors ^c	6	1	1	8
	Energy factors ^c	6	2	3	11
	Equilibrium system ^c	4	2	1	7

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

Conservation and change of energy

Model Subtype C1 and C2 explained the change of energy in chemical reactions by the net energy transfer that happens in bond breaking and formation. Here,

students with Model Subtype C1 and C2 described the energy change in combustion of butane as an exothermic reaction, saying that the energy absorbed in bond breaking is much less compared to the energy released in the formation of new bonds.

- I : Could you explain to me why [fire is hot]?
 SS030 : Fire is hot. Because the oxidation in this change is a highly exothermic reaction because bonds, the bonds formation which releases heat. ... The bonds formed after the oxidation is stronger than those in butane. Therefore, the heat absorbed for the reaction to occur is lesser than heat released due to the formation of the new bonds.
 I : Okay. Do you consider change of energy?
 SS030 : Yes.
 I : Can you explain me further with a diagram or something?
 SS030 : Yes. So, for what I understand, using energy diagram [see Figure 6.7], I assume butane has zero energy. So, for reaction to occur, energy must be supplied that is provided from the spark. This spark energy, will cause the thing to react [referring to the increments of energy toward the activation energy] with oxygen, therefore, ump ... sorry ... this energy is absorb use to break the bond and initiate reaction with butane. As time progresses, this energy is used up, and this energy become negative energy, as is released due to bond formations.

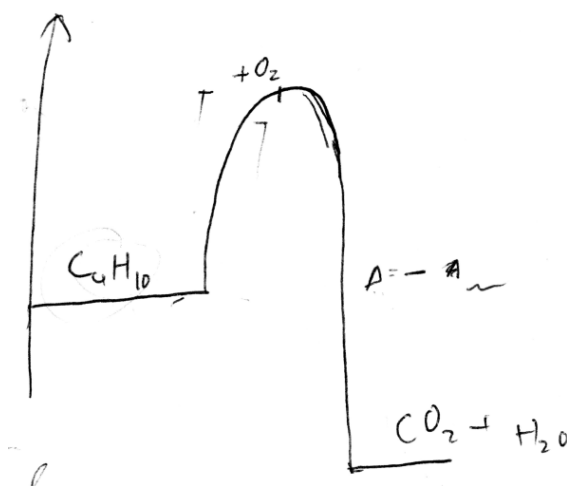


Figure 6.7 Drawing by Respondent SS030 Illustrating the Energy Change for Combustion of Butane

In an explanation for the endothermic reaction between barium hydroxide octahydrate and ammonium thiocyanate, students with Model Subtype C1 applied the similar reasoning to explain the drop of temperature that occurred in the reaction.

I : How do you explain the drop of the temperature [in this reaction]?

SS030 : The drop of the temperature is because this reaction overall is endothermic. Therefore, it has to receive heat in, heat energy from outside for reaction to continue. And judging from the drop in temperature, this reaction is very endothermic, so it will take in a lot of heat from the environment in order to continue the reaction.

I : Where's the heat go?

SS030 : The heat goes to the bond formation ... yes. No, not the bond formation, the bond breaking. Because bond formation is always releasing heat. So, from the drop of temperature, we can imply that the energy required to break the bonds is significantly higher than the energy required to form, reform the bonds. From this you can imply that the salt produced, overall have weaker bond, as compared to the initial reactants. However, the total energy will be higher, as they have absorbed more energy than they've released.

However, when confronted with the endothermic reaction, students with Model Subtype C2 failed to apply the *net energy transfer* idea when explaining the phenomena and produced explanation similar to those students in Model B and A, by seeming to think that there is loss of energy to the surroundings leaving the substances behind colder.

I : You see that the temperature dropped from twenty five to negative twenty five.

UF016 : Yes.

I : Can you explain why it is like that?

UF016 : Because this process is also an exothermic reaction [combustion of butane]. So, once the reaction occurred, it will release the energy to the surroundings, and it becomes very cold. It has already lost the energy to the surroundings.

I : What do you mean? Do you mean it also releases heat energy?

UF016 : Yes. It releases heat to the surroundings. Therefore, the energy content become lesser and also become cold.

Another variation of Model C is Model Subtype C3, which differs from the other Subtype C1 and C2 because here students considered the change of energy happened as *energy transfer*, similar to Model A and Model B. Holders of this mental model have not related the change of energy in chemical reactions with chemical bonding, instead reasoning purely on the basis of a thermodynamic explanation of energy change by considering that the change of temperature is caused by release or absorption of energy.

I : Can you explain why fire is hot?

- UF060 : Because as we know, when butane is oxidised, the energy will be given out. So, when the heat energy is given out, we feel hot. So, this is an exothermic reaction.
- I : Can do you explain how the heat is released?
- UF060 : Because butane is a big molecule. So, when its bonding has been broken, the energy is released. This is because it stored a lot of energy for it to be bonded. So, when it is broken, the energy is released.

Likewise, in the endothermic reaction between barium hydroxide octahydrate and ammonium thiocyanate, the same student explained the drop of temperature as due to energy absorption.

- I : Can you explain what you observed just now?
- UF013 : When this hydrated barium hydroxide, mixed into ammonium thiocyanate, a chemical reaction will happen, and it will produce new chemicals that are barium thiocyanate, ammonia gas, and water. The ammonia gas is alkaline, because it turns the litmus paper to blue. And, bonding is formed in barium thiocyanate, so it absorbs heat. So, temperature goes down because the energy content is absorbed to become energy content of barium thiocyanate.
- I : Can you explain what you said just now the same way like this one?
- UF013 : Before the reaction happen, the energy content for barium hydroxide and ammonium thiocyanate is lower. [drawing Figure 6.8] It is lower.

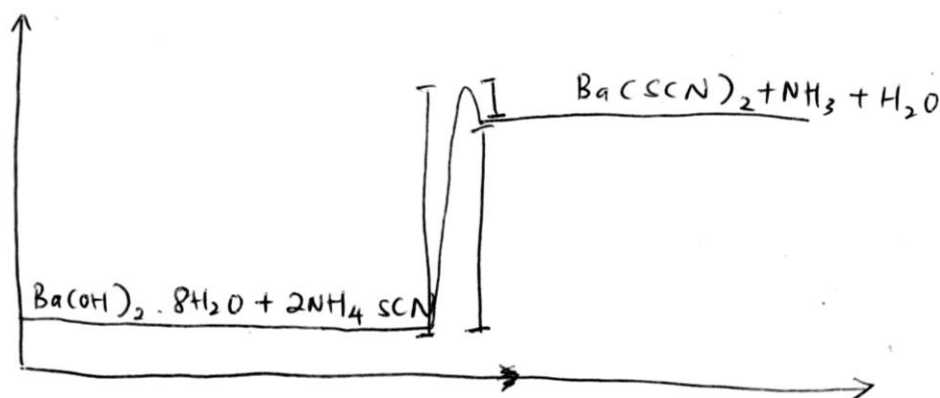


Figure 6.8 Drawing by Respondent UF013 Illustrating the Energy Change for Reaction Between Barium Hydroxide Octahydrate with Ammonium Thiocyanate

However, most of the students in Model Subtype C3 were inconsistent with their explanations concerning the energy change, suggesting that they have not fully developed their mental models of chemical reactions related to chemical energy. It seemed that they could not relate the ideas of change of temperature and

energy transfer consistently. For example, some simply said that combustion of butane releases heat when the products were formed.

I : How do you explain this reaction is exothermic?
 UF020 : Exothermic, heat is released to the surroundings.
 I : How do you explain that?
 UF020 : When the product is formed, the heat is released. That's why we feel hot.

But, when confronted with the endothermic reaction, this same student explained the outcome in a similar way to combustion, indicating a lack of connection between energy transfer and temperature.

I : Does it absorb or release heat?
 UF020 : Releases heat.
 I : Where does it releases the heat to?
 UF020 : To the surroundings.
 I : To the surroundings, so?
 UF020 : So, the reactant's temperature will go down because it releases heat to the surroundings.

Spontaneity and reversibility

When explaining reaction spontaneity and reversibility, students with Model C were quite similar to Model B, since no attributes related to the notion of entropy were used to explain the driving force of chemical reactions. The main contention of Model C was that reactive agents must be present in the system if a chemical reaction was to proceed. For example, considering that heat energy is the cause of chemical reactions, students with Model C believed that the combustion of butane continues to happen because of the continuous supply of heat energy, released during the reaction.

I : When the burning happen, why do you think the burning go on without the spark?
 SS047 : Mmm?
 I : What I mean, why does the reaction continue?
 SS047 : Because I think, when start the burning will produce heat also, and provide to the butane react again and again. I mean is continuous. It supplies the heat to its own molecule. So what's important, it needs spark first, then start the combustion and the combustion will continue their own heat to butane so that to break the bonds between them and react with oxygen to form the carbon dioxide.

In a similar way, students believed that reaction happens because there is a certain reactant responsible for starting the reaction.

I : Why do reactions happen? What is the reaction want to achieve?
 UO027 : Why reactions happen? Because of the presence of certain reaction that causes ...
 I : Certain reactants?
 UO027 : Certain reactants cause the chemical reaction to happen until the products if formed.

Other students with Model C provided evidence of their contention that chemical reactions are driven by the need for stability, where reactants are chemically transformed into more stable products. This idea was used to explain the tendency of a reaction to occur and the irreversibility of a reaction based on the stability of the product.

I : Why do the reactants [zinc and hydrochloric acid] tend to form into products?
 SS032 : I don't know. Maybe because the product is more stable.
 ...
 I : The rusting is also like that. Although it is slow, the reaction will continue until the reactant finish.
 SS032 : Yes. Maybe its stability. The reactant is more reactive, turning into something not reactive, in a stable form.

Even for the endothermic reaction, students considered stability as the driving force of the reaction.

I : Why these [reactions, the combustion and endothermic] happened? What are the factors make these reactions happen? Just now [for the combustion] you said stability and the energy level are low. But this, it seem contradicts with what you said.
 UF014 : I understand, what you mean. Turn the slide back [barium hydroxide slides] ... [pause] Maybe.
 I : That's fine. Just what you are thinking.
 UF014 : I think, because this one [combustion], the reactant's total energy is higher than the product. Its products are also two. For this one [endothermic reaction], its reactant also has two. Maybe the total energy in the compound is lower but for each single product, actually, ... what I mean is to compare this [the product] with H₂O, the energy content for this compound is actually higher than single H₂O. And then, because the three energy content in total, it is higher than this.
 I : Okay.

UF014 : I think it is like that. But, it does not contradict what I said. Because, when we analysis single product, actually the energy of the single product, maybe it is lower than the original one.

Rusting was considered an irreversible reaction because of the rust being more stable than iron.

I : But, going back my question just now, if we look at this, after it became rust, it stays as rust, and maybe it is hard to turn it into metal. Why is that? In your opinion, why is it like that?

UF013 : In my opinion, because that new substance, the iron trioxide, is a stable chemical. More stable and it won't undergo oxidation anymore.

Besides the *stability factors*, in some cases, Model C students' prediction of the irreversibility of a chemical reaction was based on the *energy factors*.

I : Why is that when the carbon dioxide and H₂O are already formed, it is hard to form back to butane and oxygen?

UF013 : Because, the energy content for carbon dioxide and water is lower. If to go back to butane and oxygen, the activation energy becomes very high. Higher than that butane to carbon dioxide. To achieve activation energy, it needs higher energy.

I : It needs more energy then.

UF013 : And this energy ah ... the main function of butane is to produce fire that is hot. But if you want to make carbon dioxide to butane, the energy will be obtained from maybe butane or methane or others to produce energy that will be supplied to carbon dioxide to form back. So, ... it is just a waste of energy.

As in the other mental model types, Model C offered various reasons for the reversibility of chemical reactions. Although the basic assumption was that chemical reactions are commonly irreversible, half of students with this mental model considered that chemical reactions can be reversed *through a different sets of conditions*. A reversible reaction as described by students with Model C, particularly Subtype C3 involves two different chemical reaction systems one that produces the product, and the other that converts it back into the initial reactants.

I : Can you explain what do you see? Why is it like that? When it became yellow, it can turn back to orange again?

SS032 : Oh. Because NaOH has OH isn't it? So, when it is added, the dichromate ions turn into chromate ions.

I : That's why it turns into yellow?
 SS032 : Yes. It turns into yellow. But when HCl is added, it has H plus, and Cl negative. After that it will react with OH negative to form water. So, it turns back to dichromate ions.
 I : So, this is reversible reaction?
 SS032 : Yes.
 I : Why this reaction is reversible? To you, what factors make it reversible?
 SS032 : It depends on the reactant. When the reactant able to react with that compound, it will turn into product.

6.4.4 Representing Model C

Model C can be represented in diagrammatic form as shown in Figure 6.9 (page 262). This diagram shows the main features of the model derived from examination of its attributes. Model C established the notion of chemical reactions as *submicro changes* through the rearrangement of chemical components of the reacting substance(s), acknowledging that there are changes in chemical structures, chemical properties, and energy. Yet, Model C students were not necessarily successful when predicting conservation of mass. However, it also seemed that students with this mental model type had drawn upon the idea of kinetic theory of particles (which includes the ideas about activation energy, effective collision, and correct orientation) in the explanation of the process of reaction, and integrated this understanding well with chemical bonding. The notion of activated complex remained vague as illustrated by the faded box in Figure 6.9.

Most students in Model C related the change of energy to bond breaking and bond formation, but sometimes seem confused about the direction of energy transfer or lack of awareness that there is both energy absorption and release in any chemical reactions. As in the earlier mental models, students with Model C had not yet developed the notion of spontaneity. This mental model used the argument of agents in occurrences of chemical reactions, which usually includes energy and reactive substances. With this argument, the direction of chemical reactions depends on the availability of agents, and maintains that reversible reaction is due to 'reversing' agents. The idea of dispersion of energy and mass appeared not to be present even in Model C.

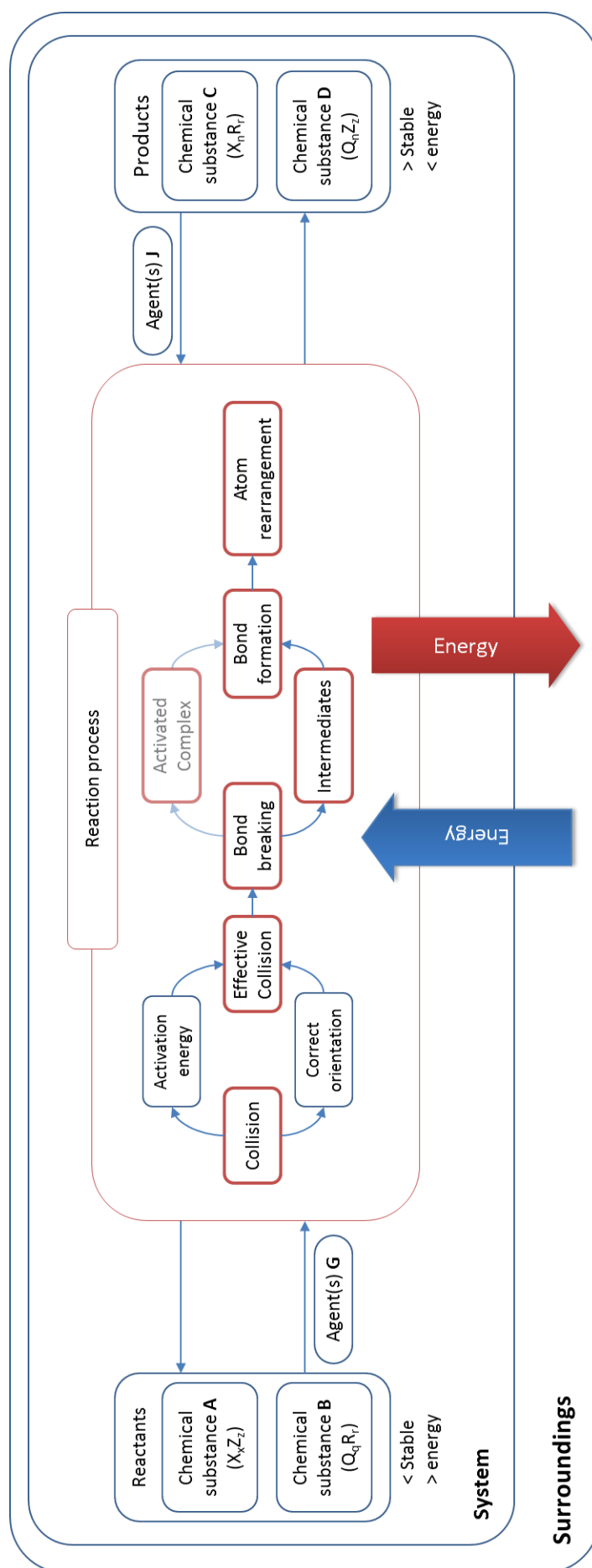


Figure 6.9 Model C of Chemical Reactions

6.5 Summary

Chapter 6 summarised the findings of this inquiry by presenting the three types of mental models of chemical reactions, namely Model A, Model B and Model C. Students classified as holding Model A, described chemical reactions as a process involving chemical substances and reacting agents including other chemical substances, energy, and surroundings. Such a reaction does not necessarily result in the formation of new chemical substances. This mental model did not draw upon chemical kinetics or chemical bonding. Commonly, students with this mental model failed to explain the energy change occurring in the chemical reactions, but rather described energy change as transformation of energy. Energy transfer here was based on the heat energy gain-loss idea, similar to the conduction of heat. Model A explanations of chemical spontaneity and reversibility had a basic assumption that a chemical reaction is a response towards reacting agents.

Students classified as holding Model B mental models held essentially similar ideas to Model A students, except that they described chemical reactions either as collisions of particles or rearrangements of atoms through the breaking and formation of chemical bonding. Finally, students classified as holding Model C held more advanced mental models. Here, chemical reactions were described in terms of particle collision and rearrangement of atoms in reactants, in formation of new arrangements of atoms in products. This process involves breaking and formation of chemical bonds, which is linked to energy transfer. In Model C, spontaneity and reversibility of reaction were influenced by stability, strength of chemical bonds, and also energy factors. Nevertheless, none of these mental model types expressed a fundamental scientific attribute of chemical reactions, which is the notion of entropy.

This chapter is followed with Chapter 7 that presents a comparison of students' mental models across levels of education.

Chapter 7 Students' Mental Models Across the Levels of Education

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This chapter addresses the third research question of the study, to do with a comparison of students' mental models according to their levels of education. It begins by analysing the distribution of each type of mental models in each educational level. This is followed by comparisons of students' mental models in each component of chemical reactions.

7.1 Types of Mental Model Across the Levels of Education

In this inquiry, it is of interest to explore differences in students' mental models based on their level of formal education, as captured in the following question,

RQ3: How do students' mental models of chemical reactions differ at different levels of education?

Figure 7.1 shows that there are differences between students' level of education and their mental models of chemical reactions. Generally, as students advanced their learning in chemistry, their mental models seem to become more advanced, complete and integrated. As might be expected, the more students are exposed to formal education in chemistry, the more their mental models become consistent with the scientific view.

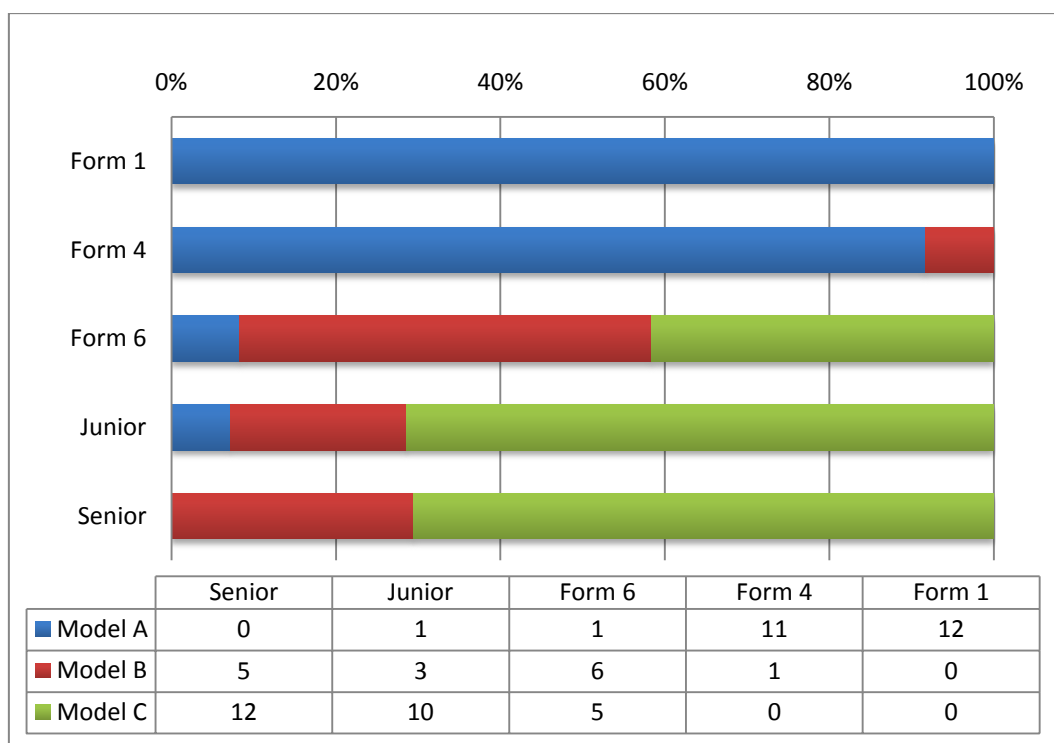


Figure 7.1 Proportion of Student for Each Type of Mental Models

As noted above, the school students in both Form 1 and Form 4 were more likely to hold a Model A, where there is a notable absence of the submicro level explanations of chemical reactions. None of these students' mental models was categorised into Model C. This result is not unexpected given the students' limited exposure to formal chemistry teaching, and it means that they are only able to describe the process of chemical reactions at the macro level. For Form 6 students, who had completed their secondary school chemistry, a little less than half (42%, $n=5$) of their mental models fell into the Model C category. Half of them were in category Model B, and able to apply their understanding of kinetic theory of particles and chemical bonding to explain chemical reactions, but only one of the theories was used at a time. They were not linked in explanations. On the other hand, most university students' mental models fell into the Model C category. At this stage, the proportion of junior and senior university students' mental models that were categorised as Model C were about the same, which is approximately 70%. However, a proportion of the university students' mental models were found to be Model B and a few Model A.

Table 7.1 shows categorisation of the actual students according to their levels of education and the types of mental models that been assigned to their expressed mental models.

Table 7.1 Categorisation of Students According to Types of Mental Models and Educational Level

Mental Model	Students				
	Form 1	Form 4	Form 6	Junior	Senior
A1	SO055	SF039, SF053			
A2	SO056	SF038, SF040, SF051			
A3	SO033, SO044, SO045, SO046, SO077	SF052, SF074, SF072, SF042, SF073	SS058	UO017	
A4	SO036, SO037, SO054, SO075	SF043			
A5	SO035				
B1		SF041	SS049, SS059, SS067, SS071		UF007, UF008, UF009, UF010, UF063
B2			SS057, SS068	UO023, UO065, UO070	
C1			SS030, SS032, SS047	UO025, UO028, UO069	UF013, UF014, UF015, UF062
C2				UO019, UO027, UO064	UF016
C3			SS031, SS048	UO021, UO024, UO026, UO029	UF011, UF012, UF018, UF020, UF022, UF061, UF060

To address the third research question further, each component of students' mental models of chemical reactions was compared in turn according to each level of education in the following sections.

7.2 Chemical Structure Characteristics Across the Levels of Education

7.2.1 Composition

When students described a chemical reaction, most of the attributes were present to some extent at all educational levels (Table 7.2). The notion that chemical reactions were considered to be an *expected natural occurrence*, was the least frequent among all students. On the other hand, the attribute *change*

of chemical substances was found mostly among Form 4 and Form 6 students, but even some of the university students were found to have this attribute in their mental models as well.

All of these three [rusting, ice melting and dissolution of sugar and salt] are chemical reactions. They are also changed. (SO046)

Also SS058, UO021, UF015

Table 7.2 Distribution of Attributes for Composition Component According to Level of Education

Attribute	Form 1 (n=12)		Form 4 (n=12)		Form 6 (n=12)		Junior (n=14)		Senior (n=17)		Total (n=67)	
	<i>F</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%
Expected natural occurrence ^a	0	0	3	25	1	8	0	0	1	6	5	7
Change of chemical substances ^a	1	8	5	42	4	33	2	14	2	12	14	21
Change in physical properties ^a	2	17	0	0	4	33	6	43	8	47	20	30
Response to reacting agents ^b	9	75	9	75	8	67	9	64	12	71	47	70
Formation of new substances ^b	1	8	4	33	6	50	12	86	14	82	37	55
Interaction between substances ^b	2	17	6	50	4	33	7	50	11	65	30	45
Submicro changes ^c	0	0	0	0	4	33	9	64	13	76	26	39

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

Chemical reactions were also characterised by change in physical appearance (especially colour) or physical state by almost all students from the different levels of education. However, only Form 6 and university students were found to relate change of physical properties with chemical changes.

We know it is a chemical reaction when there is change in colour. We look at its colour change. Like the metal, we know it was silvery and after it is corroded, the colour changed to orange. One of the elements in the metal has been reduced. (UF060)

Also SS047, SO075

This is a chemical change (chemical reaction) because lead nitrate and KI, potassium iodide both are clear (according to the video), clear solution. After the reaction, if this is a reaction, it forms lead iodide, which is a solid. So it changes the state from ion to solid. (UO064)

The most interesting finding here was that the attribute that considers that chemical reactions as a *response to reacting agents* was found held by almost all students from all educational levels (see Table 7.2). This finding is consistent

with its presence in all of the types of mental models. Nevertheless, there were slight differences between Form 1 and Form 4 students on this attribute compared to Form 6 and the university students. The lower secondary schools students' mental models seemed to be limited. In that, they viewed chemical reactions as simply a response of chemical substances towards reacting agents with the result they undergo some sort of change of physical properties – a macro level of explanation. Conversely, Form 6 and university students were able to describe the responses of the chemical substances toward the reacting agents in terms of molecules and ions – a submicro level of explanation.

[The iron is rusting.] [It is] caused by acid rain. There is something causes it to happen. Chemical reaction is something that makes something change. It involves process depends on the changes. (SF040)

Also SO045, SF039, SO037

The ice turns into water because of heat. The heat causes the molecules to change into water. (SS059)

This is an auto-oxidation, as long [as the iron] is exposed to air which contain water vapour and oxygen gas, it undergoes an oxidation process whereby Fe atom will become Fe three plus. (UO064)

Also UF007, UF010

The attribute *interaction between substances* can be considered a common view mainly among Form 6 and university students. For about half of the secondary school students, chemical reactions were thought to involve interaction between more than one chemical substance or heat energy.

Iron rusting is a reaction between oxygen with iron. Oxidised. It is between a chemical with [another] chemical. Like just now, between oxygen and iron. Normally to me, there were two like metal with something else. There is something reacting with something else. Not necessarily with something else. Maybe heat. (SF041)

Also SF040, SO033

To my opinion, [the rusting] happen because of redox reaction. The metal reacted with water and oxygen. So, when these three components are present; the metal, water, and oxygen. So the reaction that is called redox reaction that have happened and causing it to rust. (UO023)

Also UF009

Mostly among the more senior students, Form 6 and the university students, the attribute of *interaction between substances* was extended to the attribute of *formation of new substances*, which relates the previous attributes to production of new chemical substances.

When lead nitrate is mixed with potassium iodide, it produces something, some liquid. (SF038)

Also SF041

There are two reactants. Like in this metal corrosion, it has other reactants like oxygen and water. That's chemical reaction. There is product from the chemical reaction. New substances produced. (SS032)

Chemical reaction is something like, A plus B, and produces something new. So, the rust is the new product, from the reaction between metal, water and oxygen. (UO023)

Also UO017

The only attribute that was exclusive to Form 6 and most of the university students, was the recognition of *submicro changes* in chemical reactions. With this attribute, chemical reactions were described at the submicro level, with mention of the breaking and formation of chemical bonds, transfer of electrons, change in oxidation states, change in atomic constituents of chemical substances, and formation of other chemical species.

This is an auto-oxidation. As long [as the iron] is exposed to the air which contain water vapour and oxygen gas, it undergoes oxidation process whereby Fe atom will become Fe three plus. (UO064)

Also UO027, SS031

When chemical reactions happen, the composition in the molecule changes in terms of its chemistry. It reacts with other substance, and it will form new products. The previous composition is still there, but it has combined with other chemical to form new products. But, non-chemical reaction, the same molecule is maintained; the composition is still the same. (UF016)

Metal corrosion. Basically, a redox reaction happened here. It Involves oxidation and the reduction processes. ... There are transfers of electrons. For example for this picture [dissolution of salt and sugar in water], the third one, there were bonds formed, and bonds are broken at the same time, therefore, heat is released and also absorbed. So, it is also considered as a chemical reaction. (UF062)

Also UF022

Attributes of the composition component that were evident in students' expressed mental models at secondary school level seemed to be retained up to the university level, despite their exposure to advanced chemistry teaching. The most prevalent of these 'long-life' attributes is the *response to reacting agents*, which can be found in all students' mental models at all educational levels, and also in all types of mental models. The only additional attribute for the composition component that emerged from the students at higher levels of education was the *submicro changes*, and then only among those classified as Model C.

7.2.2 Conservation of Mass

About 20-30% (Table 7.3) of students from all levels of education seemed to rely on macro attributes when talking about conservation of mass – considering that change of mass as *depending on the physical states* of reactants and products – a mass-density confusion.

Table 7.3 Distribution of Attributes for Conservation of Mass Component According to Level of Education

Attribute	Form 1 (n=12)		Form 4 (n=12)		Form 6 (n=12)		Junior (n=14)		Senior (n=17)		Total (n=67)	
	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%
Dependent on the physical state ^a	4	33	2	17	4	33	3	21	5	29	18	27
More substances formed ^a	4	33	5	42	3	25	3	21	2	12	17	25
Gas properties ^a	0	0	4	33	4	33	4	29	3	18	15	22
Closed system ^b	2	17	3	25	7	58	8	57	12	71	32	48
Rearrangement of atoms ^c	0	0	0	0	1	8	2	14	6	35	9	13

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

These students thought that the mass reduces in the zinc-acid reaction because gas was assumed to be lighter than solid and liquid, and mass increases in the lead iodide precipitation because the solid precipitate was considered to be heavier than its liquid form prior to the reaction.

The mass will change because the zinc has been dissolved. That's what makes it change. I think because something in the form of liquid is lighter.
(SF040)

I still think the mass decreases [zinc-acid reaction]. Because the mass of the gas is lower than the mass of the liquid. Like this, [reaction between zinc and hydrochloric acid, it] changes into hydrogen gas, so the mass decrease.

(SS049)

Also SO076, UO025

[The mass] increases because precipitation is formed [in the lead iodide precipitation]. The precipitation is solid. So, solid's [mass] is more than the liquid.

(UF011)

Similarly, about 20-30% of students from all education levels (except Form 1) were found to believe that gas cannot be weighed since the gas was thought not to be resting on the weighing scale.

I think it changes [zinc-acid reaction]. Since, it releases gas, the hydrogen, it becomes lighter. The gas causes the mass decrease. Gas also has mass isn't it. When the hydrogen gas released, so the weight become lesser. Because [the hydrogen gas] is up there [on top part of the conical flask]. This is the only thing [the remaining solution] that can be weighed. That's why it's lesser.

(SF041)

Also SS047, UO069

I think it [zinc-acid reaction] will slightly different. The gas is released, and the substance inside the conical flask is decreasing. Then you need to measure the [mass of the] gas. Gas is quite light and the instrument is not so sensitive.

(UF061)

The mass will change. Because the zinc is heavier. And the gas will not influence the mass of the conical flask. The hydrogen gas is lighter. The mass of gas, it is harder to measure with the balance.

(UF013)

The attribute that considers an increase of mass in chemical reactions is due to the formation of more substances was found to be held commonly by Form 1 and Form 4 students (up to 40%).

It is caused from the mixing the new liquid, the new chemical. So, when mixing the new chemical, it can be said that it becomes more. Before that, the yellow thing was not there. After that, there is the new thing. Therefore, its weight increase.

(SO037)

Also SO054, SF038, SF074, SS058, UO065

[The mass] becomes more. Become heavier. Because initially it has one substance only, the lead. But when it is mixed with potassium iodide, it is like two substances. So, it will become heavier in terms of its mass. Because of the two different chemicals. The one we produced causes it to be heavier. (UF018)

On the other hand, students mostly from the higher education level (about 60-70% of the Form 6 and the university students) were found to believe that mass remained constant due to the condition of the reaction, that is a *closed system* prevents transfer of mass.

I think it [the mass in zinc-acid reaction] is the same. My opinion is that everything has mass. Although they have different masses, after being in the container, the mass will be the same. ... Because the air just goes up, and it does not become more. There is nothing that can come in or goes out.

(SF039)

Also SO045

In my opinion, the mass [lead iodide and potassium nitrate] remains the same because it is a closed system. From on the equation, there is no change in terms of addition from outside. Lead iodide is formed from the reaction between lead nitrate and potassium iodide. The weight is the same because when the reaction happens, this one reduces and this one increases.

(UO023)

Also SS030, UF015

Only those students at the higher level of education were found to use the idea that mass is conserved in chemical reactions because the number of atoms making up the chemical substances remained the same but not the atom arrangement.

[The mass is still the same] because of the elemental content is still the same. For example, in lead nitrate, its nitrate, it will use two nitrate ions, there are still have two nitrate ions. So, its mass is not changed, for the nitrate. Also with lead, lead before the reaction, it has one mole of lead, but after the reaction, it will not increase also. It exists in one mole of lead. The same with iodide, for iodide before the reaction, it has two moles of iodide ion, after the reaction, the iodide still two moles.

(UF013)

Also UF016, UO024

7.3 Chemical Kinetic Characteristics Across the Levels of Education

7.3.1 Particle Collision

A clear distinction between educational levels can be observed in terms of the particle collision component (Table 7.4). Most Form 4 students described chemical reactions in a similar way by talking about how particle arrangements change (*internal arrangement* attribute) when there are changes of physical state, where chemical reactions were described in terms of changes in physical states.

The particles will become gas. When it is mixed [zinc and acid], it becomes active and flies here and there. It will move randomly and gather energy to become gas.
(SF038)

Also SF040, SF053, SF073

I think the particles move faster. Because the state is changing from solid [zinc] to gas, so I think the particle move more randomly. So, that's why we can see, kind of full of bubble, producing hydrogen gas. I think the movement become rapid, causing it change the state, to gas and liquid.

(SF052)

Table 7.4 Distribution of Attributes for Particle Collision Component According to Level of Education

Attribute	Form 1 (n=12)		Form 4 (n=12)		Form 6 (n=12)		Junior (n=14)		Senior (n=17)		Total (n=67)	
	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%
Internal arrangement ^a	0	0	8	67	1	8	0	0	0	0	9	13
Movement of particles ^b	0	0	6	50	6	50	9	64	10	59	31	46
Collisions of particles ^c	0	0	0	0	7	58	13	93	12	71	32	48
Site of reactions ^c	0	0	0	0	0	0	2	14	3	18	5	7
Probability for reactions ^c	0	0	0	0	0	0	1	7	5	29	6	9

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

About half of students in Form 4, Form 6, and university level described the effects of heating on chemical reactions based on *movement of particles*. To these students, movement of particles became faster at a higher temperature that would increase the rate of the process. None of the Form 1 students indicated that they had this attribute relating to particle movements.

I think the [reaction of zinc and hydrochloric acid] higher the temperature, the rapid the movement become. I think because it is moving faster due to the temperature when we heat it up. The particles vibrate faster. And [then the] particles move even further. I think so, because it produces more hydrogen gas and zinc chloride. (SF052)

Also SS071, UO023,

The heat will make the reaction process between the zinc and hydrochloric faster. With less heat, the reaction of zinc is less. But with the help of heat, it will help the molecule to move faster to combine with the chloride. It will attract faster. It helps in the process of disengagement of the molecules. And then the heat is used for it to move faster. (UF018)

Only students from the higher levels of education (more than 70%) were found to relate the *movement of particles* with the *collisions of particles* when determining the rate reaction. Form 1 and Form 4 students did not have this key attribute of chemical reactions in their mental models.

Zinc will in contact with HCl. Since HCl particles moving around in water, it will collide with zinc. The reaction occurs on the surface of the zinc. When there is enough energy, collide to each other, with a correct orientation, the reaction will occur. When they collide, the bond in HCl will break. What's important is collision. There is collision, and also enough energy to break the bond. The reactants become lesser. When the reactants are less, the frequency of collision between reactants also decreases. So, the reaction also [become] less. (SS032)

Also SS030, UO023, UO028, UF011, UF016

Only some of the university students were able to provide more detailed explanations involving collisions of particles. They detailed that it was not just collisions that will result in chemical reactions, but *probability of reactions*.

For example there are twenty four atoms. First, it is fast because of high probability for the reaction to occur. So, after a period of time, there are more and more atom been used. Is like, more [people] get married and the lesser single [people]. So the probability becomes lower, so the rate [of reaction] becomes lower. (UF014)

Also UO069, UF015, UF061

They also indicated that *probability of reactions* depends on the *site of reactions* with a greater surface area providing a greater chance of reaction.

The surfaces where they are contacting become lesser when the substances become lesser. When the surface of area is bigger, the correct orientation of collisions between ions is easier. (UF020)

Also UF014

In short, Form 4 and some of the Form 6 students' mental models of chemical reactions were based on change in *internal arrangement*, similar to the idea of physical change of matter. In addition, Form 1 students were found not to have the notion of particle movement in their description about chemical reactions. Only students from Form 6 and the university students were able to express their mental models of chemical reactions using collisions of particles together with the idea of atom rearrangement and bond breaking-formation – a feature evident among students with Model C.

7.3.2 Reaction Mechanism

An interesting pattern evident in Table 7.5, was that possession of the attribute *quantity dependent* occurred for most students at all levels of education, and in all types of mental models. This attribute was used to describe the rate of reaction as chemical reactions progress, with a thought that reactions slow down when the amount of the reacting chemical substances reduces. This finding can be considered as a form of students' intuitive knowledge (or their practical model) in predicting or explaining rate of reaction.

You have this amount of reactant; you can produce a certain amount of product. So, the lesser you have, the less product you can get. So, as far I concern, mathematically saying, it's slower. Let say the time is equal to zero within this period, you have a larger amount of reactant. As time go by, let say, six to seven [second], between this period maybe most of the reactant gone right [changed into products]. Let say it less than forty percent left, so you have lesser product being formed. (UO069)

Also SO033, SF042, SF051, SS031, UF011, UF012

Table 7.5 Distribution of Attributes for Reaction Mechanism Component According to Level of Education

Attribute	Form 1 (n=12)		Form 4 (n=12)		Form 6 (n=12)		Junior (n=14)		Senior (n=17)		Total (n=67)	
	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%
Transmutation ^a	1	8	0	0	0	0	0	0	0	0	1	1
Quantity dependent ^b	5	42	11	92	11	92	12	86	13	76	52	78
Octet approach ^b	0	0	0	0	0	0	1	7	2	12	3	4
Atoms rearrangement ^c	0	0	2	17	7	58	9	64	12	71	30	45
Bond breaking-formation ^c	0	0	0	0	5	42	7	50	12	71	24	36
Transfer of electrons ^c	0	0	0	0	5	42	6	43	8	47	19	28
Redox ^c	0	0	0	0	3	25	1	7	2	12	5	7
Attraction between charges ^c	0	0	1	8	2	17	3	21	4	24	10	15
Intermediate ^c	0	0	0	0	4	33	2	14	6	35	12	18
Mechanistic approach ^c	0	0	0	0	0	0	2	14	6	35	8	12

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

Table 7.5 shows that most of the Form 1 and Form 4 students were unable to explain how chemical reactions happen at the submicro level. However, there was one student (Form 1) who stated explicitly that the combustion reaction was a process of *transmutation* (see SO033 in page 192). Two Form 4 students and about 60-70% of students from the higher levels of education, and none of Form 1 students, were found to have expressed the *atom rearrangement* attribute, which explained that atoms in the reactants were rearranged to form the products.

The butane has carbon and hydrogen. So, the carbon will combine with oxygen to form carbon dioxide and H will mix with oxygen to form water.

(SF043)

Also UF008

When the zinc dissolve into the mixture, and the zinc becomes zinc ions, then the zinc ions will attack the hydrochloric acid and form with the chloride ion inside the hydrochloric acid and become the zinc chloride. And then, the hydrogen inside the hydrochloric acid will like kick out and joint with the other with another hydrogen ion to form hydrogen gas.

(SS047)

Also UO023, UF018

Other attributes for this component were also found to be exclusive to students in the higher level of education. The most significant of all these attributes was the *bond breaking-formation* attribute, which was consistent with the *atoms rearrangement* attribute, and evidence of the particulate idea of chemical reactions. Some 42% of Form 6 students, 50% of the junior university students and 71% of the senior university students exhibited this attribute.

When they collide, the bond in HCl will break. After that it reacts with zinc. Zinc and Cl will form new bond. H with other H since it needs to be H two. Yes. There is bond breaking and then bond formation. (SS032)

Also UO028, UF008

There is bond breaking. And then, for the reaction to form CO₂, bond is broken and new bonding will be formed. This will break first [butane molecule], this H is left. CO₂ and then, oxygen is in excess. It got to be in excess so that it provide enough oxygen for the C and also H. It [oxygen] will break first, so H will take two oxygen. And then, C will also take two oxygen. (UF014)

Also SS030, UO026

Similarly, about 40-50% students from Form 6 and university described chemical reactions as something that involves of transfer of electrons.

Zinc solid become zinc two plus aqueous, plus two electrons. Then H, the real one that is happening here is H plus aqueous, plus two electrons, to form H₂ gas. Two electrons, two H plus, so this is, this is the oxidation process. (UO064)

Also SS047, SS047, UF062

About 10-35% of students from the higher level of education went further by explaining the process of chemical reactions in terms of *redox* (change of oxidation state), *attraction between charges*, formation of *intermediates*, and a *mechanistic approach* to chemical reactions. In short, what these observations indicate is that most secondary school students have not developed attributes related to a particulate view of chemical reactions.

7.3.3 Barrier to Reaction and Activated Complex

Similar to the particle collision and reaction mechanism, only higher level education students' mental models (but limited to those with Model C) were

found to have the attribute of activation energy in chemical reactions (Table 7.6). Interestingly, two attributes were shared across educational levels and even all types of mental models.

Table 7.6 Distribution of Attributes for Barrier to Reaction Component According to Level of Education

Attribute	Form 1 (n=12)		Form 4 (n=12)		Form 6 (n=12)		Junior (n=14)		Senior (n=17)		Total (n=67)	
	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%
Energy initiates reactions ^a	6	50	10	83	11	92	5	36	9	53	41	61
To lower the activation energy ^b	0	0	0	0	0	0	1	7	2	12	2	3
Energy as catalyst ^b	0	0	0	0	2	17	2	14	2	12	6	9
Energy as a part of reactions ^b	5	42	5	42	1	8	3	21	3	18	17	25
Activation energy ^c	0	0	0	0	2	17	7	50	7	41	16	24
Metastable species ^c	0	0	0	0	0	0	0	0	1	6	1	1

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

The first of these common attributes was the idea that energy is required to initiate the reaction and the most common attribute across almost all students (30% up to 90%). This finding was consistent with the attribute *responses to reacting agents*, where students specifically viewed heat energy as an agent of chemical reactions.

May be the heat will alter some of the molecules [butane], and make it regenerate and the reaction start over faster. (SO033)

The spark starts the reaction between the gas and oxygen. It provides heat. Heating starts the reaction. With the spark, the heat makes the reaction happened, these two, oxygen and butane. (SF041)

Also SS049

Secondly, students from all levels of education (but more frequently among Form 1 and Form 4 students) shared the attribute that heat energy is one of the components of chemical reactions.

You need the substances; the oxygen, and one more. I forgot the last one [laugh]. Then only the burning process can be sustained. Actually the first, the first part is still a burning, but due to the lack of substance or something. [Maybe] the lack of butane, add to the burning, because it cannot sustain the triangle [of burning]. We need oxygen, you need the burning substance, the fuel and the ignition. (UF061)

Also SO033, SF053, SS047, UO023

This finding indicates the students thought that chemical reactions will only 'start' and progress once the barrier is overcome, but the rate of reaction is not related to the activation energy or collisions of particles.

Only about 40-50% of university students and 20% of Form 6 students stated that, in order for chemical reactions to happen, activation energy needs to be achieved. The notion of activation energy in chemical reactions usually emerged when heating was involved.

When it [zinc-acid reaction] is heated, more molecules will gain energy that achieves the minimum energy, the activation energy, that initiate the reaction. When the kinetic energy is higher, the faster it achieves the activation energy, so it is for the reaction to occur. (UO028)

For butane and oxygen to react, they also need to overcome activation energy and they need something to start the reaction. That's why when we only release the gas, even though the oxygen gas is surrounding the environment, there is nothing to like some on and react. They need something make them react. So, that's the purpose of the spark. You need the spark, the reaction then start. They need to overcome the activation energy. (UO064)

Also SS030, UF008

However, students' views about activation energy varied. Some of the university students perceived activation energy as literally a barrier to reaction. In other word, students thought that the activation energy can be manipulated or lowered by the heat energy which is thought to be a catalyst.

When there is spark, the catalyst, the activation energy become lower and makes it burning. ... It is because there is a catalyst, so the activation energy is lowered down. So the reaction [combustion] becomes faster. (UO021)

Also UF014

The heat is like a catalyst. It speeds up the dissolution of zinc in the HCl. It makes the reaction faster. To my understanding, the catalyst makes the reaction become faster because it is something like giving the energy. ... The spark is the catalyst of the flames. I think when the spark is not present, there no catalyst yet, the activation energy is high. That's why it is hard to burn. But when the catalyst exist, the [butane gas] burns. (UO021)

Also UO065

In terms of the formation of an activated complex, only one out of all the participants mentioned clearly that in chemical reactions, prior to the formation of products, reactants combined to form an unstable chemical species.

Butane and oxygen in the reaction will temporary combine first and later on they will break to form the carbon dioxide and water. (UF016)

Overall, students viewed energy as required to initiate chemical reactions, but for secondary school students in Form 1 and Form 4 the energy is considered part of the chemical reactions or one of its reactants necessary for the reactions to happen. In contrast, students from the higher levels of education (Form 6 and university students) assumed that energy was required to overcome an energy barrier. This required energy was, which is the activation energy.

7.4 Chemical Energy Characteristics Across the Levels of Education

7.4.1 Conservation of Energy

For the component conservation of energy in chemical reactions, only some of the university students hold the attribute of *net energy transfer*, and only those classified with possession of Model C (Table 7.7).

Table 7.7 Distribution of Attributes for Conservation of Energy Component According to Level of Education

Attribute	Form 1 (n=12)		Form 4 (n=12)		Form 6 (n=12)		Junior (n=14)		Senior (n=17)		Total (n=67)	
	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%
Heat gain and loss ^a	6	50	9	75	6	50	7	50	4	24	32	48
Change in form of energy ^a	3	25	7	58	5	42	4	29	7	41	26	39
Energy content ^b	5	42	7	58	1	8	3	21	11	65	27	40
Net energy transfers ^c	0	0	0	0	2	17	5	36	4	24	11	16

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

The *heat gain and loss* attribute was found to be held at all levels but mostly by Form 4 students (75%) and least among senior university students (24%). Exothermic reaction was explained as hot because it absorbed or gained heat from the surroundings, while, endothermic reaction was commonly explained as cold because it loses its heat energy – even by some students at higher education levels.

When you heat a substance, and leave it at room temperature, the surroundings will become hotter. The heat is absorbed to surroundings.
(SO033)

Reactions [combustion] normally absorb heat. So, when heat is absorbed, the thing will be hot as well.
(SF038)

It [the heat in the reaction of barium hydroxide octahydrate and ammonium thiocyanate] releases heat to the surroundings. But the one inside, it involves of particles, the one inside there, loses heat energy. The outer part receives energy.
(UF012)

Also SF051, SF052, SS059, SS071, UO065

Another common attribute of students' mental models was the *change of forms of energy*. Form 1 students considered that heat energy was changed from friction that occurred in the gas lighter. Similarly, Form 4 students considered heat energy was formed when particles 'grazed' each other. On the other hand, students from higher education levels described the change of energy occurring was kinetic energy transforms into heat energy.

Maybe its particles move very fast, after that it produces heat energy. The butane's particles will move very fast, and combine with the heat and oxygen, too fast, producing heat. And the butane, if it combines with the three things [heat and oxygen], the particles move very fast, grazing each other, it will produce heat and light, the spark. So, the flame is produced.

(SF053)

Also SO076, SO056, UO027, UF012

Energy change: chemical energy [changes to] to heat energy and light energy. Chemical energy form butane and oxygen, after that the fire is formed, there is light energy and we feel hot because of there is heat energy.

(UF010)

Also SS059

Energy change in chemical reactions was also described as the energy that is contained in the reacting substances (*energy content* attribute). This attribute was held by about half of Form 1, 4, and senior university students, but less popular among Form 6 and junior university students. For most students, the combustion of butane was linked with the release of energy contained in it when it burned.

What inside it is fuel that a substance that causes the reaction and produces heat.

(SO045)

Also SF073, SF074, UF010

Because when it's solid form, it's like certain temperature trap inside the solid. And when become liquid, it releases the [temperature].

(SS071)

Similarly, for endothermic reaction, the drop of temperature was related to the drop of energy content of the reacting chemical substances.

I feels, if the reaction [barium hydroxide octahydrate and ammonium thiocyanate] is endothermic, the product of the reaction will drops [in terms of energy] because the temperature goes down. The temperature goes down and its energy goes down because it is an endothermic reaction. Endothermic, its energy goes down.

UF007

Also UO064

Only a small proportion of students from Form 6 and the university (not more than 40%) perceived that change of energy in chemical reactions is due to a *net energy transfer*. This finding indicated that only certain students understand the

change of energy in chemical reactions is due to both absorption and release of energy, which is manifested as change of temperature.

[In combustion] A higher released energy minus with a lower absorbed energy, so it result a negative value, so we say this is an exothermic reaction. To my point of view, [butane] undergoes homolytic fission, [and this] absorbs energy. Then, one of [carbon and hydrogen atom] start to form the CO two and also H two O; heat energy is then released to the surroundings. ... [In reaction of barium hydroxide octahydrate and ammonium thiocyanate] When the aqua [is broken off], they [the hydrated barium hydroxide] take in energy. But then after the reaction, since they form a much stable, the energy that they absorb already is release again.

(UO064)

Also SS030, UF016

7.4.2 Energy Change

Students' mental models of chemical reactions related to energy have also been examined to see how they explained the change of energy that happens in chemical reactions. Table 7.8 shows that a small proportion of students (less than 20% from each level of education) explained energy change in chemical reactions as *change of physical state* by relating the drop in temperature of the barium hydroxide octahydrate and ammonium thiocyanate reaction to the similar drop of temperature that happens to ice when it experiences change of physical state.

It liquefies the solid into liquid. Since the change is from solid to liquid, it needs heat energy. Because the energy already has been used to form the liquid.

(SF043)

Also SO055, SF039, SS071

[Reaction of barium hydroxide octahydrate and ammonium thiocyanate is] like the ice, it needs energy to hold the molecule so that they are arranged properly. So, when it changes, energy from outside [is needed] to make the particles to move freely inside the solid.

(UO024)

Table 7.8 Distribution of Attributes for Change of Energy Component According to Level of Education

Attribute	Form 1 (n=12)		Form 4 (n=12)		Form 6 (n=12)		Junior (n=14)		Senior (n=17)		Total (n=67)	
	f	%	f	%	f	%	f	%	f	%	f	%
Change of physical state ^a	2	17	3	25	1	8	1	7	1	6	8	12
Heat as a reactant or product ^a	4	33	3	25	2	17	4	29	6	35	19	28
Energy transfer ^b	1	8	2	17	6	50	11	79	14	82	34	51
Reverse energy transfer ^b	0	0	0	0	3	25	3	21	6	35	12	18
Enthalpy of formation comparison ^c	0	0	0	0	3	25	2	14	4	24	9	13
Energy transfer in chemical bonding ^c	0	0	0	0	4	33	5	36	6	35	15	22

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

About 20-35% of students from each level of education considered heat as a reactant or a product, which heat energy assumed as a reactant that consumed or 'used up' or as a product that produced, in the reaction.

The [combustion] reaction produces the heat. Before the reaction, the energy of the reactants is lesser. In the reaction process, the [exothermic] reaction, during the product is produced; it also produces a lot of energy. That's why it is hot. ... [In the reaction of barium hydroxide octahydrate and ammonium thiocyanate is] The energy is disappeared, used up to separate them. When the reaction happens, they combined to form new products. The energy is already lessened because a lot of it been used. A lot of energy disappeared.

(U0019)

Also SF053

Butane is considered as the fuel. The oxygen is needed for the fire to be form based on that triangle [of combustion]. When these three are present, then the fire will be formed. ... Heat formed from the combination of the fuel and oxygen and fire will be produced. [And] this [endothermic reaction], it absorbed the heat and after that combines with other substances.

(UF010)

Also SO033, SF041, SS031, SS032

However, a substantial number of students from the higher levels of education recognised that energy change in chemical reactions occurs through transfer(s) of energy. Some 50% of Form 6 and about 80% of the university students indicated that energy is either absorbed or released in chemical reactions as an *energy transfer*.

We say that burning of butane is exothermic. So, it releases heat. Like this butane and oxygen, when it is burning, from the combustion, it releases heat in the fire. That's why we feel it hot. The heat energy is not been formed but it is released. ... [In the reaction of barium hydroxide octahydrate and ammonium thiocyanate] The energy from outside is used to make the reaction between the reactants to happen. That's why the temperature goes down. It [heat energy] is absorbed so that the reactant will reach the activation energy. (UO023)

Also SS031, UF007, UF016

Some students explained energy transfers in chemical reactions through a comparison of the energy required to form the reactants and products – *energy of formation comparison*. Energy was considered to be released when the energy required to form the product(s) is less than the reactants, resulting an excess of energy, which then released to the surroundings in an exothermic reaction. In endothermic reactions, the energy needed to form the products is much higher than that required for the reactants to be formed; therefore, the extra energy required is absorbed from the surroundings resulting in drop of temperature.

Two C four H two, plus thirteen O two, gas, eight CO two, gas, plus ten H two O, gas. In chemistry, all these have its own, what we call energy contain. For example, C four H ten, to form the basic component of carbon and hydrogen, (forming these things), it requires a certain amount of energy. So, the energy of the process for making it [butane], is the energy it has. For example, we put it as A [see Figure 7.2]. Now, oxygen itself is formed from two oxygen, energy B. Then, the carbon, and oxygen, two oxygen, we have energy C. We have hydrogen two, one oxygen, let's say the energy used is D. As I say just now, B is insignificant right, let calculate the enthalpy change or the change in heat. It would be C plus D, minus A, since B is insignificant, so the amount heat here, let say it's negative, would mean that, there is extra energy, meaning to say that A is bigger than C plus D. So, energy is released. (UO069)

Also SS032, UF013, UF014

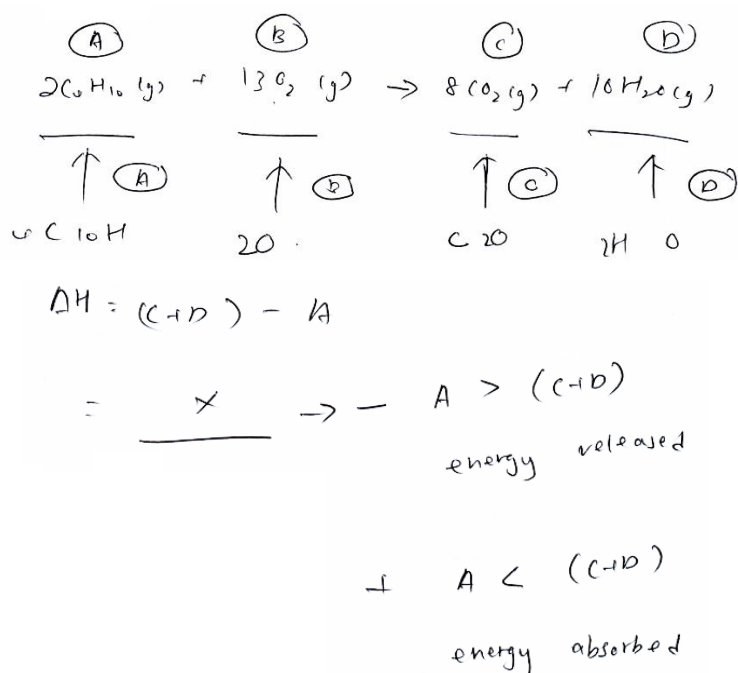


Figure 7.2 Drawing by Student UO069, Illustrating the Comparison of Energy Formation in Combustion of Butane

Less than 40% of students from higher levels of education and none of the secondary school students were found to relate energy change with *energy transfer in chemical bonding*, where energy is considered absorbed in the chemical reactions involving bond breaking and followed by release of energy in bond formation.

In my point of view is, [butane] undergoes homolytic fission, absorb energy and they break. Once the process of breaking, one of them start to form the CO two or H two O, heat energy is released, and the, I mean energy is release, we don't say heat, energy is released to surroundings, so this energy itself act as the resource of the energy for the C four H ten, I mean C atom and H atom in the molecule to start the reaction. (UO064)

Also SS047, UF014

Nevertheless, some of the students from higher levels of education considered that the reverse was true, that is energy was considered to be released in bond breaking and absorbed in bond formation.

The ammonium is positive twenty five and when it is added [with barium hydroxide], it will be reduced. When the barium hydroxide wants to bond with ammonium thiocyanate, it needs energy. The energy is absorbed from the surroundings to form the bond. So, that's why the temperature is negative.

(UF015)

Also SS032

In brief, most secondary school students were found to be unable to provide a scientific explanation of energy change for both exothermic and endothermic reactions. Some of them (along with a small proportion of students from the other levels of education) indicated that energy is treated as a part of chemical reactions, either as a reactant or a product. Most students in the higher levels of education were found to think that energy is being transferred in chemical reactions but only a small proportion of them related this transfer with chemical bonding.

7.4.3 Spontaneity

From Table 7.9, it can be seen that no student across all educational levels (and types of mental models) could employ the idea of entropy when describing or explaining the spontaneity of chemical reactions, even senior students who have been taught these concepts formally at university. A common attribute of students' mental models of chemical reactions for the spontaneity component especially among the Form 4 students, was the *presence of reactants*. Students considered that chemical reactions continue to happen because of the availability of the reactants. In explaining combustion, students considered that it continues burning because the butane gas was released continuously and there were unlimited supplies of oxygen.

Because the [butane] gas is continuously [released]. When the fire is inflaming, it will keep on released out. It will be kept opened. Like this lighter, it has something that keep on releasing the gas out. So, it keeps on [burning].

(SO055)

Also SF038, SF040, SS049, UO069, UF060

Table 7.9 Distribution of Attributes for Spontaneity Component According to Level of Education

Attribute	Form 1 (n=12)		Form 4 (n=12)		Form 6 (n=12)		Junior (n=14)		Senior (n=17)		Total (n=67)	
	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%
Nature of the reactant ^a	1	8	0	0	1	8	1	7	3	18	6	9
Presence of reactants ^b	2	17	5	42	4	33	2	14	4	24	16	24
Reacting agents ^b	0	0	4	33	1	8	4	29	5	29	14	21
Reactive agents ^c	0	0	0	0	1	8	4	29	11	65	16	24
Stability driven ^c	0	0	0	0	2	17	3	21	7	41	12	18
Electrostatic charges ^c	0	0	0	0	1	8	0	0	2	12	3	4
Electronegativity differences ^c	0	0	0	0	1	8	1	7	0	0	2	3
Energy driven ^c	0	0	0	0	1	8	1	7	2	12	4	6

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

A small proportion of students' mental models (10-30%) from Form 4 to university level were found to attribute *reacting agents* as the driving force for chemical reactions. With this attribute, chemical reactions are consistently regarded as caused by agents of reaction, which are responsible for initiating the chemical reactions. This finding is similar to the idea that chemical reactions are considered to be a process of responses towards reacting agents (see section 7.2.1 on page 267).

When the burning started, it will produce heat and provided to the butane to be able to react again and again. I mean is continuous. It supplies the heat to its own molecule. So the important things, it need spark first, then start the combustions and the combustion will continue their own heat to the butane ... react the with oxygen to form the carbon dioxide. (SS047)

Also SF041

Why reaction happens? ... Certain reactants cause the chemical reaction to happen until the products if formed. (UO027)

The surface of the iron is exposed to the surroundings like rain, water, and the surroundings, that's what causes the iron rust. The element in the iron metal reacts with the element in the water and oxygen. The oxygen make the iron undergoes reduction. (UF007)

A large proportion of students from the university level (29% junior students and 65% senior students) indicated that their attribute for the spontaneity

component was the *reactive agents*. None of the secondary schools students had this attribute. This notion is similar to the *reacting agents* but rather more specific in that chemical reactions occur because one of the reactants is considered to be more reactive.

The reactant is more reactive, turning into something not reactive, in a stable form. (SS032)

Zinc is the metal. And then hydrochloric is a form of strong acid. And when the metal react with the strong acid, the strong acid have a strong oxidising power, corrodes the metal and then produce the hydrogen gas. (UO026)

Zinc is basically quite a reactive metal. So, when it is in contact with an acid, definitely it will react vigorously. As you can see the reaction occurs just now, there's bubble. There is the hydrogen [gas formed]. (UF062)

Also UF061

It [is something about] reactivity. Maybe the barium has higher reactivity, it will take the thiocyanate. (UF011)

About 40% of senior university students and 20% of Form 6 and junior university students attributed chemical reactions to be *stability driven* where reactants undergo chemical reactions to achieve chemical stability. Similar to the previous attribute, none of the secondary schools students was found to have this attribute.

The zinc will discard its electron so that it is more stable. Cl will need one electron for it to be stable. For zinc and chloride to be stable, both them will combine. There are two of chloride atoms that combine with zinc. They will form zinc chloride. The H, it only needs one electron. So, H and H need one and one, so they will combine, so that they are more stable. To achieve stability. (UF011)

Also SS023, UO023

Only about 10% of students from Form 6 and the university levels indicated having either *electrostatic charges*, *electronegativity differences*, or *energy driven* attributes in their mental models.

7.4.4 Reversibility

Table 7.10 indicates that the attributes of students' mental models that they hold for the reversibility component indicate they think chemical reactions are

by nature irreversible – *irreversibility presumption*. This belief was found to be common among the Form 4 students.

The liquid [butane] inside the gas lighter is natural, from the sea bed. Formed millions of years ago. So, it cannot be formed back [after it is burnt]. (SO076)

Because it's already mixed together. So, mixed together, so, it's hard to separate something mixed together. (SF052)

Based on my understanding, metal corrosion is a chemical reaction. And a chemical reaction is something that is irreversible. (SS068)

Also UF014

I think it impossible [to get butane back after it is burnt]. Because any organic compound that we burnt with oxygen, we get the carbon dioxide and water, so the reaction is irreversible. (UO065)

Table 7.10 Distribution of Attributes for Reversibility Component According to Level of Education

Attribute	Form 1 (n=12)		Form 4 (n=12)		Form 6 (n=12)		Junior (n=14)		Senior (n=17)		Total (n=67)	
	f	%	f	%	F	%	f	%	f	%	f	%
Irreversibility presumption ^a	3	25	5	42	3	25	2	14	3	18	14	21
Physical state ^a	0	0	3	25	1	8	0	0	2	12	6	9
Matter is not conserved ^a	2	17	4	33	2	17	4	29	3	18	14	21
Through a different set of conditions ^b	4	33	5	42	5	42	7	50	6	35	27	40
Stability factors ^c	0	0	0	0	3	25	4	29	7	41	14	21
Chemical structure factors ^c	0	0	1	8	5	42	4	29	5	29	15	22
Energy factors ^c	0	0	0	0	1	8	4	29	7	41	12	18
Equilibrium system ^c	0	0	0	0	1	8	3	21	4	24	8	12

Note. Details may not add up to total due to some students held more than one type of attribute or none.

^aInitial attribute. ^bSynthetic attribute. ^cScientific attribute.

There were several attributes where students mentioned the irreversibility of chemical reactions. First, about 20-30% of the students from all levels of education indicated that chemical reactions are irreversible because, in this process, some components of the reactants were lost or destroyed – as if *matter is not conserved*.

When, butane is added with oxygen, I think they turn into its by-products. So, it, when you, mix carbon dioxide and water, heat up, I think it won't produce the initial component, like butane and oxygen. Because it [carbon dioxide and water] are by-products. (SO033)

[If] carbon [dioxide] and water are mixed, it cannot produce heat [and butane]. Because, some parts of the butane are already been used up.

(SF053)

Also SS058

It cannot [turn back into butane and oxygen], because it has already formed into products. The bonding is already different. Atoms that making up the molecules are different. Chemically it is different. (UO028)

Also UF016

Form 6 and the university students' mental models included either the *stability factors*, *chemical structure factors* or *energy factors* attributes when describing the irreversibility of chemical reactions. About 30% of junior and 40% of the senior university students were found to have *stability factors* and *energy factors* as attributes when explaining the chemical irreversibility. They considered chemical reactions are irreversible because the stability state of the products is higher than those of the reactants.

This one [carbon dioxide] is more stable, and as you know, carbon and oxygen is a double bond right. So, it might more stable because breaking a double bond is harder than breaking a single bond. (UO069)

Both of these, the reactants are not stable, but these reactants are mixed, it will produce salt and water. Salt and water, the products are stable. So, reaction happens to produce more stable products. (UO023)

In these two reactions, the more stable products are these two [combustion and reaction between barium hydroxide octahydrate and ammonium thiocyanate]. So, if a substance is in a stable condition, it does not go to unstable [condition]. (UF063)

Also UF061, UF020

To reverse products (that are sometimes thought to be more stable) to reactants was considered unfavourable because the process requires more energy. This finding is commonly related to *activation energy*, in which greater energy is needed to reverse a reaction since the activation energy is believed to be much greater for the reverse reactions compared to the forward reactions.

If the reactant wants the product it has to overcome the activation energy but if the product wants to become the reactant, the activation energy will become higher compare to the original one [for forward reaction]. (UO026)

Also UO064, UF020, UF013, UF016

Some 40% of Form 4 students and about 30% of the university students justified their judgement of irreversibility of chemical reactions based on the attribute of *chemical structure factors*. Chemical reactions were considered irreversible because the products have simpler chemical structures or stronger chemical bonds compared to the reactants.

Certain conditions to be met because, butane is only consisted of two different elements, whereas these two already in total different elements.

(SS030)

When carbon dioxide is mixed with water, it will only form a mixture. Butane's chemical structure formula is complex, rather than the mixture of the carbon dioxide and water. So I believe it's irreversible.

(SS068)

Also SS071

If it [a reaction] that is reversible, the bonds are not broken completely. So, it can form back to the original substances. But for this one [combustion reaction], it is completely broken. It is completely broken forming into this new one [carbon dioxide and water]. [For the endothermic reaction], they are not broken completely. [They are] still similar molecules. Chromate molecule is still ionic molecule, it is still the same, [with] chromate and oxygen.

(UO028)

[This chromate-dichromate reaction] is reversible because it is still [the same]. [Both chromate and dichromate], Cr Cr still has O O. It is just differ in terms of oxidation number.

(UF009)

Nevertheless, about 30-50% of students from every level of education indicated that they believed chemical reactions can be reversed *through a different set of conditions*. In other words, the reactants of a chemical reaction can be obtained through certain conditions or in the presence of certain reacting agents. In these situations in which the forward and reverse reactions seem to be considered as two different chemical systems. This view was often evident in their explanation of the chromate-dichromate equilibrium.

Yes [we can get the butane back] but through different kind of reaction.

(SF039)

Also SF043

It is possible [to reverse the reaction]. For carbon dioxide to turn back to oxygen, it needs photosynthesis process. Plants use the carbon dioxide in the photosynthesis and it produces oxygen. Maybe we can if we heat it up.

(UO019)

Also SS030, UO064

And when the chromate ions are formed and then added with hydrochloric acid, it will tend to donate electrons to the hydrogen ion from the hydrochloric acid to form back the dichromate ions. So, it is due to the present of hydroxide ions and hydrogen ions, which are the agents that react on them [the chromate and dichromate ions].

(UF016)

Also SO033

7.5 Summary

Based on the comparison of types of mental models and educational levels, it seems that most secondary schools students (Form 1 and Form 4) in this study held Model A for chemical reactions. About half of the Form 6 students and some of the university students held Model B. Model C, on the other hand, was held by most of the university students and half of the Form 6 students. Although there were obvious differences between students' mental models according to their educational level and also between types of mental models, they shared some common attributes.

Students' mental models of chemical reactions from various levels of education were also compared in terms of structure, kinetics, energy. This comparison showed that the attributes of *response to reacting agents* are related to students' mental models across levels of education. Only students at the higher level of education described chemical reactions as the *formation of new substances* process that involved *submicro changes*. In terms of conservation of mass in chemical reactions, students across all levels of education tended make prediction based on the macro level such as *closed system* and *dependent on the physical state*. Only some of the university students explained the conservation of mass based on *rearrangement of atoms*. Similarly, as might be expected, only students from high levels education recognised *collisions of particles* and described chemical reactions in terms of *atoms rearrangement* and *bond breaking-formation*. Secondary students were less likely to express these

submicro level attributes. Nevertheless, most students, even those at higher levels of education, expressed mental models were lacking in the attributes related to barriers to reactions. Only about half of university students recognised *activation energy* as a factor of rate of reaction while most of the students considered that *energy initiates reactions*.

In terms of conservation of energy in chemical reactions, most secondary students explained exothermic reactions as occurring due to absorption of heat and endothermic reactions as being due to loss of heat (*heat gain and loss*). These students expressed that the energy change in chemical reactions as transformation of energy, that is chemical energy into heat energy. Secondary school students were also found to possess less attributes in terms of energy change in chemical reactions, but some offered explanations that energy change is related to *change of physical state* and *heat as a reactant or product*. Although it expected the university students tended to express more advanced attributes, less than half of them mentioned *net energy transfer* in chemical reactions. Most of the university students explained energy as *energy transfer*; indicating that they thought energy is released in exothermic reactions and energy is absorbed in endothermic reactions. However, less than a quarter of them linked any energy transfer to chemical bonding.

A common pattern across levels of education is that the limitations of students' mental models in explaining chemical spontaneity and reversibility, as indicated by only a third of the students offered their idea regarding to these aspects of chemical reactions. Nevertheless, an overarching observation was the idea a causal agentive as the driving force of chemical reactions held across level of education, which includes attributes such as *reacting agents*, *reactive agents*, and *presence of reactants*. These attributes were expressed when explaining chemical spontaneity and reversibility. Only a few students at the university level expressed other attributes such as *stability driven*, *energy driven*, and *chemical structure factors*, which are not based on the causal agentive idea.

Chapter 8 now provides interpretations and discussions of the research findings about students' mental models of chemical reactions in comparison to the literature.

Chapter 8 Analysis and Interpretation

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This chapter begins with a review of the purpose of this study. This is to provide a framework for the interpretation and discussion of the findings presented in the three previous chapters. The chapter then discusses the main findings as they relate to the research questions and the relevant literature.

8.1 Introduction

The purpose of this cross-age study was to explore students' mental models of chemical reactions at different levels of education. Specifically, the work sought to identify the attributes of students' mental models, types of mental models, and how these mental models vary from one another and at different levels of education. It is hoped that a better understanding of students' mental models of this fundamental idea in chemistry will provide insights into how to develop their mental models that are closely aligned with the scientific models.

This study was a naturalistic qualitative inquiry framed within a constructivist/interpretivist paradigm. The data for this inquiry were generated from semi-structured interviews by the researcher with 67 students from secondary schools and a university using an Interview-About-Instances (IAI) format. The data were coded, analysed, and organised according to the systems and components of chemical reactions and then by attributes that emerged from the data, to address the following research questions:

1. What are the attributes of students' mental models of chemical reactions?
2. Do students' mental models of chemical reactions differ and in what way?
3. How do students' mental models of chemical reactions differ at different levels of education?

This thematic analysis revealed an overarching finding that students' mental models about chemical reactions are built upon the causal agentive concept, a perception that a chemical reaction is a process driven by a causal agent(s) that also determine the reaction rate and spontaneity. This assumption about chemical reaction was also found to be at the core of students' mental models across all levels of education. In addition, their mental models were based on either non-particulate or particulate models of matter, and included various models of energy. Interestingly, the idea of chemical bonding in chemical reactions seemed to help students to describe the change of energy. Based on the attributes that emerged from the analysis, different types of mental models of chemical reactions were identified and a comparison of students' mental models across levels of education was carried out.

In the previous chapters, the findings were presented by organising the data (i.e., the attributes of students' mental models) around the tasks used in the interview including students' utterances and sketches about the following chemical reaction components: chemical composition, conservation of mass, particle collision, barrier to reaction, energy change, spontaneity, and reversibility. The purpose of this chapter is to provide an interpretive insight into these findings. While the previous chapters concerning the attributes of students' mental models were rather fragmented, showing only students' views of chemical reaction, this chapter's purpose is to augment understanding of the nature of students' mental models through a process of synthesis. This synthesis is framed by the interlinked patterns that occurred between the mental model attributes and the literature, and holistic explanations of the findings. The analysis, interpretation, and synthesis of the findings are aligned to the research questions and organised into (1) the nature of students' mental models of

chemical reactions (2) types of students' mental models, and (3) the comparison of students' mental models.

8.2 The Nature of Students' Mental Models of Chemical Reactions

The first research question sought to determine the characteristics of students' mental models through identification of attributes linked to the target systems of chemical reactions that include structures, kinetics, and energy. The attributes that students assigned to each of the target systems are discussed in turn in the following sub-sections.

8.2.1 Chemical Structures in Chemical Reactions

The findings of this present research suggest that about half of the students have a basic assumption that chemical reactions result in the formation of new chemical substances. However, not all students actually understood how new chemical substances differed from the initial substances. Less than half of the students invoked the notion of the particle model of matter when describing chemical reactions as the formation of new chemical compounds with submicro changes, including a change of chemical composition, modification of chemical bonds, electron transfer, and change of oxidation state. An indication of the limitations in students' mental models of chemical reactions is the difficulties they expressed when distinguishing between transformations of matter as either chemical changes or physical changes. About half of the students considered that ice melting and dissolution of sugar and salt were chemical reactions, and their descriptions of chemical reactions were based on changes in physical appearance such as colour, physical state, and texture. Such difficulties for students in identifying and differentiating physical changes from chemical changes have been well reported in the literature (see, e.g., Ayas & Demirbas, 1997; Stavridou & Solomonidou, 1989; Tsaparlis, 2003), where it seems many students thought of some chemical reactions as physical changes (Abraham et al., 1994) and vice versa (Ahtee & Varjola, 1998), or viewed chemical and physical changes as equivalent (Abraham et al., 1992; Boujaoude, 1991; Hesse &

Anderson, 1992). Furthermore, Andersson (1986b, 1990), Schollum (1981a, 1981b), and Solomonidou and Stavridou (2000) maintained that students do not necessarily recognised that there are changes happening in a chemical reaction; the students in these studies thought that, in chemical reactions, the original substances remained the same but have only undergone a displacement or modification process.

The findings in this current work also indicate that students have difficulties understanding conservation of mass in chemical reactions. A minority predicted no change in mass in both the zinc-acid and lead iodide precipitation reactions and were able to explain conservation of mass based on the particulate model. About a third of the students predicted a change of mass based on the physical state of the chemical system, seeming to believe that mass depends on the state of matter (e.g., a solid is heavier than a liquid, or a gas is lighter than a liquid) or that gases cannot be weighed or do not have weight. These findings are similar to those reported by Barker and Millar (1999), Agung and Schwartz (2007), and Özmen and Ayas (2003), who said students thought that the formation of a precipitate results in mass increase for the chemical system. Similarly, Mitchell and Gunstone (1984), Barker and Millar (1999), and Dahsah and Coll (2008) reported that students tended to think that a gas has little or no mass. Stavy (1990, 1995) suggested that such reasoning by students about mass change in chemical reactions may stem from students' construction of an intuitive rule or proposition concerning the correlation between weight or mass of matter and its state. This construct was referred to as a mass/density confusion by Barker and Millar (1999), and it was seen as an indication that students' thinking tends "to be dominated by perceptually obvious features" (Driver, 1985, p. 164).

In this study, the limitations of students' mental models related to conservation of mass indicate they failed to invoke the particulate nature of matter in their thinking of how matter changes. This finding suggests these students' mental models may not have been based on the fundamental idea of the particulate nature of matter. This assertion is supported by previous works that posited the idea of the particulate nature of matter is essential for students to make sense of

how matter changes and the relation of the changes with the macro characteristics of substances (Eskilsson & Helldén, 2003; Löfgren & Helldén, 2009; Vogelezang, 1987; Watson & Dillon, 1996). Students' inability to incorporate the particulate view of matter into their mental models led them to reason on the basis of their intuitive knowledge and understanding of matter on the macro level. This non-particulate construct in their mental models is also indicated in this present work where students' descriptions about the process of chemical reactions at the submicro level are considered. These students' descriptions are discussed in the following section.

8.2.2 Chemical Reactions at the Particulate Level

Students' mental models in relation to how chemical reactions happen at the submicro level, were deduced from the attributes identified in their responses about the process and rate of reaction. This analysis suggested that more than half of the students hold a particulate model and/or kinetic model involving particles. These students, who were mainly from the higher levels of education, described chemical reactions as a process of rearrangement of atomic constituents or the chemical structures of the reactants to form the products. This observation provides a strong indication that these students have incorporated the particulate model of chemical reactions into their mental models. This is supposedly expected due to the fact that they have been introduced to the particle model of matter since in their upper secondary education. Nevertheless, only about two thirds of this cohort of students offered details of the process in terms of bond breaking and formation, transfer of electrons, and formation of intermediate species. About half of the students commonly explained that in chemical reactions, some chemical species or free particles such as ions and free radicals were formed prior to the formation of the product particles. To illustrate this construct in the context of zinc and hydrochloric acid reaction, students often described that the reaction at the submicro level involves electron transfer from zinc, formation of zinc ions, chloride ions, and hydrogen ions, and the formation of a new chemical bonds between zinc ions and chloride ions, while, hydrogen ions combined to form

hydrogen molecules. Furthermore, the same students described combustion of butane as breaking bonds to form free carbon and hydrogen atoms, which then react with oxygen molecules to form carbon dioxide and water. Lee (1999a, 1999b) and Hinton and Nakhleh (1999) also reported such patterns of thinking on how chemical reactions occur at the submicro level.

Lee (1999a, 1999b) reported her participants (pre-service teachers) thought that the oxidation of magnesium and decomposition of copper carbonate involved the formation of free ions and atoms before reacting with each other – something she considered to be scientifically invalid. Furthermore, even senior undergraduates in this present study described chemical reactions at the particulate level as merely a process of rearrangement of atomic constituents without consideration of possible reaction mechanism. Lee also observed this scenario in her study where some pre-service teachers failed to provide a mechanism or a step-by-step process portraying how a chemical reaction happens at the submicro level. Instead, her participants provided illustrations of the arrangement of atoms for reactants and products. Lee also found that science lecturers commonly employed activated complexes in their explanation of chemical reactions. However, this construct is almost always absent in the mental models not only among her pre-service teachers but, unsurprisingly also absent among students in this present study. This finding may indicate that the students in this present study either did not prefer to use the transition state model in chemical reactions, or were not familiar with the model, similar to Lee's findings¹.

As mentioned previously (see Section 8.2.1, page 299), it was also notable that many students' mental models were not based on a particulate model of chemical reactions, especially those in the upper secondary school level. It seems that these students do not necessarily realise that changes happen to the

¹ It is worthwhile to note that the transition state model of chemical reaction may not been invoked in this study because of interview tasks employed, which may not have demanded such an explanation. Suckling et al. (1978) said that transition state theory is more useful when geometrical factors are involved in reaction.

original chemical substances as in zinc-acid reaction; instead they described a change of physical state (i.e., from solid to gas) without explaining that hydrogen gas was produced as a result of the interaction between zinc and hydrochloric acid. There was a similar observation in students' responses about the rusting process, where iron was considered to be unchanged chemically but changed in terms of its appearance. On the other hand, some students seemed to recognise there were changes to the reactants, but even these students were inclined to think that the change happened via a transformation of the reactants into products – as if the products are entirely different from the reactants. In other words, the chemical composition of the products bears no relation to that of reactants. For example, one student clearly stated that zinc atoms get separated in the zinc-acid reaction but that new atoms were produced when forming the gas. Similarly, upper secondary students (Form 4) seemed unable to envisage how a gas was produced in the reaction when there was no heating involved, describing this as a physical change (*internal arrangement*), which accords with observations from the previous section that students have difficulty distinguishing between chemical reactions and physical changes. These findings are consistent with the ideas of Andersson (1986b, 1990) who suggested that, in contrast with the scientific view of chemical reactions as an interaction between chemical substances, chemical reactions were also viewed by many students as involving displacement, modification, and transmutation processes. Andersson (1986b, 1990) argued that with regards to the concept of displacement, chemical reactions were often described by students as a process in which there are no changes to the original substances but only change in the position of atoms or other particles. In this 'modification' view of chemical reactions, certain physical properties were thought to have changed but the original substances remain the same. This view is consistent with the findings in the current study; here, students' views of chemical reactions differed from the scientific view of chemical reactions since they thought that chemical reactions just involve change in physical appearances. That is, the substances are the same but with different physical properties. This view of chemical changes is called transmutation, but in this work, the students thought that the original

substances changed into completely new substances or even heat energy. Although Andersson (1986b, 1990) said that such views of chemical reactions were applied by students at both submicro and macro levels, in this current work the students expressed such views in the absence of the submicro notion of the particulate nature of matter. Here, the secondary students (Form 1 and Form 4) in this study have used the terms like 'particles' and 'atom' in their descriptions (e.g., 'particles change' or 'atoms break up to form more atoms' or 'butane particles combine with heat and oxygen'). However, this practice does not necessarily mean they were using these terms as scientists do. Instead, it seems to indicate that these terms were used to refer to small objects (cf. Garnett et al., 1995; Novick & Nussbaum, 1978; Reiner et al., 2000).

8.2.3 Kinetics in Chemical Reactions

Similar to the above description of students' mental models in relation to the particulate model of chemical reactions, in this study, only a small proportion of the students were able to describe or use the kinetic model of particles and the idea of particle collision, when explaining reaction rate. For example, when explaining their predictions for the rate of reaction for zinc and hydrochloric acid, a minority of students invoked the kinetic model by relating the reduction of the quantity of reactants to a decrease in the occurrence of particle collisions, and hence a reduction in the rate of reaction. Only in the case of heating did more students invoke the notion of particle collisions predicting (correctly) an increase in the rate of reaction at a higher temperature. The idea of particle collisions is also sometimes used together with the idea of probability for reactions and reaction sites to explain reaction kinetics. However, about half of the students in this study predicted that the reaction rate would decrease as the reaction progresses but increase at a higher temperature without utilising the idea of particle collisions. They justified their prediction by explaining that the reaction rate depends on the quantity of the reactants – fewer reactants means fewer products are produced, therefore equating to a slower rate. However, at a

higher temperature the increase in reaction rate occurs because of the faster movement of particles¹.

Cakmakci and colleagues reported that students either predicted that as a chemical reaction proceeds, the rate of reaction increases, or increases to a plateau, or increases to a maximum peak and decreases gradually to zero (Cakmakci, 2010; Cakmakci, Donnelly, & Leach, 2005; Cakmakci, Leach, & Donnelly, 2006). Although the findings from the current study are slightly different to that of Cakmakci and his colleagues, what is consistent is that, in the students' explanation, they tended to neglect the application of the kinetic model of particles in chemical reactions. In a similar situation, Gómez Crespo and Pozo (2004) reported that secondary school students tended to not use kinetic theory when explaining chemical reactions and changes of state. Such difficulty in applying the kinetic model of particle to understand physical phenomena involving matter, such as evaporation, condensation, solubility, and gas pressure is reported by Gopal, Kleinsmidt, Case, and Musonge (2004) and Lin, Cheng, and Lawrenz (2000) among students, and even for pre-service science teachers (see Taylor & Coll, 2002). Interestingly, Fensham (1994) argued that the kinetic/particle model is not suitable for students because it does not make 'sense' to them. This argument could be applied in this current inquiry, where students failed to use both the particulate and kinetic models of particles in their explanation. Additionally, Niaz (2006) who looked at students' understanding of heat energy and temperature in chemical reactions, said that switching to the kinetic model from a view of heat as a substance requires a radical cognitive restructuring, which is not a straightforward process for students. It seems then that it is common for both the particulate idea of matter and kinetic models to be absent in students' mental models. This absence may indicate that students choosing not to use the kinetic model to predict reaction rate is due to a limitation on their part in grasping the particle model of matter (Johnson, 1998a, 1998b).

¹ The works related to students' intuitive knowledge may provide some insights which discussed further in Section 8.2.5 , page 296.

The idea of activation energy as a barrier to chemical reaction was not instantly employed by students when explaining or predicting the rate of reaction. For example, in the zinc-acid reaction, the idea of activation energy was only called upon when students were required to predict the rate of reaction at a higher temperature. In this instance, they presumed that the heat energy provided at the higher temperature enabled the reactants to achieve the activation energy. When considering the combustion of butane, activation energy was only invoked when the students were specifically asked about the need of spark for the ignition. In this study, students primarily thought that the energy provided from heating or the spark was needed for the reactants to achieve the activation energy and change into products. Some of the students are of the idea that the activation energy can be lowered which is inaccurate. This misunderstanding may be an indication that students' mental models did not include the idea of an energy barrier for chemical reactions.

Such limitations in understanding and application of the idea of activation energy were also reported by Cakmakci (2010) who observed that students may think that the activation energy is the kinetic energy of reactant particles, or the amount of energy released from a reaction. Likewise, Ribeiro et al. (1990) and Boo and Watson (2001) observed that students perceived activation energy as the *causal* energy of chemical reactions. Cakmakci (2010, p. 454) argued that understanding activation energy as part of chemical kinetics requires "integrated conceptual understanding of some fundamental ideas: the particulate nature of matter, the kinetic molecular theory, and dynamic aspects of chemical reactions," but this seems to be lacking in the students' mental models in this current work. Justi (2003, p. 298) pointed out that difficulties in understanding the idea of activation energy may be rooted in the curriculum itself or in the teaching, since the model of colliding particles was presented with a lack of details about "the notion of activation energy and of the spatial structure and orientation of the particles."

8.2.4 Energy Change in Chemical Reactions

In the current study, the attributes of students' mental models concerning energy change in chemical reactions were examined based on their explanations of exothermic and endothermic reactions. About half of the students said that energy is contained in the chemical reactions and the energy content of the substances determines the temperature of the chemical reactions. Combustion was thought to be 'hot,' since butane was perceived as a source of energy or the heat source that gives off its energy content in its reactions. In contrast, the endothermic reaction of hydroxide octahydrate and ammonium thiocyanate was considered to be 'cold,' since the chemical substances experienced a drop of energy content. However, for the more experienced students, explanations of energy change in chemical reactions using energy content ideas were more coherent. In combustion, these students explained that the energy content of the reactants was higher than the products, meaning the excess energy is released to the surroundings. Some students used the notion of enthalpy of formation when explaining the energy change, saying that the enthalpy of formation for the products is lower than the reactants. Likewise, such students said the temperature drop in the endothermic reaction meant energy from the surroundings was absorbed as the energy content of the reactants is lower than the products. This idea of energy content as a property of substances in a chemical reaction is common in students' mental models. Papadouris et al. (2008), for example, reported that students' models of energy were based on the view that energy is 'stored' in various objects such as batteries or wind and this understanding was used when explaining physical systems. This finding is also similar to the idea reported by Watts (1983) that energy was viewed as an ingredient of things. Barker and Millar (2000) and Boo (1998) noted that students viewed that energy is stored in chemical substances, which is similar to the idea that fuel or food contains energy. In the present work, students referred to butane as a "fire substance" – a direct translation for fuel in Malay – that gives off heat when burned. However, the view that energy is stored in chemical bonds or molecules of chemical substances, as reported by Barker and

Millar (2000), Boo (1998), Boo and Watson (2001), Ebenezer and Fraser (2001), and Galley (2004), was not found in this present study. The absence of this view may be due to the fact that the reported studies above involved students at a higher level of education, while in this current study, students were mostly from secondary school level. They viewed energy as being contained within chemical substances and were not yet employing a particulate model in their mental models of chemical reactions.

In this inquiry, students offered several descriptions of how energy change happened in chemical reactions when energy is 'contained or stored' in chemical substances. About a third of the students described the energy change that happened in combustion as a process of energy transformation from one form into another. Typically, the students said that the combustion reaction is hot because of the transformation of chemical energy into heat energy, arguing that energy is conserved, and neither destroyed nor created. Some of these students offered explanations at the submicro level, saying that the transformation of energy originates from the kinetic energy of particles, with particle colliding or grazing each other to form heat energy. However, such students did not use the same attribute when explaining the temperature drop in the endothermic reaction between hydroxide octahydrate and ammonium thiocyanate. This partial explanation indicates that these students may not have linked the energy change with the change of chemical structures. This interpretation suggests that they have not grasped the idea that energy transformation is a result of bond breaking and/or formation (cf. Duit & Haeussler, 1994; Kesidou & Duit, 1993).

Students' mental models of chemical reactions in relation to the target system of energy are also attributed to a view of *heat as a reactant or product*, where heat energy is considered equivalent to a reactant or product of chemical reactions. About a third of the students seemingly held this attribute and maintained that combustion is hot because heat energy is produced together with other chemical substances. About the same proportion of students assumed that the energy has changed in the endothermic reaction between hydroxide octahydrate and ammonium thiocyanate because heat energy is either being 'used up' or is a

reactant. The treatment of heat energy as one of the reactants or products in chemical reactions is similar to the work reported by Schollum (1981a, 1981b) with secondary schools students and teachers' college students, who apparently thought that heat energy is produced by burning gas. Watts (1983) identified this view of energy as both an ingredient (where the energy is needed to make something happen), and a product, to be consistent with the view that energy is a byproduct of a situation. In this construct, energy is not conserved; instead is treated as a relatively short-lived product that is generated, is active and then disappears. This understanding may be rooted in the students' belief of energy, treating energy as an invisible substance or matter that can be consumed or produced by visible chemical substances (cf. Boo & Watson, 2001; Erickson, 1979; Watson & Dillon, 1996).

The majority of the students in this study appeared to perceive energy change in chemical reactions in terms of energy flow or transfer, which Watts (1983) refers to as the flow-transfer model of energy. However, in this work such a view was not consistently held amongst all students. About half of the students seemed to hold the attribute that energy change in chemical reactions occurs as energy gain or loss. This involves explaining the increase of temperature in combustion as gaining heat energy, and the drop of temperature in the endothermic reaction between hydroxide octahydrate and ammonium thiocyanate as losing heat energy, which is similar to the idea of heat conduction of an object. This belief may be connected to the 'caloric model of heat energy' (Niaz, 2006), that rejects the notion of heat as motion (Brush, 1976), in favour of treating energy as a fluid substance. Such an interpretation means that when 'losing' energy, we see the energy drop in the system thus resulting a drop in temperature. Again, this finding is an indication that students' mental models of chemical reactions may not be based on a particulate model of matter.

Another cohort of students held the attribute of *energy transfer*. In this view, the energy change in an exothermic combustion is explained as the release of energy to the surroundings, while in an endothermic reaction it is explained as the absorption of energy from the surroundings. Students who held this

construct seem to be more successful in explaining the temperature change in chemical reactions, compared to those who held the *heat gain and loss* idea, despite both groups of students using the idea that energy is transferred. This showed that only those were able to identify or distinguish between system and surroundings, were able to explain more accurately about the energy change in chemical reactions. This finding indicates that these students have yet to develop a model depicting a system and surroundings in relation to energy transfer and temperature. Similar confusion about the relationship between heat transfer and temperature was also reported by Sreenivasulu and Subramaniam (2013, p. 23), who found that students believed “temperature must increase if heat is being absorbed by the system.” Likewise, Chu, Treagust, Yeo, and Zadnik (2012) reported that students assume that temperature rather than heat, can be transferred from one body to another. As Greenbowe and Meltzer (2003) noted, students’ confusion about heat transfer and temperature may have roots in students’ difficulties identifying what is referred to as the system and surroundings, and how the energy flows from the reacting system (i.e., the chemical bonding) and is transferred to the surroundings. This finding is considered to be consistent with this current study, where it seems students who have such ideas about energy transfer attributes, were seldom able to link energy change with the alteration of chemical bonds.

Only a small cohort of the students in this study explained the energy change in chemical reactions based on the attribute of *net energy transfer*. Possession of this attribute would mean that they were aware that temperature change is due to both energy absorption and release. For the exothermic combustion of butane, more energy was being released to the surroundings than absorbed, which results in an overall increase of temperature, while for the endothermic reaction between hydroxide octahydrate and ammonium thiocyanate, more energy was being absorbed from the surroundings than energy being released, which results in a drop of temperature. Students who have this attribute appeared to be able to provide a consistent explanation for both chemical systems. The success of this attribute may have origins in the attribute of *energy*

transfer in chemical bonding, where students recognised the energy change related to the breaking and formation of chemical bonds. This interpretation may suggest that these students recognised that heat energy originates in the chemical system or that it is in the chemical bonds of the reactant molecules. Nevertheless, some students linked the energy change inappropriately with chemical bonding, thinking that energy was released in bond breaking and absorbed in bond formation – *reverse energy transfer in chemical bonding*. Again, this confusion may have been contributed to by the ontological belief of energy as a substance, whereby students think that energy is part of the chemical bonds, which is released when broken, and needed to form chemical bonds (Barker & Millar, 2000; Boo, 1998; Boo & Watson, 2001).

8.2.5 Impetus of Chemical Reactions

The research findings in this study suggest that a core attribute of students' mental models of chemical reactions was reaction as an agentic process. The *responses to reacting agents* attribute of students' mental models was found to be possessed by about a third of the participants. These reacting agents included other chemical substances, air, heat, light, humans, and the surroundings, all of which were assumed to be responsible for the changes that happen in chemical reactions. In this study, most students are of the opinion that rusting is caused by acid rain or water, or air or oxygen, and these agents were responsible for the changes in the iron metal. Similarly, students' thinking was that the acid responsible for chemical change in the corrosion of zinc metal. This observation is in line with previous research, such as that conducted by Schollum (1981b, 1982), who reported that water and oxygen were seen as active agents by students in rusting. Interestingly, in other domains such as physics, students were reported to explain motion as being caused by force or gravity (Bliss, 2008) or by the influence of a human 'actor' as the agent of motion (Bliss & Ogborn, 1994). In biology, causal agents like sunlight and weather were used to explain a variety of biological phenomena (Southerland, Abrams, Cummins, & Anzelmo, 2001; Tamir & Zohar, 1991).

Such attributes or explanations were termed by Hatzinikita et al. (2005) as the “*agentive explanation*.” We can differentiate these attributes or explanations based on the roles played by the components in the chemical reactions, i.e., action and interaction. For action type explanations, chemical reactions were “based on the asymmetry of roles that the component-agent (active role) and the affected component (passive role) play in the change of the latter” (Hatzinikita et al., 2005, p. 476). In other words, substances in chemical reactions do have equivalent roles, but one substance was thought to bring about the change of the other substance (Stavridou & Solomonidou, 1989; Talanquer, 2006). The component-agents or the reacting agents were not necessarily considered to undergo changes themselves, but rather the changes only happen to the affected component/substances. On the other hand, Hatzinikita et al. (2005, p. 476) noted that the interaction type of the agentive process is based on a “symmetry of the roles that the components of the system play,” which is similar to the findings in the present work about students’ assumption of *interaction between substances*. In this case, chemical reactions were described as interactions between equal counterparts, which are all equally required for the production of changes; that is, students perceived chemical reactions as getting the product from the ‘correct ingredient(s)’ (Stavridou & Solomonidou, 1998). Such symmetrical roles of chemical substances in the reaction were also reported in other studies such as Boujaoude (1991) and Gabel, Stockton, Monaghan, and MaKinster (2001). In these studies, young students saw the need for oxygen in burning; correspondingly, students in this present study also saw energy as an important agent in chemical reactions. Energy was considered to initiate chemical reactions and appeared to be one of the reaction components. A sizeable number of students in this present study thought that heat energy from the spark was the initiator or the component in the combustion reaction; this is consistent with previous research, which reported that heat energy was seen as an active agent of change, not only in chemical reactions but also in changes of physical state, and other physical phenomena such as motion (cf. Erickson, 1979; Papadouris et al., 2008; Papageorgiou & Johnson, 2005; Watson et al., 1997; Watts, 1983).

The agentic attribute of students' mental models in this study was extended to explaining both kinetics and thermodynamics aspects of chemical reactions. In predicting the rate of reaction, about a third of the students justified their prediction by using the attribute *quantity dependent* – the lesser the quantity of reactants the slower the reaction, or conversely, the greater the quantity of reacting agents, the faster the reaction will go. Following this reasoning, students said the rate of reaction reduces as it progresses because the quantity of reactants (which are either the active agent or the passive component) has diminished. Similarly, most students simply predicted that rate of reaction increases at a higher temperature, because the heat energy is assumed to be an active agent responsible for chemical change – the more of it that is present, the faster the reaction goes. This explanation is rather different from findings reported by Cakmakci (2010), where secondary and university students held the idea that rate of reaction either remains the same or increases as the reaction progresses. However, Cakmakci observed that students may have thought that because a reaction is an exothermic process, the system supplies energy as heat to the surroundings, and as a result, the reaction speeds up. Such thinking may lead these students to view heat energy as the active agent affecting the rate of reaction.

When the agentic attribute is at the core of students' mental models of chemical reactions, it also appears to play a prominent role in explaining the spontaneity of chemical reactions. Heat energy was perceived to be responsible for sustaining the continuity of combustion, and zinc metal was identified to be a reactive agent that displaced the hydrogen from chloride in hydrochloric acid. In some cases, chemical reactions were considered to take place whenever the components of a reaction are present in the reaction system. Besides this, almost half of the students thought that chemical reactions are reversible. This is possible through a different chemical system achieved with suitable causal agents or conditions that enable the backward reaction. The observation of chemical reactions driven by causal agents in this study was also recognised by Barral, Fernández, and Otero (1992), Boo (1996, 1998), Boo and Watson (2001),

and Thomas and Schwenz (1998). These authors reported that students held the idea that chemical reactions are driven by heat energy and reactive reactants, instead of being driven by the increase of energy dispersion or entropy.

This finding is also consistent with the students' explanation about the reversibility of the chromate-dichromate equilibrium system, which was considered to be influenced by the reacting agents for forward and backward reactions, and their notion that chemical reactions can be reversed through a different chemical system. Although there are no direct reports regarding research on reversibility and causal agents, the findings in this study seem to be consistent with the finding that students were often found to have misapplied Le Châtelier's principle, by simply identifying the causal agents in determining the equilibrium shift that minimises the effect of the identified agents (cf. Quílez-Pardo & Solaz-Portolés, 1995; Wheeler & Kass, 1978).

The students' agentic attribute of their models of chemical reactions can be understood in light of what is referred to as intuitive and implicit knowledge¹. It might be considered that the agentic nature of students' mental models is more closely reflecting "a fundamental intuition of causal mechanism" (Taber & García-Franco, 2010, p. 134) based on diSessa's (1983, 1988) 'force as mover p-prims,' which was re-described as 'actuating agency' by Hammer (1996). Andersson's work (1986a) based on that of Lakoff and Johnson (1980a, 1980b, 1980c), claimed that students' explanation and prediction of physical phenomena were based on a common fundamental belief, known as the *experiential gestalt of causation*. The experiential gestalt of causation, which is constructed at a very early stage of human life through interaction of a child with their surroundings, enabling people to explain the occurrence of changes by identifying an 'active agent.' The active agent uses an 'instrument' to cause direct or indirect effects on an object that Lakoff and Johnson referred to as a

¹ Among other names, this knowledge is referred as implicit assumptions, heuristics (Talanquer, 2002, 2006), or phenomenological primitives - *p-prims* (diSessa, 1988), intuitive rules (Stavy & Tirosh, 1996, 2000), core intuitions (Brown, 1993), experiential gestalt of causation (Andersson, 1986a; Lakoff & Johnson, 1980a, 1980b, 1980c), and presupposition (Vosniadou, 1994).

patient. Such understanding that underpinned the common experiential gestalt are: that the greater an agent's effort, the greater the effects on the object; that resistance of different objects differ in intensity; and that several agents have a greater effect than just one. For example, Andersson reported that children predicted the temperature of water (the object) at boiling point would increase when the hot plate (the agent) was turned to a higher heating level. Such gestalt is similar to that observed by Stavy and Tirosh (1996, 2000), where children's reasoning is often based on the intuitive rule 'more of A, where the more of B,' where-by the perceptual quantity (A) can serve as a criterion for comparing another quantity (B). In the case of chemical reactions, students' mental models may be governed by such gestalts, which makes them think that the rate of reaction depends entirely on the quantity of reactants (one of which is the agent), and the spontaneity or direction of reaction depends on suitable conditions, which include an agent acting on the chemical system.

In contrast to the view of chemical reactions as an agentic process, a minority of students, mostly from the higher education level, seemed to consider that chemical reactions are *stability driven*. Based on this attribute, chemical reactions were thought to happen in the direction that forms more stable chemical compounds, hence explaining why reactants undergo the chemical reactions. The *stability driven* notion resonates with students' explanation of chemical irreversibility, in which reversing chemical reactions were viewed as unfavourable because these properties of the product(s) will change from a more stable form to become unstable. In this mental model, when considering reversible reactions, both reactants and products were judged to have similar stability when backward reactions happen readily. This observation is similar to those of Boo (1996) who found that some students who viewed chemical reactions are driven by causal agents also think that chemical reactions were driven by a need to achieve stability. Most students who held the notion of stability as a driver of chemical reactions believed that chemical reactions happen in order to produce more stable products. They appeared to think that the products are less reactive or energetic compared to the reactants and have

lost the ability to react; thus, the backward/reverse reaction is considered unfavourable because it would not result in the preferred more stable state. Besides that, Boo also discovered that in his study, students believed the chemical structures of the products to be more stable because they possessed stronger or less complex chemical bonds compared to the reactants.

Generally speaking, this *stability driven* attribute was used in explaining not only how chemical reactions happen, but also the spontaneity (or otherwise) of chemical reactions. For students in this study, the notion of chemical stability as the impetus of chemical reactions was not explicitly linked with the idea of electron configuration or atomic structure as reported by Taber (2009) in his work on college students' conceptions of chemical stability. In contrast with this current study, Taber argued that students' concepts of chemical stability were based on the 'octet heuristic.' Talanquer (2007), however, may offer insights into the stability driven attribute. He noted that, aside from causality, this reliance on the stability idea is a form of students' heuristic or reasoning which he referred to as teleological (i.e., a view that a process is directed towards a goal or to fulfil some purpose). This teleological heuristic may be rooted in instructional explanation, which is "based on the idea that chemical systems evolve in ... the direction of *increased stability* [original italics]" (Talanquer, 2007, p. 864). He asserted that chemical teleology has values in chemistry instruction and should be further developed in students understanding of chemical systems. As he claimed, chemical teleology provides explanatory reason for a particular chemical transformation, and he went on to note that it is:

tightly linked to the existence of a rule, principle, or law that governs the behaviour of the system, and that explicitly or implicitly implies the minimisation or maximisation of some intrinsic property (e.g., total energy, entropy, free energy). This law or principle tends to provide a sense of preferred direction in the evolution of a transformation. (Talanquer, 2007, p. 860)

Nevertheless, an overarching observation of students' mental models concerning chemical spontaneity is the absence of any connection between the chemical reactions and change of energy, such as the total energy, entropy, and Gibbs free

energy. Despite the use of exothermic and endothermic reactions in the study and exposure to physical chemistry at the university, not one student even mentioned the term entropy or Gibbs free energy. This finding suggests that not even the university students have developed this concept and that it does not feature as an attribute of their mental models for chemical reactions. Additionally, this finding may also imply that the idea of entropy, i.e., dispersion of energy and mass, may not be fully understood or be too difficult to be comprehended by the university students (Sözbilir, 2003). This difficulty is probably rooted from the abstract representation of this scientific idea solely in mathematical expressions that university students may not be able to make sense of.

8.3 Types of Students' Mental Models of Chemical Reactions

The data analysis led to the identification of three common types of mental models of chemical reactions held by students, which are referred to as Model A, Model B, and Model C. The grouping of the mental models into these types was based on the classification of the attributes and their distinction in relation to the attributes that comprise the target system.

Model A

Model A is that held by students who mainly described chemical reactions as a *response to reacting agents* and who sometimes recognised the *formation of new substances*. When considering conservation of mass in chemical reactions, students with this mental model did not include the *rearrangement of atoms* attribute, but rather relied on the physical appearance of the chemical system to describe and explain changes. This mental model is not based on the kinetic model of particles as evidenced by the absence of the attributes of *collisions of particles* and other related attributes. Although students holding Model A were able to describe the change in *internal arrangement* and *movement of particles*, these attributes were only invoked when describing the changes of physical state. Adherents of Model A tended to hold a non-particulate view of chemical

reactions and a transmutation view of chemical changes (Andersson, 1986b, 1990). These students seemed to have little capacity for distinguishing chemical reactions from physical changes and understanding conservation of mass.

The main assumption underpinning Model A is that chemical reactions are an agentive process, which has its roots in intuitive knowledge (e.g. p-prim or experiential gestalt of causation). Despite the simplistic assumption of this model, such mental models do help students make sense of different aspects of chemical reactions. For example, in chemical kinetics, Model A supports the observations that: when there are more agents present, the faster a reaction goes; heat energy as a causal agent can initiate chemical reactions; the occurrence of chemical reactions depends on the presence of causal agents; and that chemical reactions are reversible when suitable causal agents are present. Model A appears to fit well with the model of chemical reactions derived from primary schools students' understanding of changes of matter, as observed by Hatzinikita et al. (2005), who claimed that students holding such mental models think that matter is continuous and static. These students described the change in terms of macro entities and explain the process via the action of external agents. Another important characteristic of Model A is that energy change in chemical reactions is based on heat gain/loss. This characteristic is similar to Lavoisier's 'caloric theory of heat' (Greenberg, 2007), where Lavoisier considered heat as a form of substance that may be present within certain chemical substances, released during chemical change, and which subsequently causes 'hotness.'

Since Model A is not related to any obvious scientific models of chemical reactions, it can be regarded as an initial model of chemical reactions (cf. Vosniadou, 1994; Vosniadou & Brewer, 1992, 1994). Based on the findings reported here, it can be assumed that students' initial mental models of chemical reactions are essentially a non-particulate one, where chemical changes are regarded as a transmutation process controlled by causal agents. Holding this mental model will likely limit individuals in their explanation of what chemical reactions actually are: for example, describing chemical reactions as physical

changes, or treating chemical and physical changes as the same phenomena, and thinking that change of mass in chemical reactions depends on the changes of physical state. However, despite these limitations, students holding Model A seemed to be successful to some extent in predicting the rate of reaction, explaining energy (or rather heat) change, and also making sense of chemical spontaneity and reversibility based on the causality assumption. Thus, Model A is an acceptable mental model for students at early levels of education, because, as might be expected, they have only been introduced to chemical reactions at the macro level.

Model B

Model B is a mental model held by students who recognised that in chemical reactions there is the *formation of new substances*, *submicro changes*, and that chemical reactions occur as a *response to reacting agents*. In this model, the conservation of mass was reasoned by students in this study using the notion of a *closed system*. Although the attribute, *rearrangement of atoms* was not revealed here in terms of composition and conservation of mass components, Model B may be considered to be based on a particulate model of chemical reactions as it depicts the *rearrangement of atoms* when explaining the process of chemical reactions at the submicro level. The first subtype of this mental model, Subtype B1, is found to primarily rely on the particulate model when explaining the process of chemical reactions, which is regarded as *bond breaking or formation*, and *rearrangement of atoms*. Subtype B1 models rely on an intuitive idea that the rate of reaction is *quantity dependent*, without acknowledging the role particle collisions play in chemical reactions. Subtype B2 adherents, on the other hand, perceived chemical reactions as resulting from *collisions of particles*, a model partially consistent with the kinetic model of particles in chemical reactions, but they do not incorporate the idea of *activation energy*. In contrast with the previous subtype, Subtype B2 does not contain the idea of *bond breaking or formation*, although it comprises the *rearrangement of atoms* attribute.

In summary, both subtypes of this mental model are partially consistent with the particulate model of matter and the kinetic model of particles. In terms of energy change in chemical reactions, Model B sees the energy change involving transformation of energy from chemical energy to heat energy. Only Subtype B1 links energy change to energy transfer, relating energy change to modification of chemical bonds or as a component of chemical reactions. This relationship indicates that this model links energy change to the chemical systems. Subtype B2, unlike Subtype B1, provides little or no explanation about energy change. Nevertheless, students who held Model B also regarded chemical reactions as an agentive process in which chemical spontaneity and reversibility were controlled by causal agents, which is similar to those with Model A.

Since, Model B appears to share some features with scientific models of chemical reactions such as the particulate model of matter and kinetic model of particles, it may be best regarded as a synthetic model (cf. Vosniadou, 1994; Vosniadou & Brewer, 1992, 1994). It utilises particle collisions, rearrangement of atoms, and energy change in relation to chemical bonding, but also in combination with intuitive knowledge, it is obviously based on experiential gestalt of causation (Andersson, 1986a). Considering the Form 6 students who had just completed their secondary schooling and have yet to grasp the scientific models fully, it is understandable that they held a mental model of such a synthetic nature of mental model (i.e., Model B, which is incoherent and/or incomplete) (Chi & Roscoe, 2002). However, some university students who were expected to have more sophisticated mental models, were also found to be categorised into Model B. This observation may indicate that they have yet to develop their mental models according to their current level of education, or chose to use their preferred mental models (in this case a synthetic mental model) instead of scientific models.

Model C

Model C is considered to be the most advanced model identified in this study. This model views chemical reactions as a process involving *formation of new substances* along with *submicro changes*. This view suggests that Model C

consists of a particulate model of chemical reactions, since prediction of mass change is reasoned according to the idea of *rearrangement of atoms*. This model also includes a kinetic model of particles which is expressed in the attributes of *collisions of particles*, *site of reactions*, and *activation energy*. This mental model type differs from Model B in that it also integrates attributes such as *atom rearrangement*, *bond breaking-formation*, *electron transfers*, and formation of *intermediates* when explaining the process of chemical interactions at the submicro level and rate of reaction. Energy change in chemical reactions for Model C is attributed to *energy transfer* or *net energy transfer*, and *energy transfer in chemical bonding*, indicating that adherents to this model see energy change linked to the chemical system or the chemical bonds. In addition, Model C indicates the emergence of more scientific attributes such as chemical stability, chemical structures, and the use of energy change when explaining chemical spontaneity and reversibility.

Despite the expression of attributes that are more consistent with the scientific view of chemical reactions, Model C does have some discrepancies. For example, some students with Model C predicted a decrease of reaction rate as the reaction progresses, based on the notion that rate of reaction is dependent on quantity – consistent with an agentive attribute of chemical phenomena. Even with this mental model, students thought that chemical spontaneity was controlled by *reacting agents* and believe that chemical reactions were reversible through a different set of chemical reactions. This reasoning is consistent with the intuitive notion that chemical reactions are driven by causal agents, and also it dominates students' mental models despite being attributed with some scientifically acceptable ideas. It should be noted here that even though Model C is considered the most advanced mental model identified in this current study, the notions of entropy and Gibbs free energy were not expressed. Model C is coherent, is well interconnected and systematic, is able to provide consistent and predictable explanation but it is incomplete, especially in terms of the relation between energy and chemical reactions. This deficiency in some aspects of chemical reactions in Model C is consistent with assertions of other researchers

that mental models need not be entirely complete or accurate in order for it to provide successful explanation or prediction (cf. Coll, 2008; Franco & Colinviaux, 2000; Gentner, 2001; Johnson-Laird, 1985; Norman, 1983). As Chi and Roscoe (2002) argued, coherent mental models can still be flawed when based on incorrect beliefs or principles, and individuals who hold such mental models may not be aware of any lack of coherence or attributes since their mental models are capable of providing consistent and adequate explanations or predictions. After all, according to Anderson, Howe, and Tolmie (1996, p. 248), “mental models need neither be wholly nor correspond completely with the model in order to be useful.” Nevertheless, although Model C may provide students with a plausible explanation, inference, and prediction with concern to chemical reactions, because of the underdeveloped component of spontaneity (with confusion with activation energy), it may not be adequate for students to understand further advanced chemical systems such as chemical equilibrium and chemical synthesis.

8.4 Students’ Mental Models of Chemical Reactions Across to Levels of Education

Types of Mental Model According to Levels of Education

In this inquiry, students’ mental models were also compared across levels of education to identify if and how students’ mental models vary within different levels of education. A general observation that can be drawn from the analysis (see Figure 7.1 on page 266) is that student’ mental models will advance with level of education.

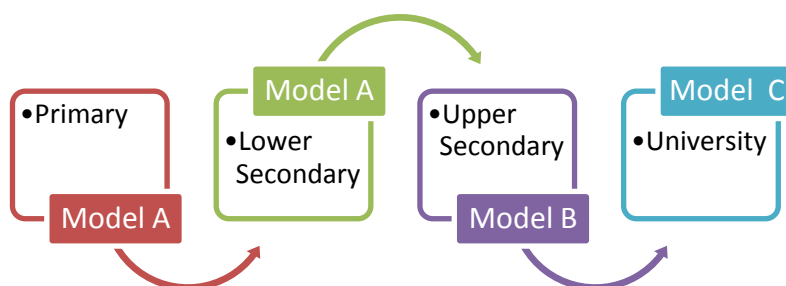


Figure 8.1 Type of Students’ Mental Models According to Level of Education

Figure 8.1 shows that the secondary school students in Form 1 and Form 4 were more likely to hold Model A, which is considered as an initial mental model of chemical reactions (i.e., a non-particulate model). This finding reveals that primary school students entering lower secondary level commonly hold Model A and remained at the same level of understanding until the end of lower secondary education. Thus, at the lower secondary school, the mental model of chemical reactions remains undeveloped. Form 6 students tended to hold either Model B or Model C, which indicates that the mental models for upper secondary education have progressed, and the university students are more likely to hold Model C, suggesting that most students have developed a more coherent mental models. It is, therefore, reasonable to say that the more exposure students get in formal chemistry education, the more consistent their mental models become with the scientific view. Model A is an initial mental model, progressing to Model B by secondary school level, and Model C at the university level. The sophistication of students' mental models at the higher level of education is consistent with other research. For example, Coll and Treagust (2001, 2003a, 2003b) said that although students exhibit a preference for simple and realistic looking mental models, undergraduate, and postgraduate students tended to utilise more sophisticated and abstract models (in their study of chemical bonding). Similarly, Vosniadou and Brewer (1992) observed that Grade 5 students' mental models of Earth were based on a sphere, while Grade 1 students viewed Earth as hollow or a flattened sphere indicating a slow process of changing from an initial mental model to a more sophisticated spherical earth model.

Nature of Students' Mental Models According to Levels of Education

In this current inquiry, students' mental models have also been examined through a comparison of their mental model attributes. Several notable patterns emerged during this data analysis. The first pattern shows that as the level of education increases, students' mental models progress from a non-particulate view of chemical reactions using macro modelling to a particulate model based on a submicro modelling. This pattern is evident in students' responses when

explaining the concept of chemical reactions, conservation of mass, and chemical reactions at the submicro level. Secondary school students (Form 1 and Form 4) described chemical reactions in terms of physical appearances, which is supported by Rahayu and Tytler (1999) who reported that primary schools students' notions of combustion were typically non-particulate. On the other hand, students from higher levels of education described chemical reactions as a process of *submicro changes* and *rearrangement of atoms*. These findings are consistent with their explanations of reaction mechanism, and indicated their ability to apply ideas about atomic structure and chemical bonds, something that was not found in Form 1 and Form 4 students. Although some of the secondary school students explained about the chemical reactions presented to them in terms of change of *internal arrangement* and *movement of particles*, even though they possessing these attributes may not support the view that they have developed a particulate view of matter that scientists have. This is due to the fact that they used these terms only to explain the chemical phenomena presented to them as physical change of matter, which may not require the understanding of atoms and molecules, and mainly explained the chemical phenomena at the phenomenological or macro level. This assertion is also supported in terms of students' prediction of mass conservation in chemical reactions, whereby only some students at the higher levels of education were found to have expressed the attribute *rearrangement of atoms*. This finding suggests that understanding of the relationship between mass and atoms emerges only after completion of secondary school chemistry schooling, and then only for some students. Therefore, a comprehensive understanding of the conservation of mass idea cannot be expected from students based on their educational level, but rather it seems to depend on the development of their mental models for chemical reactions. This situation can be explained based on the degree of exposure about particle theory of matter received by most Malaysian students at the lower secondary level. At this level of education, the term 'particle' is introduced without employing the idea of atoms and molecules, and chemical reactions such as combustion, decomposition of metal carbonates,

and neutralisation are presented as change of substances, without the idea of chemical equation and stoichiometry (see Section 1.3.3 on page 13).

Similarly, when considering the kinetics view of chemical reactions, only Form 6 and university students sought to explain chemical reactions as a process that involves collisions of particles. This is not to say that the Form 4 students do not have the idea of particle movement. As mentioned previously in this section, they do possess this idea of movement, but their ontology of particle may be non-atomic; that is, they perceived particles as small sized, dust-like matter (cf. Garnett et al., 1995; Novick & Nussbaum, 1978; Reiner et al., 2000), and in essence inherently view chemical reactions as similar to physical changes. After all, the word 'particles' was only used when the researcher used the word in probing their idea about how zinc-acid reaction occurs at the particulate level (see Section 6.2.2 on page 227). Nevertheless, it is noticeable that more than half of the Form 6 students and about 20% of the university students were categorised as Model B (and even Model A), which indicates these students especially those in Form 6 have not fully developed their mental models in terms of chemical kinetics, although they are supposed to have developed this idea in their upper secondary education. In fact, only a fraction of Form 6 and university students used the notion of a barrier to reaction when considering activation energy. This limitation in the use and understanding of kinetic theory in relation to chemical kinetics is also reported by Cakmakci et al. (2006), whereby secondary school students were more likely to explain the rate of reaction at the phenomenological or macro levels, rather than using particulate modelling. Similar to this study, Cakmakci (2010) reported that about 60% of secondary school students and about 30% first year university students indicates difficulties in explaining how rate of reaction changes as the reaction progresses, such as assuming that rate of reaction increases with time or remains constant. Justi (2003) suggested that the struggle in developing their mental models may have be rooted in the interferences of everyday meanings of words such as 'catalyst' or 'activation' with students' attribution of meaning in the chemical kinetics

context, and also the challenges faced by students to “go beyond the empirical macro world, thus reaching the sub-micro world of explanation” (p. 309).

In terms of energy change in chemical reactions, students across all levels of education seem to hold the notion that energy is contained in chemical substances, and they explained energy change through a comparison of energy ‘stored’ in reactants and products. This attribute seems to be prominent among Form 1, Form 4, and the senior university students, but less among Form 6 and junior university students. The secondary school students’ views of ‘energy content’ is expected for the reason that at this level of education, the notion of ‘energy’ is presented phenomenologically around the topics such as uses, types and sources of energy. However, the senior university students’ notion of energy content differs slightly from those of the secondary schools students, in that what they may actually mean here is the energy level or enthalpy of formation (similar to Form 6 and junior university students), rather than energy content *per se*.

About a third of all the students indicated that they viewed energy change that happens in chemical reactions as a *change in form of energy*, such as the transformation chemical energy into heat energy, or thought that *heat as a reactant or product*, which is either used up or produced. This model of energy change may have its roots in the introduction of transformation of energy from one type into another in primary and lower secondary level, which seems to be a practical way (even for the university students) to explain energy change from chemical energy into a different form of energy in chemical reactions. However, most students viewed energy change as energy flow, which was explained in different ways. For most of the secondary school students, this explanation included *heat gain and loss*, whereas it meant *transfer of energy* for most of the Form 6 and university students. The attribute *heat gain and loss* was consistent among Form 1 and Form 4 students, and could be explained based on their ideas of exposure to energy in primary and lower secondary school level. In these levels, change of temperature of an object depends on gain or loss of heat energy (i.e., heat conduction), which may have influenced the students thinking

about the energy change that happens in chemical reactions. On the other hand, the higher level students viewed energy change in terms of *energy transfer*, and they were less likely to relate changes to *energy transfer in chemical bonding*. The preference of higher level students to explain energy change in chemical reactions as energy transfer could be due to their training in classical thermodynamics, which mainly emphasises on the explanation of energy transfer between chemical systems and surroundings at the macro and symbolic level without much concern with the submicro level. With the classical thermodynamic view of chemical reactions, students may developed their mental models in terms of energy change as absorption or release of energy.

These observations indicate that students' mental models of chemical reactions in relation to energy were poorly developed, and they incorporate simple models of energy change. Only students who have Model C were able to explain the relation of bond breaking and formation with the absorption and release of energy that results in a net energy transfer. Therefore, students' mental models of chemical reactions in relation to energy can be said to be derived from an understanding of energy change that is not linked to the chemical system or chemical bonds. However, this progression seemed to be limited because only about a third of the Form 6 and university students talked of the relation between energy change and chemical bonding despite the exposure to these concepts in their formal learning. Remarkably, Papadouris et al. (2008) reported that the formation of coherence in students' model of energy may not be much influenced by science teaching or maturation. This claim is supported by the works of Boo (1998) and Barker and Millar (2000), both of whom found that A-Level (ages 17–19 years) students failed to apply this idea when reasoning about overall energy change in exothermic reactions, despite having learnt the concept of chemical bonding and its relation with energy change in formal schooling. Greenbowe and Meltzer (2003) reported a similar observation among undergraduate students.

Students' mental models across levels of education can be considered to be strongly influenced by a causal agentic notion of chemical reactions. This

influence is evident from their mental model attributes; *presence of reactants, reacting agents, reactive agents*, and the thought that chemical reactions can be reversed *through a different set of conditions*. Although these mental models seem to have roots in students' intuitive knowledge, students' belief that chemical reactions are caused by agents (most popular among Form 4 students) and/or *reactive agents* (popular among university students) was not echoed among Form 1 students. This finding indicates that students' mental models may have been influenced by their formal learning in lower secondary level (but not in the primary education). This idea is then probably retained or further 'enhanced' at the upper secondary level of education, in which it is clearly stated in the syllabus that "chemical reactions cause chemical changes to substances," and "matter interacts to produce new substances and causes energy change" (Ministry of Education Malaysia, 2006a, p. 13). Hence, this view became the core or heuristic for students beyond primary level of education in explaining chemical spontaneity. This agentic view of chemical reactions is consistent with works reported by Boo (1996, 1998) and Boo and Watson (2001) for A Level students. However, the current study was unable to ascertain if an agentic view of chemical reactions is strongly present among Form 1 students, indicating that it may not have been developed during primary education. This somewhat contradicts findings reported by Hatzinikita et al. (2005) for Greek primary school students, whose mental models of chemical reactions are apparently based on agentic processes. Hatzinikita et al. (2005) stated that, in Greek primary education, students were exposed to the categorisation of physical and chemical changes and particle idea in changes of physical state; but these concepts are only introduced at the lower secondary level in Malaysia. Lin and Chiu (2010) argued that formal instruction is the most influential factor on students' mental models, which may explain this apparent contradiction between the Greek and Malaysian context.

The retention of an agentic view of chemical reactions among junior university students can perhaps be explained in terms of their formal teaching at postsecondary level. Students are only introduced to thermochemistry,

extending a bit further from what they have learnt in upper secondary chemistry, and the concept of spontaneity and entropy, which explains why chemical reactions happen, is not introduced at this level. Nevertheless, despite having taught the notion of entropy in the university level, the senior university students were also found to use the agentic view in explaining chemical spontaneity. A possible explanation that can be offered here is that these senior university students may prefer to use this unsophisticated model because of its ease of use as reported elsewhere (Coll, 2008; Coll & Treagust, 2001, 2003a) and they chose to avoid the use of the freshly introduced idea of entropy, which they may be struggling to understand. Although students' mental models in this study were found to lack the idea of entropy as the impetus of chemical reactions, a few other attributes seem to have emerged among students at the higher level of education; namely, *stability driven*, *energy factors*, and *chemical structure factors*, which are more scientifically sound ideas. These attributes may link to a *teleological* view of chemical reactions as noted above (Talanquer, 2007), which emerges during higher levels of education. Therefore, it can be argued that students' mental models may develop from an agentic model towards a chemical teleological view of chemical spontaneity.

8.5 Summary

This chapter presented an interpretation of the research findings concerning students' mental models of chemical reactions. It was shown that students' mental models are either particulate or non-particulate in nature. The mental models that were attributed as non-particulate showed to confuse between chemical reactions from physical changes, to misrecognise of the conservation of mass in chemical changes, and to describe chemical reactions as either transmutation or displacement. On the other hand, when holding particulate mental models, students described chemical reactions as a process of *submicro changes*, *formation of new substances*, and *rearrangement of atoms*. However, students' mental models were commonly not associated with the idea of a barrier to reaction, in absence of the activation energy notion. In terms of energy change, most students had energy transfer attributes in their mental

models. However, this aspect of their mental models was inconsistent, with some thinking that energy change was either energy gain-loss or energy transfer that is linked to energy absorption and release in chemical bonding. An overriding finding of this study is that the causal agentive attribute is at the core of students' mental models, with the idea that chemical reactions are driven by agents that determine both rate of reaction and chemical spontaneity. Based on these attributes, three types of mental models were isolated, namely Model A, B, and C, which were distinguished in terms of particulate and energy change attributes. Additionally, students' mental models progress from Model A to the more advanced Model C.

The next chapter provides the conclusions and implication of the findings, the possible limitations of the study, and suggestion for potential research arising from the research findings.

Chapter 9 Conclusions and Implications

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This chapter provides highlights of the major findings of the study. This is followed by the implications and recommendations drawn from the findings. The methodology of the study is reconsidered in light of the limitations, and the chapter conclude with some suggestions for future research.

9.1 Conclusions and Implications of the Inquiry

The purpose of this cross-sectional study was to explore the nature of students' mental models at different levels of education. The conclusions and implications of the findings are discussed across four areas: (1) the non-particulate mental model of chemical reactions, (2) the plurality of energy in chemical reactions, (3) the agentive model of chemical reactions and (4) the progression of students' mental models. Following in sequence are the researcher's recommendations for addressing the issues raised in the implications.

9.1.1 Non-Particulate Mental Models of Chemical Reactions

Although about half of the students in this present study indicated that their mental models are based on the particle model of matter, there were indications that their mental models may be non-particulate mental models. This is consistent with the findings that students have difficulty distinguishing chemical changes from physical changes, fail to recognise conservation of mass in chemical systems, and are limited in describing chemical changes even at the macro level. These students also struggled to provide an explanation of how

chemical reactions happen at the submicro level, which includes the notion of particle collisions. Taken together, these findings suggest that these students' mental models are non-particulate in nature and comprise a transmutation view of chemical reactions, a model which possesses little capacity for explaining chemical changes. Despite being taught about the particulate nature of matter during formal instructions, the students seemed either to choose not to apply the model or were incapable of incorporating the particulate model into their mental models. This finding implies that the notion of matter comprising particles has not been firmly developed in their education, although these ideas are clearly stated in the Malaysian Integrated Curriculum for Secondary School (KBSM¹) Science syllabus.

Holding a non-particulate view of matter in students' mental models likely their mental models development concerning the concept of matter. This is because chemistry, in this era, is a study of matter that is mainly based on the idea that matter is atomic, and "without this fundamental understanding of the composition of matter, chemistry would be intellectually amorphous" (Atkins, 2005, p. 20). This gap in their understanding also implies that teaching a variety of chemical reaction types, such as acid and alkali, metal and non-metal reactions, metal compounds, and other physical properties of matter such as solubility and air pressure, are likely to be futile because these phenomena are best described and understood from the particulate perspective. Besides that, with the non-particulate view in their mental models may also delayed the mental models development in terms of chemical kinetics, which another important aspect of chemical reactions.

Thus, it is recommended that the idea of atomic matter (rather than mere particle) need to be nurtured and become the central underpinning idea in studying and understanding the nature of matter. Students should also be taught on how to *use* this model in explaining chemical phenomena (i.e., chemical and physical changes). This emphasis may also then help them

¹ Local acronym which stands for *Kurikulum Bersepadu Sekolah Menengah*.

integrate the macro and submicro levels of chemistry in their development of understanding of chemical reactions. In other words, science teaching should be geared towards developing students' initial non-particulate mental model of matter using concrete representations (such as concrete models, role-playing, and computer simulations) and encouraging them to apply the particulate model to make sense of their everyday experiences regarding chemical phenomena.

9.1.2 Non-Kinetic Mental Models of Chemical reactions

This study also suggests that students' mental models can be non-kinetic. This is indicated from the observation that the ideas of particle collisions and activation energy are used only by a minority of students in explaining the prediction of change in rate of reaction, even though these ideas are taught in their classroom. Despite the lack of application of these ideas, students were able to correctly predict or explain the rate of reaction in different conditions. These findings suggest that the idea of particle kinetics is either not fully grasped by students (especially those at upper secondary school) or they chose not to apply the idea and preferred to use their 'practical' intuitive rules (like - more of A, then more of B) in explaining rate of reaction, because the idea is too complicated for them to utilise. This conclusion also suggests that this limited understanding of the particulate nature of matter may impede students' understanding of particle collisions and especially the idea of activation energy.

Thus, it is urged that before the ideas of particle collision and activation energy are introduced, the ideas of particulate nature of matter and energy are firmly constructed. In the Malaysian context, the idea of particles (as well as atom and molecules) needs to be introduced in lower secondary school science before students are exposed to more sophisticated ideas. However, as indicated by science educators, the introduction of kinetic model of particles may not be easily 'installed' into students' mental models. Therefore, the introduction of a kinetic model of particles in upper secondary school should be enhanced with representations or visualisations such as computer simulation, which would help

create a link between the macro level and submicro levels of chemical reactions that are essential for facilitating the development of students' mental models.

9.1.3 Plurality of Energy in Chemical Reactions

The notion of energy in chemical reactions seems to be a conundrum in students' construction of their mental models. This problem is indicated from the mixture of models or ideas for energy held by students, which they have used when explaining about chemical reactions. These models include the transformation of energy model, the quasi-substance model, the energy transfer for physical system model, and the energy transfer for chemical system model. The idea that energy change in chemical reactions involves transformation of energy was found to be held by many students across all levels of education. The preference for this model could perhaps lie in the straightforwardness in the explanation of energy change in chemical reactions. Energy was viewed as a quasi-material that can be added, removed, or stored in matter. Although this may be flawed, students' treatment of energy as quasi-substance may actually function as a means for students to comprehend energy change in chemical reactions. After all, energy and matter are not necessarily different, for example, from a quantum mechanics point of view. In addition to the transformation of energy model, some students incorporated the energy transfer model, where the energy flow in chemical reactions is seen as similar to energy flow in a physical system. For students from the higher levels of education, energy transfer may have been incorporated in their mental models of chemical reactions; nevertheless, some of the students cannot link energy change with chemical bonding. Therefore, it may prove fruitful to emphasise the notion of chemical phenomena that involves a system and surroundings during instruction. This emphasis may provide students with a foundation for building their mental models of chemical reactions with regards to energy change.

An overarching implication of these findings is that students' mental models are not well attributed in terms of energy involvement in chemical reactions. This problem may have been compounded by students' attempts to apply their

fragmented models of energy that they have experienced in different learning areas (e.g., thermal conduction in physical systems or kinematics), in chemical systems. Therefore, this conclusion implies that students have inadequate understanding of the nature of models in science, which again suggests that science teachers should emphasise developing students' understanding of the nature of models and modelling in science as a whole.

9.1.4 Agentive Model of Chemical Reactions

The core attribute of students' mental models across all levels of education is considered to be agentive in nature; that is, chemical reactions are viewed as driven or controlled by causal agent(s), including chemical substances and heat energy. Two implications can be derived here. First, the agentive model of chemical reactions may impede students' understanding of the chemical thermodynamics dimension of chemical spontaneity. In the scientific explanations, entropy and Gibbs free energy are used to explain a spontaneous reaction as "having the potential to proceed without the assistance of external agency" (Sanderson, 1964, p. 13) – the exact opposite of the causal agentive notion of spontaneity. Therefore, this study recommends that students at postsecondary level need to be challenged and shown that their agentive mental model cannot explain chemical phenomena such as the auto-decomposition of chloramines to ammonia that occur without 'intervention.' The same is true for the well-known 'clock-reaction' also known as the Belousov-Zhabotinsky oscillating reaction¹ that seems to change forward and backward without any 'agent' involved. The spontaneous endothermic reaction of barium hydroxide octahydrate and ammonium thiocyanate, which seems to progress without the intervention of heat energy, is also a good example to confront students' causal agentive idea. We can present these unfamiliar types of chemical reactions to students not only in the classroom but also by encouraging students to explore

¹ Other oscillating reactions like the Briggs–Rauscher reaction may not be suitable since they require stirring that student may consider it as the agent.

such reactions using technology, such as video streaming over the Internet and interactive multimedia.

The second implication that may be drawn here is that the agentic model of chemical reactions was used by most students not only in explaining the direction of a reaction but also the rate of reaction – again using the role of causal agent(s). This could be one reason why students get muddled between chemical kinetics and thermodynamics. Crucially, it is students' pre-existing agentic model of chemical reactions that renders the introduction of chemical kinetics and thermodynamics ineffective; thus, they will not grasp the complex idea of activation energy, and entropy. This limitation (especially among students of higher levels) can be averted through series of modelling exercises. This shift could be further reinforced with more teleological explanations such as dispersal of energy and matter, stability, and equilibrium, rather than using words that imply causality such as 'cause,' 'agent,' and 'because' during formal instruction.

9.1.5 Types of Mental Models of Chemical Reactions

There are three main types of mental models of chemical reactions that were identified in this study. They are Model A, B, and C. Model A is considered an initial mental model that students may have developed by interaction with their surroundings. This mental model is typically non-particulate, builds upon intuitive assumptions, and treats energy and matter as similar entities. It needs to be restructured carefully, building the notion of chemical change based on a particulate model of matter. As mentioned above, introducing the notion of chemical reactions and even physical changes without links to the submicro level will not only fail to develop a scientific model but may also further cement their initial mental models. Furthermore, Model A, which is mainly held by Form 1 and Form 4 students, indicates that science education at lower secondary school seems unsuccessful in terms of evolving the initial Model A into a particulate mental model of chemical reactions. It is apparent that the non-particulate view of chemical reactions is retained by most students in their lower secondary

schooling. This finding implies that this initial mental model is, like many alternative concepts, highly stable, and it should not be taken for granted that such a model can be readily replaced, because students holding Model A were capable of using their model to make logical explanations and predictions about at least some of the phenomena that were presented to them. Teachers need to be aware that the idea of particles such as atoms, molecules, and kinetics, is not readily comprehensible to students when introducing the topic of chemical reactions and physical changes. Therefore, lower secondary students should be introduced to the particulate idea of matter (including the concepts of atoms and molecules) through more concrete or tangible models (i.e., models with concrete modes of representation) such as 3D models, scale models, and physical simulations that lead to the development of understanding of the nature of models.

The second type of mental model (Model B) is considered a synthetic model. Students who hold this mental model expressed both initial and scientific attributes. This mental model type is mainly held by Form 6 students, which indicates that they were only able to restructure some aspects of their mental models about chemical reactions during their learning in upper secondary education. This observation implies that students' retention of non-particulate mental models in the lower secondary education may well inhibit them from engaging in fully-fledged chemistry education at upper secondary level. Holding a non-particulate mental models of matter means they will find it difficult to make sense of the concepts of atoms, atomic structure, electron configuration, and chemical bonding, as well as chemical reactions. Therefore, it is strongly urged that greater focus is made on developing a particulate model of matter (with the introduction of atoms and molecules) as a component of students' mental models of chemical reactions at the lower secondary education. Specifically, this means that lower secondary school students should be introduced to model-based instruction that encourages them to construct acceptable mental models of particles and link these models with the chemical phenomena.

The third type of mental model that was identified is Model C. These mental models integrate coherently the notion of particulate, kinetics, chemical bonding, and energy change in chemical reactions. Nevertheless, despite this more coherent integration, even senior university students who hold Model C were limited in their discussion of chemical thermodynamics, particularly the notion of entropy. This finding indicates that students' mental models of chemical reactions are either entirely reliant on a causal or on a teleological notion of chemical reactions when seeking to determine chemical spontaneity and reversibility. Students holding this model are also seemingly prone to confusing the spontaneity of reactions with the speed of reactions. The implication that students did not express or invoke the notion of entropy may simply be that they have yet to grasp the idea of entropy and incorporate it into their mental model because either this idea is too difficult to understand, or that it is being presented in a way that cannot be understood. It could also be that entropy is seen as irrelevant and too complicated to be utilised anywhere other than in response to examination questions. This situation can be better understood by considering the fact that chemical thermodynamics is only introduced at the university level in the expectation that students would be able to grasp the idea through mathematical expressions. Therefore, if university students were expected to graduate with a sound understanding of the most fundamental idea of chemistry, they would need a basic foundation of thermodynamics prior to their entry to the university. Looking at previous research about this issue (e.g., Goedhart & Kaper, 2003; Stylianidou & Boohan, 1998), it seems that thermodynamics needs to be introduced 'softly' in secondary education or at the pre-university level, by employing the idea of entropy in terms of spreading out or decreasing difference when trying to explain why chemical reactions happen (e.g., Ben-Naim, 2010). Besides that, it is also worthwhile to consider an improvement of the teaching practice at the university level, by not assuming students' ability to grasp abstract ideas such as the entropy without problems but by providing them with more concrete models.

9.1.6 Students' Mental Models at Different Levels of Education

In general, secondary school students' mental models of chemical reactions were more likely to be Model A; that is a non-particulate model. It is expected, however, that Form 1 (fresh from primary school) would have limited mental models because of the phenomenological approach used in their introduction to properties of materials. This, however, should not be the case with Form 4 students, who have been exposed considerably more to the idea of particles (but without the notion of atoms and molecules) and kinetic theory in their lower secondary level. This observation implies that students mental models are not much improved in lower secondary level.

Since, the idea of particulate nature of matter, as mentioned previously, forms the foundation of understanding for other aspects of chemical reactions especially particle collisions and activation energy, it is recommended that at lower secondary level, the submicro level ideas (i.e., particles, atoms and molecules) be the central component in developing students' mental models of matter and consequently their mental models of chemical reactions. This idea needs to be nurtured at the lower secondary school level, because with a firm understanding of the particle model of matter prior to upper secondary school, students may develop a robust mental models, which serves as a foundation in developing other aspects of chemical reactions especially in kinetics. This also implies that even at the lower secondary level, students need to be taught about the submicro level of chemistry (applying the idea of atoms and molecules) through representations and modelling, because phenomenologically introducing them to chemical reactions, such as decomposition of metal carbonates, neutralisation, and metal-nonmetal reaction, may not serve any improvement in students' mental models of chemical reactions.

Although the findings of this study suggest that only Form 6 and university students were able to incorporate the idea of particle collisions and activation energy in explaining chemical reactions at the submicro level, a substantial number of students even from these levels of study did not utilise or expressed

these ideas (i.e., using Model B). A conclusion that can be drawn here is that although kinetic theory of particles is apparently a straightforward and essential idea to the understanding of chemical kinetics, students even from the higher levels of education tend not to apply this idea. It may be that the university students choose not to use the model because it is easier to use simple and practical intuitive rules, or the idea of particle kinetics is not a component in Form 6 students mental models because it was not well developed during their upper secondary school chemistry.

In cases where university students did not apply the kinetic theory in understanding chemical phenomena, it is proposed that students need to be given more opportunities in applying this idea in informal ways, beyond the classroom or in test papers, such as in problem or project based activities, so that they would be able to apply and internalise the idea of particles and its kinetics meaningfully, thenceforth, developing further their mental models of chemical reactions. However, in the later case, the underdevelopment of mental models in terms of kinetic components, as mentioned in previous section, calls for a better representation or modelling of particle kinetics that enables students at upper secondary level to link between the empirical level of rate of reaction and submicro level, such as by computer simulations or role playing or analogy but with the understanding of the nature of models in science.

In terms of energy in chemical reactions, students across all levels of education seemed to hold the notion of energy as quasi-matter, thinking energy is contained in chemical substances, and explaining energy change through a comparison of energy 'stored' in reactants and products. Energy also was viewed as being transformed from chemical energy into other forms of energy, especially heat energy, which was usually treated as reactant or product in chemical reactions. Moreover, 'hotness' or 'coldness' of chemical reactions were also explained in a way similar to heat conduction; that is, a drop of temperature indicates a drop of heat energy. Only a small fraction of students at the high level of education expressed scientifically sound attributes in terms of energy change in chemical reactions such as energy transfer and its relation with

chemical bonding. These energy attributes for students' mental models may be acceptable for students at the secondary level. However, postsecondary and university students who expressed these attributes may indicate that their mental models of chemical reactions in relation to energy were poorly developed. This may imply that the notion of energy has never been further developed after lower secondary level, and continued to be viewed as 'something' that is in many forms and interchangeable. This is probably because the notion of energy in lower secondary school is only extended in the subject Physics, and that is not compulsory for students taking chemistry at the upper secondary and postsecondary levels.

A lack of understanding of the notion of energy interferes with students understanding of both chemical kinetic and thermodynamic concepts such as activation energy, enthalpy, and entropy. Therefore, learning chemistry inevitably implies the demand of the substantial understanding of energy, similar to the demand in understanding the concept of matter. As a recommendation, this call for Malaysian science education to integrate the learning about energy, a similar emphasis with the understanding energy in physics, or to make physics as compulsory subject at the upper secondary and postsecondary levels as a preparatory to embarking on university chemistry.

Finally, this study also revealed that a common view about chemical reactions is that of the causal agentive notion, which was used to explain chemical spontaneity, chemical reversibility, and rate of reaction. This attribute of mental models, however, emerged among students except those in Form 1, which indicates that this attribute may have developed only in lower secondary level, but not a primary level. This may mean that the science curriculum in Malaysia at secondary and postsecondary school level may have indirectly inculcated this idea in students' understanding of chemical phenomena through introduction of concepts such as "the factors of rusting are air and water," oxidation agents, and reactive metals. Therefore, it is inevitable for students to develop such view of chemical reactions and further crystallised the causal agentive view of chemical reactions throughout primary, secondary, and postsecondary. Furthermore, the

question about why chemical reactions happen is not being address even at the postsecondary level. The senior university students also tended to apply causal agentive view (together with other views such *stability driven*, *energy factors* and *chemical structure factors*) in explaining chemical spontaneity and reversibility, despite the fact that they were introduced to the idea of entropy in physical chemistry. This may imply that the entropy concept may not been easily integrated into their mental models, since the notion of causal agentive has been long established during their secondary or postsecondary level.

In short, the idea of entropy, or the question of why chemical phenomena happen, is not adequately addressed prior to the university level. As has been recommended previously (Section 9.1.4 on page 335), this aspect of why chemical reactions and the idea of entropy, as dispersal of energy and matter, should be introduced at secondary and postsecondary level, to provide opportunity for students to reconstruct their mental models, which basically run on a causal agentive assumption. This also leads to a call for improvement of instructional practices in chemistry, by avoiding statements or representations that can imply cause-effect or causality, such as ‘agents,’ ‘because,’ and ‘factors’ in the classroom and also textbooks.

9.2 Limitations of the Inquiry

Measures taken to ensure the trustworthiness of this inquiry have been described in a previous chapter (Section 4.9, page 166). However, a number of caveats need to be noted regarding the present study. Jaeger (1998) argues that any inquiry, no matter how robust, how long, or how well resourced, inherently has some limitations. He argues that this is not of concern but that it is important for researchers to acknowledge limitations and attempt to communicate to readers what these limitations are, and consider what impact they may have. That is the purpose of this section. The findings in this inquiry were not designed or intended to generalise to a population. This claim is made because the study is limited by the use of a cross-age design, which does not permit identification of causal relationships. Thus, the study is only able to

produce a 'snapshot' and the findings may be different if the study was conducted with a different research design such as longitudinal or experimental design. In addition, the sample for this inquiry, whilst wholly appropriate for an interpretive inquiry is small, based on convenience, and relied on students' voluntary participation. Hence, since the sample is non-random it may not be a good representation of the population. Additionally, the research methodology was interpretive and designed not to generalise but to provide an in-depth understanding (Guba & Lincoln, 1989; Lincoln & Guba, 1985).

It also is very important to remind ourselves that mental models are complex, implicit and multi-faceted (Jonassen & Cho, 2008). As a consequence, although there are advantages of using interviews in mental models studies as noted in the methodology (see Section 4.5.2, page 143), the Interview-About-Instances (IAI) that was described in Chapter 4 (see page 148) may in itself imposed some limitations. The semi-structured nature of the interviews, in which an attempt was made to access particular aspects of students' mental models of chemical reactions, does not necessarily allow students to fully express their mental models. The choice of chemical phenomena used in the interviews may have been too complex for some students, especially the younger ones, to comprehend, hence inhibiting their ability to express their views. Furthermore, as mentioned in Chapter 1, Malaysian students are not encouraged to explain or express themselves verbally, and may then have felt uneasy to fully express their mental models, due to a lack of communication skills and language proficiency¹. Finally, because the scope of topics covered in the interviews was comparatively extensive and with time frame constraints, the interviewer's ability to probe for in-depth understanding was somewhat limited, and some of the students' responses late in the interview were rather brief.

¹ The generation of the students in this study were those who learn science in English which may not even their second language. This was addressed by letting the students to use whatever language(s) that they are comfortable with.

9.3 Suggestions for Teaching of Chemical Reactions

This study results in some general observations concerning students' mental models of chemical reactions. Students were found to express their mental models in a way that showed absence or a lacking of scientific models such as particle model, particle collisions, activation energy, internal energy and entropy, despite that they should have had understanding, based on their formal learning about these scientific ideas. This study also indicated that students across all levels of education rely on their intuitive assumptions as their core of their mental models, such as the notion of a causal agentive that governs the occurrence of chemical reactions and simple heuristic rules in predicting conservation of mass and rate of reaction. These students can be considered higher achievers (at least higher than average) since they were in the science programmes that require good result in science subjects. As discussed in the previous section, any lack of scientific attributes of these students' responses may indicate that their mental models were not developed towards was expected based on their levels of education. Therefore, this study is consistent with the challenge in science education, as noted by Gilbert and Osborne (1980) who say it is hard to develop students' mental models of phenomena to become scientists' mental models, and not merely provide simple knowledge of science content that is facts and laws (Borges & Gilbert, 1999), and this calls for strategies to help students to construct their mental models. As discussed in Section 2.3.2 (page 59), students' learning of science is not only about learning scientific models but should also involve the process of modelling; that is building models as a process of expressing or externalising their mental models. Consequently, several suggestions for the teaching of chemical reactions and moving towards developing students' mental models are made below.

While the introduction of chemical change at the primary school level is appropriate at the phenomenological level (macro level), lower secondary school students need to be introduced to submicro ideas. This includes the particulate nature of matter, the compositions of chemical substances, and the application of these ideas not only to physical changes but also in chemical reactions. This

necessitates confronting students with various phenomena that requires the application of the particle model. The development of the particle model is crucial at this level of education, since it is the first time of students' mental models are used to link between the macro level and the submicro level of transformation of matter, (i.e., physical change and chemical reactions), and also serves as the foundation of upper secondary chemistry. In the classroom, this may be done by the use of simple 3-dimensional analogical models such as puzzle blocks that can be used to portray or explain physical changes and chemical reactions at the submicro level and its relation to the macro level. Potential phenomena that maybe good for this strategy is comparing between evaporation and hydrolysis of water, whereby a 3-dimensional model can be used to show how the arrangement of water molecules change in evaporation but not the arrangement of hydrogen and oxygen atoms, and how chemical composition of water changes into hydrogen gas and oxygen gas in the hydrolysis of water. Students may also be encouraged to use these 3-dimensional models in exploring and described other phenomena, such as rusting and acid-alkali reactions at the macro and submicro levels. Nonetheless, such a model should not be expected to explain itself, its limitation and its functions as mere a representation, but need to be communicated by the more able persons, the teachers.

At the upper secondary and postsecondary level, the next stage in developing students' mental models of chemical reactions is the relation between the transformation of matter and energy change. The approach by linking between macro and submicro through modelling also can be used in this level of education, with an expansion to the kinetics and energy changes in chemical reactions. A potential analogical model that can be used for the purpose of facilitating the development of students' mental models the mousetraps and ping-pong balls model¹ (Figure 9.1). Through this analogical model (either as a video presentation or re-enactment), the nature of chemical reactions at the

¹ The video of mousetrap and ping-pong ball can be viewed from NatSciDemos (2010, June 8) and ScienceBob (2012, November 28).

submicro level can be represented in terms the energy change from potential energy to kinetic energy and the dispersal of mass and energy. Again, however, this analogical model should be used through discussions between teachers and students on how it bridge between macro and submicro levels.



Figure 9.1 Mousetraps and Ping-pong Balls as an Analogical Models for Chemical Reactions (Arbroath, 2011, May 3)

For further enhancement of students' mental models at higher level of education, they should be provided with more opportunities, not only using scientific models and their mental models, but in the expression or construction of models or representation of chemical phenomena. Approaches that would facilitate such intention are problem-based or case study or project-based learning that enables students to explore the fundamental ideas of chemistry about how and why the transformation of matter happens. This may include special cases of reactions, such as spontaneous reactions of diamonds that turn into graphite, oscillating reactions, polymerisation, and egg denaturation. However, the key component of this approach is that students would need to use their mental models to understand their surroundings, and more importantly, would express their mental models through communication (presentations and paper work) that enable them to get feedback from teachers and also practicing scientists.

9.4 Suggestions for Future Research

The participants in this study are students from primary, secondary, pre-university and university who mainly studied in science or who were intending

science majors. Therefore, comparison of mental models of chemical reactions among those students studying chemistry, such as organic, inorganic, physical chemistry, chemical engineering, and also among the practitioners would merit further research. Likewise, a longitudinal inquiry may be of interest in providing insights into how students' mental models of transformations of matter (chemical and physical changes) develop over time.

The findings from this study raised some pertinent issues for the teaching and learning of chemistry in schools. This study suggests that secondary school students' mental models of chemical reactions and matter are not well developed, potentially an indication that science education in this particular context failed to help students develop mental models. Therefore, an inquiry investigating the impact of an intervention would be beneficial. For instance, the application of modelling-based instruction that requires students to learn what a model is, how to use a model, how to construct a model, and how to evaluate the model, would be of interest to science education researchers.

Additionally, this study also found that students' intuitive knowledge of a causal agentive idea of chemical change plays a significant role in students' learning of chemistry. However, this study did not seek to address why and how this notion came to be so strongly embedded in students cognitive structure. This question may require research from another perspective, such as cognitive psychology and activity theory, looking at the development of knowledge concerning change of matter.

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Appendixes

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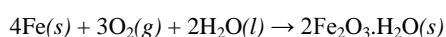
Appendix A Interview Protocol¹

Task 1 Metal Corroding

Picture²



Metal corroding



Questions

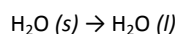
- By looking at this picture, tell me the change or changes that you think have happened?
Berdasarkan kepada gambar rajah ini, jelaskan apa yang kamu fikir, perubahan atau perubahan-perubahan yang telah berlaku?
- Do you think this is a chemical reaction (chemical change)?
Adakah ini tindak balas kimia (perubahan kimia)?
- Why do you think this change occurs?
Pada fikiran kamu, mengapa perubahan ini berlaku?

Task 2 Ice turning into water

Picture³



Ice turning to water



Questions

- By looking at this picture, tell me the change or changes that you think have happened.
Berdasarkan kepada gambar rajah ini, jelaskan apa yang kamu fikir, perubahan atau perubahan-perubahan yang telah berlaku?
- Do you think this is a chemical reaction (chemical change)?
Kamu rasa, adakah ini tindak balas kimia (perubahan kimia)?
- Why do you think this change occurs?
Pada fikiran kamu, mengapa perubahan ini berlaku?
- Why do you think the process of turning ice to water is easier than reverse process?
Mengapa proses ini lebih mudah berlaku dari pepejal kepada cecair jika kita bandingkan dengan proses yang berlawanan?

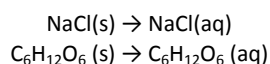
¹ Find attached CD for viewing the MS PowerPoint slide show used for the interview.

² (Wallpaper World, n.d.)

³ (Market Wallpapers, 2010)

Task 3 Adding salt and sugar together into a glass of water

Picture¹

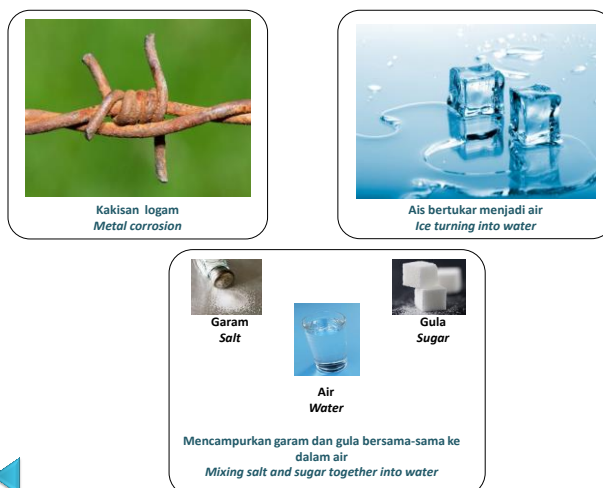


Questions

- What do think happen to the salt and sugar when they are mixed together into water?
Apakah yang kamu fikir akan berlaku apabila garam dan gula ini dimasukkan ke dalam air?
- Do you think this is a chemical reaction (chemical change)?
Kamu rasa, adakah ini tindak balas kimia (perubahan kimia)?

Alternative (This is used when time is restricted)

Pictures



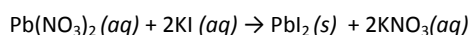
Questions

- What do you think happen in these pictures?
Apa yang kamu fikir berlaku dalam setiap gambar rajah tersebut?
- Which of these you think are chemical reactions?
Mana yang kamu fikir dalam gambar rajah ini merupakan suatu tindak balas kimia?
- How do you know that the changes are chemical reaction or not?
Bagaimana kamu dapat tahu perubahan tersebut adalah tindak balas kimia atau di sebaliknya?

¹ The pictures of salt, sugar cubes and glass of water are respectively downloaded from Science Science Media Centre (2011, July 6), Kathy (2011, December 12), and Osumo (2011, January 8).

Task 4 Double displacement reaction

Video clip¹

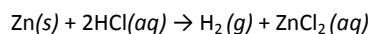


Questions

- What do you think the mass of the mixture will change after the change is completed?
Pada fikiran kamu, apabila campuran dan alat radas ini ditimbang semula selepas perubahan tersebut berlaku, adakah jisimnya akan berubah?

Task 5 Single displacement reaction

Video clip²



Questions

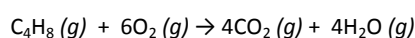
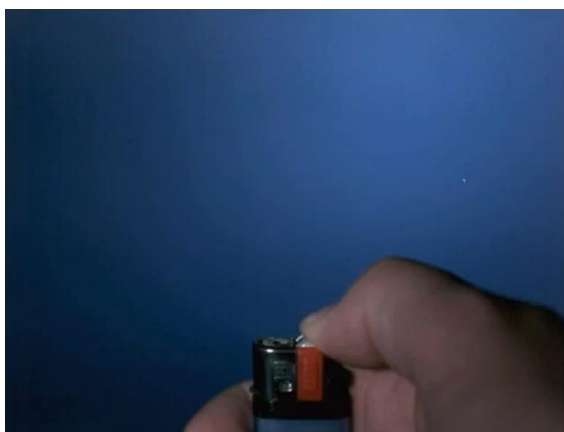
- If we put the conical flask and the rest of the mixture on top of a balance, what do you think of the weight will be?
Jika kita letakkan kelalang kon bersama-sama belon dan campuran tersebut di atas suatu alat penimbang, apa yang kamu fikir berlaku ke atas jisimnya?
- If you imagine the smallest particles of zinc and hydrochloric acid, can you draw or describe what you think how these substances change into its products that are zinc chloride and hydrogen gas?
Jika kamu bayangkan zarah-zarah zink dan asid hidroklorik, bolehkah kamu lukiskan atau jelaskan bagaimana zarah-zarah bahan ini berinteraksi sehingga membentuk zink klorida dan gas hidrogen?
- Do you think this change will be faster or slower as it takes place? Why do you say so?
Adakah proses perubahan ini akan semakin cepat atau lambat jika ia dibiarkan mengalami perubahan ini dalam tempoh masa yang agak lama?

¹ (ThirstForScience, 2009, February 22)

² (Alathrop, 2009, January 31)

Task 6 Gas lighter

Video clip¹



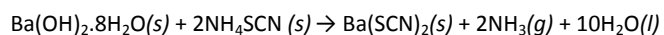
Questions

- What can you observe from the video clip?
Apa yang dapat diperhatikan daripada video klip ini?
- Why do we need to flick the gas lighter to enable it to light?
Mengapa kamu fikir kita perlu memetik mancis gas tersebut?
- If you imagine the smallest particles of butane and oxygen, can you draw or describe what you think how these substances change into its products?
Sekali lagi, jika kamu bayangkan zarah-zarah terkecil bagi butana dan oksigen, bolehkah kamu lukiskan atau jelaskan apa yang kamu bayangkan zarah-zarah bahan ini berubah menjadi karbon dioksida dan air?
- How is heat formed in this reaction?
Bagaimana kamu fikir haba daripada perubahan (tindak balas) ini boleh terhasil?
- Now, I would like you to think of the energy changes that would occur as this reaction proceeds from starting materials to products.
Cuba fikirkan mengenai perubahan tenaga apabila proses tindak balas berlaku daripada bahan awal kepada hasilnya.
- Could you draw a diagram for me that show the changes that you think occur as the reaction proceeds?
Bolehkah kamu lakarkan suatu rajah yang kamu fikir dapat menunjukkan perubahan tenaga semasa tindak balas tersebut berlaku?
- To your point of view, why this reaction tend to produce the reactant but not they way around?
Pada pandangan kamu, mengapa tindak balas ini cenderung kepada penghasilan hasil tindak balas dan bukan di sebaliknya?
- Why is the reaction continues (proceed) until its reactants used up?
Kenapa tindak balas ini berlaku berterusan sehingga semua reaktan tersebut habis bertindak balas?

¹ (Jul15, 2006, July 7)

Task 7 Endothermic reaction

Video clip¹



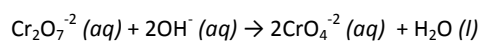
Questions

-
- What does the change in temperature mean to you?
Bagaimana kamu boleh jelaskan perubahan suhu tadi?
 - Again, I would like you to think of the energy changes that would occur as this reaction proceeds from starting materials to products.
Sekali lagi, saya ingin kamu fikirkan mengenai perubahan aras tenaga yang berlaku dalam proses ini daripada bahan asal kepada hasilnya?
 - Could you draw a diagram for me that shows the changes that you think occur as the reaction proceeds?
Boleh kamu lakarkan rajah yang menunjukkan perubahan aras tenaga tersebut.
-
- Why do you think this change takes place?
Pada fikiran kamu, mengapa perubahan ini boleh berlaku?
 - Why is the reaction continues (proceed) until its reactants used up?
Kenapa tindak balas ini berlaku berterusan sehingga semua reaktan tersebut habis bertindak balas?
-

¹ (Jacobsen & Moore, 2000)

Task 8 Equilibrium and reversibility of chemical reaction

Video clip¹



Questions

- What do you observe here?
Apa yang dapat diperhatikan daripada video klip ini?
- Can you tell me about the quantity of the chemicals when it is orange in colour and when it is yellow in colour?
Apa yang berlaku kepada kuantiti bahan-bahan tersebut semasa campuran itu berwarna jingga dan juga semasa ia berwarna kuning?
- The reaction seems to change colours as alkali or acid is added alternately, why do you think these happen?
Tindak balas ini menunjukkan ia berubah warna apabila alkali dan asid itu ditambahkan secara selang seli, pada kamu mengapa keadaan ini berlaku?
- Why this reaction is reversible?
Mengapa tindak balas ini berbalik?

¹ (ChemToddler, 2008, August 16)

Appendix B Thematic Codes

Component	Thematic code	Description
Composition	Expected natural occurrence	Chemical reaction is a natural occurrence, happening without manipulation.
	Change of chemical substances	Chemical reaction is considered as evident in any changes that happened to any chemical substance.
	Change in physical properties	Chemical reaction based on changes in the physical appearance such as physical state, colour and density, as all which characteristics of chemical reactions.
	Response towards reaction agents	Chemical reaction or changes happens to a substance as a result of some response towards other chemical substances or other agents such as surroundings, air, heat, light, etc., which is assumed to be causing the chemical substances to change.
	Formation of new substances	Chemical reaction as the production of new substances, which are chemically different from the initial substances
	Interaction between substances	Chemical reaction is a process to produce the product from a 'correct' ingredient - recipe of making a product. There is more than one chemical reacting, but neither of the reacting substances causes the reaction.
	Submicro changes	Chemical reaction in terms of submicro changes, which include modification of chemical bonding, transfer of electron(s), change in oxidation state, and chemical composition
Conservation of mass	Dependent on the physical state	Whether the mass will change or not, depends on the state of matter of the product.
	More substances formed	Formation of new substances contributes to increase of mass in the mixture.
	Gas properties	Gas cannot be weighed using a balance because the gas is too light or it is not on top of the balance or because of gas buoyancy
	Closed system	Mass of the mixture would remain the same regardless the formation of precipitation or gas.
	Rearrangement of atoms	The mass remains the same based on the notion that in a chemical reaction, atoms are rearranged in to make up any new product.

Component	Thematic code	Description
Particle collision	Internal arrangement	Change in internal arrangement similar to what they explain the change of physical state
	Movement of particles	The reaction becomes faster just because the movement of particles becomes faster.
	Collisions of particles	The rate of collision depends on the quantity of reactants – more reactants, more collision, therefore, more reactions happen.
	Site of reactions	The rate of reaction depends on the surface of the substances where the reactions occur.
	Probability for reactions	Chemical reaction is considered in terms of probabilistic events, and depending on the quantity of reactants.
Activation energy	Energy initiates reactions	The energy (or heat energy from the spark) is needed by the chemical substances, in order to make them react, or undergo a change.
	To lower the activation energy	There is energy barrier in chemical reaction but it can be manipulated by lowering it.
	Energy as a catalyst	Heat energy is assumed to be a catalyst that makes reactions take place faster or/and influences the magnitude activation energy
	Energy as a part of reactions	Heat energy provided from the spark as one of the reactants. Combustion is assumed to happen when only the entire component for combustion presence.
	Activation energy	Students thought that a chemical reaction is influenced by the activation energy. Energy is needed to overcome that energy barrier.
Activated complex	Metastable species	A chemical species similar to an activated complex, where formed before this decomposes into the reaction product(s).

Component	Thematic code	Description
Reaction mechanism	Transmutation	Atoms change into different types of atoms, or the thought that chemical substances change into a totally different chemical substances or energy.
	Quantity dependent	The formation of products depends on the quantity of reactants. More reactants, the products will be formed.
	Octet approach	The formation of the products mimics the formation of a compound from its elements. Electron transfer happens as described in the octet rule.
	Atoms rearrangement	Chemical reaction as described as rearrangement of atomic constituent of the substances, which result the formation of new substances with new atomic composition.
	Bond breaking-formation	The molecules of the reactants undergo bond breaking, and bond formation result in the formation of new product molecules.
	Transfer of electrons	Chemical reaction is explained as a process of manipulation of electron; it is either being transferred or received by atoms.
	Redox	Reaction is simply described as change in the oxidation state of the substances.
	Attraction between charges	Chemical reaction involves the attraction between charges in chemical reaction to form the product.
	Intermediate	Chemical reaction is explained based on the formation of intermediates or other chemical species in the process of chemical reaction before the formation of the product.
Conservation of energy	Mechanistic approach	Reaction described carefully through bond breaking, transfer of electrons and bond formation in which there is a consideration of the transfer of electrons towards suitable recipient and attraction between charges.
	Heat gain and loss	Temperature change in chemical reactions is explained based on the gain or loss of heat energy similar in heat conduction.
	Change in the form of energy	Heat energy in combustion reaction is explained merely on the change of energy form.
	Heat content	Heat energy is considered something that can be contained in the substances.
	Net energy transfers	Energy is both absorbed and released in chemical reaction. In exothermic reaction, more energy released compared to the energy absorbed. While, endothermic reaction, more energy absorbed compared to energy that is released.

Component	Thematic code	Description
Energy change	Change of physical state	The change of temperature mimics with the change of temperature in physical state of matter.
	Heat as a reactant or product	Heat energy is either product or reactant in chemical reaction. Combustion is explained to be hot because the reaction produces heat as part of its product, while heat considered used in the endothermic reaction.
	Energy transfer	Energy transfer in chemical reaction is either released or absorb. Exothermic reaction released energy and endothermic reaction absorb energy.
	Reverse energy transfer in chemical bonding	Bond breaking is assumed to release heat and bond formation absorbs heat.
	Enthalpy of formation comparison	The energy change in chemical reaction is explained based on the energy of the formation of the reactants and products.
	Energy transfer in chemical bonding	The energy change in chemical reaction based on chemical bonding.
Spontaneity	Reaction naturally happens	Occurrences of chemical reaction are considered as natural events or something that are meant to happen.
	Presence of reactants	Reaction depends on the presence of the reactant. It is a similar notion of the ingredient in culinary. When all of the required ingredient presence in the mixture, it supposed to undergo some chemical reaction.
	Reacting agents	The presence of agents such as heat, rain, and environment cause the reaction to occur and continue to happen.
	Reactive reactants	The causal agent presence in the chemical system is based on the reactivity of the reactant.
	Stability driven	Chemical reaction is assumed driven by the tendency of the reactants to form a more stable chemical compound or product.
	Electrostatic charges	The formation of the products is determined by the stronger electrostatic force between chemical species.
	Electronegativity differences	Compatibility in terms of the electronegativity drives the reaction to happen.
	Energy driven	Lowering of energy is more preferable in chemical reaction.

Component	Thematic code	Description
Reversibility	Irreversibility presumption	Preconceived notion of unfavourable in reversing a process.
	Physical state	Reversibility depending on the physical state of the product. If it is different, it is considered irreversible.
	Matter is not conserved	Some of the component in the reactant somehow loss, therefore, it is impossible to get the reactant.
	Through a different set of conditions	Chemical reaction is reversible when suitable condition was provided.
	Stability factors	Chemical reaction is considered to be irreversible since the product are more stable compare to the reactants. It is not preferable for the more stable product to revert to the less stable reactants.
	Chemical structure factors	Chemical reactions are irreversible because the chemical structures of products are totally different from the original reactants.
	Energy factors	Irreversibility in chemical reaction is rationalised based on the idea that energy required to reverse the chemical reaction, in which more energy required in the reverse reaction because of various reason.
	Equilibrium system	Reversible reaction as equilibrium system by reasoning the reversibility base on Le Châtelier's principle.

Appendix C Interview Excerpts According to Thematic Codes

Composition

Expected natural occurrence	
SF038	(Task 1) Chemical reaction is something happened naturally. Iron has something inside it that will gradually react with water and air, and rusting happened.
SF052	(Task 1) Chemical reaction, I think metal is the corrosion and ice turning into water. Yea. I think because it is something that we don't purposely do. It involves the nature, but mixing salt together, we don't make it happen. It doesn't happen naturally.
SF053	(Task 1) Chemical reaction ... maybe this one, it happens naturally, but this we make it. ... something we mixed ... this is natural.
SS071	(Task 1) Rusting happened in naturally. You cannot make something to rust, unless you scrap off the paint.
UF008	(Task 1) What I know is that, in our air, there is oxygen, everywhere, even here where we are sitting, except in vacuum. This thing is a natural phenomenon in the world. It is like why chickens lay eggs. It is the same with iron rusting. The reason it rusted because it was exposed.

Change of chemical substances	
SF039	(Task 2) I think all of them are chemical reactions. But they are different. Ice changed into water, is also chemical reaction. Because it also comes from chemicals. So, I think everything has chemical reaction.
SF042	(Task 1, 2, & 3) Chemical reaction ... all of it, isn't it. ... All of them have chemicals.
SF043	(Task 1, 2, & 3) All. Ice, because it absorb heat. It also one of chemical process. For this one, it dissolves. It is a mixing of solvent and solute to form solution. ... everything is chemicals. It involves chemistry.
SF072	(Task 1, 2, & 3) Chemical reaction, all of them. Because ... the element in the thing that makes it ... [change]
SF073	(Task 1, 2, & 3) Chemical reaction. Mixing salt and sugar together into water. Because the book says that water, salt and all these are chemicals. It is also. Because oxygen or carbon dioxide is in the air and also water, rain. That is why it rusts.
SO046	(Task 1, 2, & 3) All of these three are chemical reaction. They also changed.
SS030	(Task 1, 2, & 3) ... a changing of ions, wait, solid ion to aqueous ions, and in the process, mm, involve of change. If like that definition, ice into water, would also be chemical reaction. Actual I think, all three are chemical reactions. Because it involves all changes of state, in a way or another.
SS031	(Task 1, 2, & 3) Ice, everything is a chemical reaction. But ice change to water, change from solid to liquid. Chemical reaction, for me, a reaction that can cause a change. It seems everything is chemical reaction.
SS058	(Task 1, 2, & 3) It turns into water. From solid to liquid. This one, from solid and we put it into liquid, it dissolved. So it disappears, meaning that it is blended together. It is a chemical change.
SS059	(Task 1, 2, & 3) Chemical reaction, this one, the rusting. Rusting. Yes. Chemical. Rusting because it has hydrogen, oxygen ferum. For water salt and sugar, it is also chemical [reaction]. Because there is chemical substances. What's important there are chemicals.
UF015	(Task 1, 2, & 3) Substances change from one state to other state through chemical reaction. The substance changes from one state to another state. The substance changes into a different form. But it is not necessary change in terms of its content. It changes.
UF020	(Task 2) Because it involves change of matter, from solid to liquid. This change is a chemical reaction change. ... Because it involves change in state. Change from solid to liquid.
UO017	(Task 2) [Ice melting is] chemical reaction. Because everything inside is chemical.
UO021	(Task 2) Yes. It happens because of chemical reaction. Because it causes the ice changes to water. Yes. There is change happened.

Change in physical properties	
SO044	(Task 1) It [iron] mixes with water and air. A mixture of both.
SO075	(Task 2) [Rusting is a chemical reaction] Because when it is raining ... the air mixed with it, turn into rust. From the mixture of those two. Rain air, and iron. There is change in colour.
SS047	(Task 4) ... inside the solutions is the ions, so they will react each other and give a result, change colour to yellow colour.
SS057	(Task 1) I think it contains metal, water element and also ...
SS058	(Task 4) Because the product of the reaction, we know that before the process, it is already neutral. No colour, but suddenly it changes colour. Maybe the product of the reaction between lead nitrate with potassium iodide, produces lead iodide and causes the change of colour. Chemical change.
SS068	(Task 1, 2, & 3) [Chemical reactions are] Irreversible. Yes. ... ice and water can change back. And actually mixing salt and sugar into water, they are reversible ... when they are both dissolved, inside into water, right, we can distil them and or evaporate to get the salt back. [So it is not chemical reaction]
UF009	(Task 4) It seems the lead reacts with iodide, potassium reacts with nitrate ion. That's why it turned into yellow. Lead iodide. In terms of its colour. It react, so it changes in colour. After that, in terms of physical state. It also changes. So, chemical reaction happen.
UF010	(Task 1) Changes in colour and we can feel the rust. ... it is like corrosion, the arrangement of the metal is smooth, closely and joined. And when the rust is formed, it has holes on its surface. It is like decayed.

Change in physical properties	
UF011	(Task 1) [Rusting is a chemical reaction] Because the original colour has changed into reddish.
UF012	(Task 1) Become lighter and brittle. Ferum three are brown in colour. It changes into different substances.
UF014	(Task 1) ... chemical change is a non-reversible process. Because there are no new substances. And then it is reversible.
UF016	(Task 1) [Rusting is a chemical reaction] Because of the physical aspect. Looking at picture, it is already corroded and changed in colour. And based on what I understand, ... the composition inside is already changed. Then it will change in colour.
UF020	(Task 1) Involve chemical change, in terms of physical or appearance. It will change, so we can say it is chemical change.
UF060	(Task 1, 2, & 3) For chemical reaction, we know it when there is change in colour. We look at its colour change. Like the metal, we know it is silvery and after it is corroded, its colour changed to orange. So, one of the elements in the metal has been reduced.
UO021	(Task 1) I believe the colour of the metal wasn't like this before. It is maybe silvery, and after reaction happened between the metal and the surroundings, the colour changes like that. We know there is change only by looking. If there are no obvious changes that we can see, we will not know what changes already happened to the metal.
UO024	(Task 1) ... initially when it was bought, it is like shiny, silvery. Eventually, exposed to rain, two or three months, maybe it become something like this. Rusted.
UO028	(Task 1) ... physically we can obviously see its colour, from the metal's colour to reddish colour.
UO064	(Task 4) This is a chemical change, chemical reaction, because lead nitrate and KI, potassium iodide both are clear, according to the video, clear solution. After the reaction, if this is a reaction occurs, it forms lead iodide, which is a solid. So it changes state, from ion to solid.
UO065	(Task 4) It is a chemical reaction. Initially it is colourless but when the content in the test tube mix with the content in the conical flask, it started to show some changes. So, obviously, it changes in colour from colourless into yellow colour.
UO069	(Task 1) ... we know metal corrode because of the actually what when I say metal corrode is something extra on the surface in other words the metal reactions with oxygen to form what we call metal oxide. So it forms on the layer of the surface making what we call rust, corrosion.

Response to reacting agents	
SF038	(Task 1) Metal corrosion, it caused by ... there is water and air reaction and [these] caused the rusting.
SF039	(Task 1) The reaction of oxygen with the metal and water.
SF040	(Task 1) For the metal corrosion, it is rusting. Caused by acid rain. Although it is weak acid, does not give any impact to our skin, but is give impact to that. Let me explain more about the rusting process. It happens when there are water and air. ... The acid rain will combine, filling in the empty spaces. ... It [acid rain] able to change the colour because of the present of water and air, as I said just now, it can cause rust. Caused by the acid rain. There is something causes it to happen. Chemical reaction is something that makes something change. It involves process depends on the changes.
SF042	(Task 1) Rusting because there is water and air.
SF043	(Task 1) This one involves oxygen. And some other things. ... But it needs oxygen for rusting.
SF052	(Task 1) Metal corrosion, it happens when metal is surrounded by oxygen, metal oxide, so the substance in the oxygen causes the metal to corrode. So, that's why metal corrosion happen. Because of the oxygen.
SF072	(Task 1) It is exposed to sunlight, water, because of chemical reaction. From the chemical in the iron. It is exposed, after that it changed. The chemical inside of the iron. It causes the iron to change.
SF073	(Task 1) It is rusting because there is water and air. It is rusting because ... when something is exposed to water, it will rust. Where did the rust comes from? I don't know.
SF074	(Task 1) Maybe because of water or air. Because this one is exposed with to water or air, so it rust. The other one [ice melting] turned into water, when there is heat.
SO036	(Task 1) [The iron] Exposed to acid rain. Because it is exposed to sunlight. When zinc exposed to acid rain [actually referring to the roof], the zinc [roof] become hot or rusty.
SO037	(Task 1) [Rusting of iron] Rain erosion. Caused by heat, and water. It's, iron being heated. After that, when in contact with water, it get corroded. ... I have tried one iron wetted with saline water. I brought it home and I didn't wash it. The next day, I see that it has rusted. ... The air. The air outside, then when it is in contact with water, saline water, so nothing happened to it at first, then with the air, it become rust it [Ice melting] caused by the air. There is air, involving air.
SO045	(Task 1) It is caused by oxygen. When the water and oxygen meet. Meet with things that easily rusted. ... The zinc mixes with the liquid [HCl] and causes it to react.
SO046	(Task 1) Metal corrosion, it is caused by air and water.
SO054	(Task 1) Maybe it is in contact with lights and air. It is exposed to air and light. It happened because it is exposed to air and light.
SO055	(Task 1) It is because of water. Water causes it to rust.
SO056	(Task 1) The metal is rusting because of three factors; air, water ... We look at that. There's grass. Meaning, it is exposed to air and water. This orange thing, it's the rust.
SO075	(Task 5) Because the zinc in contact with the acid, mixed.
SO077	(Task 1) It was exposed to acid rain. Exposed to wind [air]. It caused by heating.
SS031	(Task 1) About the metal corrosion, it happened because ... when the metal is exposed to air and water, so the metal will corrode.

Response to reacting agents	
SS049	(Task 5) Because, the reaction causes some hydrogen gas to be released ...
SS057	(Task 1) The metal becomes rusted. Because the iron is metal, it is rusting because of exposure to water and air. I think it is a chemical reaction. It is the product of the reaction, and then it produces the rust. I think it contains metal, water element and also HCl that changes the colour.
SS058	(Task 1) It is rusting. It reacts when exposed with water and air. When exposed to the surroundings, exposed to rain and air, the roof [the local people calls roof as "zinc"] also rust. It is like the product of chemical reaction when it is exposed to factors like air and water.
SS059	(Task 1) The first one is rusting. Rusting because of present of oxygen. It has something to do with oxygen, carbon like that. It takes a long period of time, depends on the thing. ... (Task 2) The ice turns into water [also chemical reaction] because of heat. Because the heat provided cause the molecules to change into water.
SS067	(Task 1) [Rusting happened] Because the present of oxygen and water.
SS068	(Task 1) The first one is about rusting. Of course. And I'm thinking about is something to do with the oxidising ... When the metals react with the present of oxygen in the air.
SS071	(Task 1) Rusting. It is like an oxidation. I can see, like everywhere, every day. Especially like those gates without paint, unprotected. The rust is from chemical substance. It's formed from the rain. Rain water come in contact with the steel which is unprotected and the reaction happen, so it rusts.
UF007	(Task 1) When the surface of the iron is exposed to the surroundings like rain, water, environment. That's what causes the iron to rust. When the element in the iron metal but not sure what is its element, reacts with the element in the water like oxygen. The oxygen makes the iron undergoes reduction.
UF008	(Task 1) what I know is that in our air, there is oxygen, anywhere, even here where we are sitting, except in vacuum. ... The reason it [iron] rusts because it is exposed. So, it will rust.
UF009	(Task 1, 2, & 3) There is other substance reacting. There is an agent.
UF010	(Task 1) Between metal and the agents; air and water. The air and water molecules influence the structure of the metal. Because there is air in our surroundings. When there is air and water, even we put it in a container, the corrosion still happens.
UF011	(Task 8) Because when it is added with NaOH, it oxidised. After that, ion turns into chromate ions. If HCl is added, it turns back to dichromate ions.
UF012	(Task 1) The environment [surroundings] causes that the ferum suitable to change into ferum three. It [environment] stops it [rusting] to reverse. The environment forbids the reaction. Rusting happened when there is water and oxygen.
UF013	(Task 1) Rusting happened when there is water and oxygen.
UF014	(Task 1) Add with oxygen, the iron exposed to water and air. The environment that causes it to rust.
UF015	(Task 1) Metal corrosion occurred. Rusting. The iron initially without rust but when it is exposed to the humidity in the surroundings, the rust will form on the surface of the metal.
UF020	(Task 1) Rusting of the iron because of the presence of water and oxygen.
UF022	(Task 1) Because it is exposed to the other element. If we want it not to happen, we can prevent it.
UF060	(Task 1) Because in this chemical reaction, like ferum, it is easy to be oxidised when it surfaces is exposed to the air with oxygen in the environment. So, when ferum is oxidised, it turns to yellowish. ... (Task 8) Because OH can reduce the oxygen in dichromate. But when we add HCl, since it is strong, and has hydrogen plus, so the hydrogen plus will oxidise it to dichromate.
UF061	(Task 1) Ferum two to ferum three is an oxidation process due to the present of water and oxygen,
UF062	(Task 1) The iron been oxidise because of exposure to air
UO017	(Task 1) The metal is corroded because, because it has the presence of oxygen, so with the oxygen in the air, it will corrode.
UO019	(Task 1) For metal, it normally rust because it is exposed to water for a long period. So the process of rusting is a chemical reaction. I know it is a chemical reaction because there is metal and it gets rusted because of the water.
UO026	(Task 1) [Rusting happened] Because it is exposed to agents, like air and water. In this case the metal rusted because of the presence of the agents like air and water, that is oxygen.
UO027	(Task 1) Because there is water and oxygen. Because the present of those things.
UO028	(Task 1) It's also because of the iron changed. With the present of air and water.
UO029	(Task 1) It is a chemical reaction. The iron is exposed to the air. ... Eventually, it is exposed to air, that causes it to rust. It causes it to rust, the air and oxygen. ... I think chemical reaction is something that we do.
UO064	(Task 1) This, oxidation is auto-oxidation, as long as expose to air which contain water vapour and oxygen gas, it start oxidation process whereby the Fe atom will become Fe three plus.
UO070	(Task 8) So when sodium hydroxide is mixed, it forms chromate ion and the colour change to yellow. So, when HCl is added, NaOH and HCl will form sodium chloride and water. The sodium chloride is colourless. So, dichromate ions are formed again.

Interaction between substances	
SF038	(Task 1) Iron has something inside it that will gradually react with the water and air, and rusts.
SF040	(Task 1, 2, & 3) All of the three. Because these chemicals, as we know, interacts with the surroundings. It means reaction between something with something.

Interaction between substances	
SF041	(Task 1) Iron is rusting. A reaction between oxygen with iron. Oxidised. ... [the reaction] between chemical and chemical. Like just now [rusting], between oxygen and iron. Normally to me, there are two, there are two things. There is something reacting with something else. [But] not necessarily with something else. Maybe heat.
SF051	(Task 1 & 3) I think it is like something and with something that are combined. Is not only two, but maybe more. Is like being combined. It is still there, but it is already combined with the other one. So, both are mixed, but still in there.
SF052	(Task 4) Combine to the, with potassium iodide. And then become solid.
SF053	(Task 1) Rust. Metal corrosion, it happens because of combination of oxygen and metal. After that, forming from the air and iron, after that it rusts. ... It is from the element of oxygen, oxygen combines with iron, it became like that [i.e., rusted]. ... (Task 5) The zinc, when combine with the hydrochloric acid, it releases gas.
SO033	(Task 1) Chemical reaction is a response between two chemicals, when they mix together. But after a chemical reaction, between the water vapour and oxygen, it turns into rust. ... chemical reactions of metal and water vapour in air.
SO045	(Task 2 & 3) Reaction between two types of particles that involve in the chemical reaction. And the particles changed.
SS032	(Task 1) ... there is reaction with water and oxygen. This one, it just changes from ice to water. (Task 2) It changes into water by taking in the heat energy. So, there is no chemical reaction. (Task 3) While the salt and sugar just dissolving. No chemical reaction [happened].
SS047	(Task 1) Metal reacts with the oxygen or water [rusting]. So, the metal is corroded.
SS058	(Task 1) I know that metal corrosion is a chemical reaction between ferum, air and oxygen, causing it to rust. I know that chemical change causes the rust comes out. ... Chemical reaction is when the reactants are combined, and products are formed.
SS067	(Task 1) Chemical reaction. I will say the metal corrosion ... (Task 3) Yes. Salt and sugar. [It is chemical reaction] because it includes of oxygen. But ice turning into water, it includes only heat.
UF007	(Task 1) That's what causes the iron rust. When the element in the iron metal (not sure what is its element), reacts with the element in the water like oxygen. ... (Task 4) The Pb two plus react with the ion oxide [but written as OH].
UF008	(Task 4) Lead nitrate reacts with sodium iodide. It will turn into lead iodide. ... (Task 8) Interchanges between dichromate with chromate. When, dichromate is added with sodium hydroxide, it will reacts and become chromate. But, chromate, when it is reacted with hydrochloric acid, it become dichromate.
UF009	(Task 1) The substance, the metal corroded because it undergoes rusting process. Maybe it reacts with the surroundings, like water, acidic environment. Chemical, some changes happened to something. ... There are two things reacting [metal corrosion]. Chemical reaction has happened. ... (Task 4) It seems that lead reacts with iodide, [and] potassium reacts with nitrate ion. That's why it turned into yellow. Lead iodide.
UF010	(Task 1) When the object or the metal is exposed to air and water. After that, there is a reaction between the water and air with the metal until to one point it changes the structure of metal. This causes the metal becomes corroded.
UF011	(Task 1) the ferum ion reacts with oxygen and moisture, the water vapours. So, it is changed. It is oxidised.
UF013	(Task 1) The reaction between iron, oxygen and water. And produces a new substance that is the iron oxide. Ion hydroxide.
UF015	(Task 1) The reaction between the metal and the surroundings like the air, oxygen and ... the surface of the metal reacts with the air in the surroundings. After that chemical reaction will happen there.
UF016	(Task 1) The iron is rusted because it is oxidised by oxygen and also reaction with water. It reacts with oxygen and water.
UF018	(Task 1) The rusting process. Reaction between the water and air that makes it rust. ... when metal mixed with air and moist it will be like that. When the water, the moist from the air mixes with the metal it will reacts. ... (Task 3) Salt also chemical reaction. When the two are mixed, there is chemical reaction. ... Chemical reaction is when two chemicals are mixed together and new substances are produced.
UF020	(Task 1) [Rusting is a chemical reaction] because the iron is actually a type of chemical that reacts with oxygen. Therefore, we can say it is a chemical reaction. The rust must have reacted with oxygen so that we get the ferum oxide.
UF022	(Task 1) The metal reacts with water and air. And the metal is being corroded.
UO017	(Task 1) Chemical reaction is something that, the substance reacts chemically. When it reacts with the oxygen, so it will corrode. So this is a chemical reaction. A chemical reaction is something happen within react with something.
UO021	(Task 1) It is rusting because there is a reaction between the metal layers with the surroundings. That's what makes the rust surfaces. ... Surroundings, maybe from the air. Mixture of water and ,so forth. The metal and the surroundings.
UO023	(Task 1) Because chemical reaction is something like A plus B and it will produce something new. So, the rust is the new product, from the reaction between metal, water and oxygen.
UO024	(Task 1) When the thing [rust] is produced, the metal mixes with water, and reacts inside it, the iron, oxidised when mixed with water. So, this thing comes out; the yellowish is the rust, formed when, the thing, the chemical substances mixes with water.
UO025	(Task 1) From the reaction with air, the oxygen and forms the rust.

Interaction between substances	
UO026	(Task 5) When the zinc is in the solution, the hydrochloric acid, chemical reaction occurs between them. The hydrogen gas is given out. ... the reaction is very vigorous, so the gas, the hydrogen gas is given off, causing the balloon to expand.
UO029	(Task 1) The iron reacts with the oxygen.
UO069	(Task 1) ... the metal reactions with oxygen to form metal oxide. It forms on the layer of the surface making what we call rust.

Formation of new substances	
SF038	(Task 4) When lead nitrate is mixed with potassium iodide, it produces something. Producing something, some liquid.
SF041	(Task 4) compound produced after the reaction. I don't know which and which. But what I'm sure is it reacts, its product. ... (Task 5) When the zinc dropped inside, it reacts with the acid, so the zinc combines with the chlorine. It becomes zinc chloride. The gas formed, the hydrogen is released.
SF051	(Task 5) The reaction between zinc and hydrochloric acid. After that, it produces hydrogen.
SF052	(Task 5) When zinc mixed with hydrochloric acid, it produces hydrogen gas.
SO055	(Task 4) It is mixed, and something has been formed [lead iodide]. ... He mixed, then something else formed, like foam or something, maybe the weight is increased.
SS030	(Task 1) Chemical reactions are once where either a compound or element is formed from its constituent elements is considered a compound. ... (Task 2) [In ice melting] Only involves change of state as in from water to ice or ice to water, I don't feel it is a chemical reaction, just change of state. A physical change. (Task 5) The zinc would react with hydrochloric acid. ... This hydrogen gas then will be released and escaped to the balloon, where it's collected, leaving behind the zinc chloride in the solution.
SS031	(Task 5) The reaction of zinc and hydrochloric acid releases hydrogen gas. So, the hydrogen gas causes the balloon to inflate.
SS032	(Task 1) There are two reactants like in this metal corrosion, it has other reactants like oxygen and water. That's a chemical reaction. There is product from the chemical reaction. New substances are produced. ... (Task 5) [It is a chemical reaction] Because of the hydrogen gas been produced.
SS057	(Task 1) It is the product of the reaction, then it produces the rust.
SS058	(Task 1) Chemical reaction is when reactants combined and products are formed. Produces new product. ... (Task 4) the product of the reaction between lead nitrate with potassium iodide, produces lead iodide and causes the change of colour. ... (Task 5) When zinc is mixed with two mole of HCl, it will produce hydrogen gas.
SS068	(Task 5) When the zinc reacts with hydrochloric acid, it will release hydrogen gas.
UF007	(Task 1) The Pb two plus react with the iron oxide [but written as OH]. When it received electron, it will have charge. The iron becomes decomposed. ... (Task 3) Like the one, salt and water, there are two substances mixed together, it will produce new substance. ... When substances mixed together, something else, other substances produced. That is a reaction. We can see in terms of colour or colours of the new compound. Or, the other properties that can be observe or measured. ... (Task 2) [Ice melting] There is no new product. It is only the state is changed.
UF008	(Task 1) Yes it is chemical change and change of matter. It changes from ferum to ferum oxide. Two different thing. ... [Ice melting is not chemical reaction] Because it is not a reaction that change from one thing to another thing. Ah ... if it like this. It is corroded. This one it is close together. The ferum not joint together. It has not ... it is the same thing. Now, it combines with other thing. Here, there are other things, the ferum oxide. Two different substances. ... (Task 4) From what I see, it is reaction [lead iodide precipitation]. Because lead nitrate reacts with sodium iodide. It will turn into lead iodide. ... (Task 5) Reaction between zinc and water ... zinc with hydrochloric acid. When zinc reacts with hydrochloric acid, hydrogen gas will be produced. The gas filling in the space of the balloon. The balloon inflates.
UF009	(Task 1) Because change from iron forming (there is water) ferum hydroxide, something like that. So, maybe chemical reaction. This, there are two things reacting [metal corrosion].
UF010	(Task 8) It is the same with just now, they are moving and pulling each other and combined to form new substances. It will break and combine with hydroxide ion, to form chromate ion.
UF011	(Task 1) [Rusting is a chemical reaction] Because its iron reacts with the surroundings. So, it will produce new component. Reaction is when ... there are products [actual she meant reactant] and will react to form new compounds. It is ionised. It is a chemical reaction.
UF012	(Task 1) It is chemical reaction. Because it has, it involves two different substances which are called reactants and its products. The reactant is ferum, the iron wire, the air and water, the product is this one, the ferum three. Ferum three is brown in colour. It changes into different substances. Change from one substance to another one. It depends on the reaction, depends on the substances that are mixed and the reaction happened. ... For the corrosion, when the environment has water and air, it produces new product, something that is different. (Task 2) It is also the same with ice and water. When we melt the ice, it becomes water, new substance. (Task 3) But this one, when we add more, it is still salt and sugar, when they are saturated. ... So, there is no new substance. When we add [the sugar and salt] until it become saturate. ... Lead has already reacted with iodide and potassium nitrate is the product of the reaction from potassium with nitrate. It produces new product. New product.

Formation of new substances	
UF013	(Task 1) Rust is actually a type of chemical with new formula of molecule, different from the metal. ... The reaction between iron, oxygen and water. And produce a new substance that is the iron oxide. Ump ... ion hydroxide. Initially the metal exists as atoms. Exist as metal atoms. But, after this reaction, new substances formed. The formation of the new chemical, different from the metal atom. It exists as a type of ion. ... (Task 5) When the zinc and hydrochloric acid are mixed, chemical reaction will happen and hydrogen gas will be produced and zinc chloride as precipitate in the bottom.
UF014	(Task 1) From ferum to ferum oxide. It is a redox process and oxidation. ... it produces new substance. That brown one. The one brown in colour is the new substance. Ferum oxide, the rust. And then the reactants are the ferum and the oxygen. It forms ferum oxide. So the new thing, the new substance is the ferum oxide, the rust. ... (Task 5) This is a reactive metal. If it reacts with strong acid, it will release hydrogen gas.
UF015	(Task 1) The rust the product of the metal oxidation. Is like the product of the reaction of metal with the surroundings. ... (Task 5) hydrogen gas release from the reaction between zinc and hydrochloric acid.
UF016	(Task 1) Because it is ferum, made from ferum. And during the process, it changed from ferum two to ferum three. Ferum ion, positive two turn to positive three. And then it will change in colour. ... (Task 3) This is chemical reaction. This one none. Because there is changes from the sodium chloride. At first the molecules are together, once it is in solution, they become ions. From molecules to ions. ... Maybe, sugar will react with salt. ... When chemical reaction happen composition in the molecule changed, change in terms of its [chemical properties]. It reacts with other substance and it will form new products. The previous composition is still there but it combines with other chemical to form new products. But, none chemical reaction, it will maintain the same molecule; the composition is still the same.
UF018	(Task 1) The rust actually produced when oxygen mixes with water. The rust is not really from the metal. It is like between the metal, one from the metal and another one is from the air. It is not all from the metal. ... (Task 3) The sodium will combine with H ₂ O and sugar will also combine with H ₂ O. Yes. There are new substances. ... Chemical reaction is when two chemicals are mixed together and new substances are produced. The new solution is also chemical reaction. Because when there are different chemicals mixed up, it will form new substance. So, it is called chemical reaction. ... (Task 5) When the zinc and acid were mixed up, they will react and then hydrogen gas and zinc chloride will be produced.
UF020	(Task 1) It will form into ferum oxide compound. The rust must have reacted with oxygen so that we get the ferum oxide. They will form new particles. ... (Task 5) The zinc reacts with hydrochloric acid, producing the hydrogen gas and zinc chloride.
UF062	(Task 1 & 3) Chemical reaction, basically, when you combine some, for example, a chemical with another metal or chemical. If there is a reaction, then may be release of gas, or may change of colour, formation of the precipitate.
UF063	(Task 1) it [the rust] is from conversion of the oxidation of ferum to ferum two plus and ferum three plus.
UO017	(Task 1) Because the reactants react together and then undergo a process that change into the product. So, this is the same what happen in the [metal]. The metal reacts with the oxygen in the air, and then produces products. ... (Task 5) This is a reaction between metal and acid. So, the salt and the hydrogen gas will be produced, so when the hydrogen gas produced
UO019	(Task 1) Maybe in chemical reaction, from the original thing to something else. ... I think this is also chemical reaction. Because from salt and sugar added into the water, it becomes a new product. Before and after are different. ... (Task 5) it [zinc and hydrochloric acid] becomes solution, a mixture. It produces hydrogen gas and zinc chloride.
UO021	(Task 3) It is a chemical reaction because when salt and sugar are mixed it becomes solution. If there is change, then I consider it is a chemical reaction. New compounds.
UO023	(Task 1) Chemical reaction is something like A plus B, and it will produce something new. So, the rust is the new product, from the reaction between metal, water and oxygen. We say that chemical reaction when it produces new substance.
UO024	(Task 1) Rusting is a chemical reaction, redox reaction, so when the iron or metal are mixed with water or reacts with water, it will produce the rust. ... Chemical change, from something silvery, so inside it just normal metal, so when mixed with water, it change to new substance. So, it turns into new thing, like from Fe turns to new thing which is not Fe any more. New substance. ... (Task 5) From the hydrochloric acid component. So, it will precipitate at the bottom. New solution, zinc chloride.
UO025	(Task 1) What I know in Form 5, when the ferum reacts with the air which contains oxygen, it forms rust. Ferum trioxide. Chemical reaction, it will form something ... substance. It will change, forming new things. Something that produces the new product, like in rusting, from the metal, it reacts with oxygen to form the rust.
UO026	(Task 1) The iron reacts with the oxygen to produce oxides. Oxide ion. And then surface of the iron that expose to the air will undergo the process of rusting. Chemical reaction, for example, is when a chemical substance reacts with another chemical and then we can see the product.
UO027	(Task 1) For chemical reaction, it must involve loss or gain of electrons so that from reactants turns into products. When the reaction is carried out, the product is produced. ... (Task 3) Mixing salt and sugar will produce the product.
UO028	(Task 1) The ferum two plus change into three plus. Chemical reaction, it changes from something.

Formation of new substances	
UO064	(Task 1) This is an auto-oxidation [process], as long as expose to air which contain water vapour and oxygen gas, it start oxidation process whereby the Fe atom will become Fe three plus. the first one, because if it's ion bar, let say Fe atom change from Fe into Fe three plus, or Fe two plus, say, so this is a change of the oxidation state, which happen only in chemical reaction. ... (Task 3) Salt itself is originally as NaCl, Na plus, Cl minus. So, when it dissolves in water, it is still Na plus and Cl minus, but it's just surrounded by water molecules, and this do nothing to the state, I mean the original state, I mean it's still as Na plus and Cl minus. So, this is a physical change.
UO065	(Task 1) The metal corrosion is something like from ferum two reduce to Fe three. ... (Task 5) It is a reaction between zinc and hydrochloric acid will produce the zinc chloride and the hydrogen gas.
UO069	(Task 3) Chemical reaction is something changing from one form to another regardless of we see through physically or chemically. ... (Task 5) Metal, as I say, is only forming a new substance.

Submicro changes	
SS030	(Task 1) From the first one, I understand that this iron, this is iron undergoing oxidation ... (Task 5) The zinc would react with hydrochloric acid. ... and the will be an oxidation-reduction, whereby oxidises zinc into zinc ion reduces hydrogen into hydrogen gas, oh wait, reduce hydrogen ions into hydrogen gas. ... (Task 8) The hydroxide ion, will undergo oxidation, whereby donating electrons to dichromate, which therefore undergoes reduction. This reduction would change the oxidation number of chromate, into different oxidation number, which causes it to interact with light, differently. ... [It] seems of a different colour.
SS031	(Task 1) When the metal is exposed to air and water, the metal will corrode. ... the process of oxidation and reduction occur ...
SS048	(Task 1) Because the metal undergoes oxidation. Oxidation means release of electron ...
SS049	(Task 1) Metal corrosion, because is the redox reaction.
UF007	(Task 1) It is a reaction called as oxidation and reduction. Whereby, it involves oxidation and reduction.
UF010	(Task 4) Lead has positive two charges and iodine have negative. They will be attracted to each other. The lead attracts to iodide and potassium attracts with nitrates. ... the initial substance, KI is in contrasting charge. Pb and NO ₃ also in contrasting charge.
UF011	(Task 1) The iron metal is been oxidised. [to form] the chemical name is Fe ₂ O ₃ , ferum trioxide.
UF012	(Task 4) Lead has already reacted with iodide and potassium nitrate is the product of the reaction from potassium with nitrate.
UF013	(Task 1) Rust is actually a type of chemical ... with new formula of molecule ... different from the metal.
UF014	(Task 1) From ferum to ferum oxide. It is a redox process and oxidation.
UF015	(Task 1) From the oxidation of the metal.
UF016	(Task 1) The iron is rusted because it is oxidised by oxygen and also reaction with water. ... When chemical reaction happen composition in the molecule changed, change in terms of its chemistry. It reacts with other substance and it will form new products. The previous composition is still there but it combines with other chemical to form new products. But, none chemical reaction, it will maintain the same molecule; the composition is still the same.
UF022	(Task 3) Salt and sugar, it is chemical reaction because there is change in terms of the initial structure of the substance. Maybe there is certain change happen, maybe change in the position between them. Salt with water [there is reaction between them]. I think so.
UF060	(Task 1) For this metal, people from the villages say that if the iron gets wet with water, it will rust. Specifically, when metal is wet with water, it will corrode, the ferum get corroded, oxidised. ... In this chemical reaction, like ferum, it is easy to be oxidised when it surfaces is exposed to the air with oxygen in the environment. So, when ferum is oxidised, it turns into yellowish. Yes. It [the rust] is with the metal. So, it is reduced and becomes rust.
UF061	(Task 1) Metal corrosion. Obviously, it is oxidation process. From ferum two to ferum three, it is an oxidation process due to the present of water and oxygen, atomic, molecular change, something like.
UF062	(Task 1) This is metal corrosion. Basically, a redox reaction happened here. Involves the oxidation and the reduction process. The iron has been oxidised because of the exposure to air.
UF063	(Task 1) From the metal corrosion I think it's an oxidation of ferum to ferum two plus and ferum three plus.
UO019	(Task 1) What happened here is rusting. Maybe, there is an oxidation happened.
UO023	(Task 1) My opinion is, it happens because of redox reaction.
UO024	(Task 1) Rusting, it is a chemical reaction, redox reaction, so when the iron or metal is mixed with water or reacts with water, it will produce the rust. ... The chemical substances mixes with water, called redox reaction. There is something being oxidised and reduced.
UO027	(Task 1) Oxidation loses of electron and reduction is gain of electrons. For chemical reaction, it must involve loss or gain of electrons so that from reactants turns into products.
UO028	(Task 1) Metal corrosion. It involves oxidation process. It can be something that changing its phase but can also something is not changing its phase, but changing in terms of oxidation number. It has reduction, it has oxidation.
UO029	(Task 1) The rust is from the iron. It undergoes oxidation process ...
UO064	(Task 1) Metal corrosion, should be an iron and it undergo oxidation. ... Fe atom change from Fe into Fe three plus, or Fe two plus, so this is a change of the oxidation state, which happen only in chemical reaction. ... (Task 5) Displacement reaction, whereby zinc displaces hydrogen, forming zinc chloride, and with the release of hydrogen gas ...
UO065	(Task 1) The metal corrosion is about oxidation-reduction reaction.
UO070	(Task 1) It [iron] undergoes corrosion. Its surface has undergone oxidation process. So, it is in oxide form.

Conservation of mass

Dependent on the physical state	
SF040	(Task 5) The mass will change because the zinc has dissolved. That's what makes it change. I think because something in form of liquid is lighter.
SF074	(Task 4) Because, at first it is in form of liquid. From liquid to solid, become harder. So the mass increases.
SO044	(Task 4) Decreases. Because the atom becomes closer. I think it will decrease because it is not compact anymore.
SO045	(Task 4) It has been mixed. ... involves chemical reaction. The particles like molecules have already changed. It is like more solid. It became more. It increases. ... Because the solid is formed inside.
SO056	(Task 4) I think increase. Maybe be it is not compact. After that, been shaken, gradually the water become more compact. That's why it combines. More compact, heavier. ... (Task 5) Change. Become lighter because this is hydrogen air. It went up.
SO076	(Task 4) Increases. Because it became more concentrated. ... (Task 5) The mass decreases because it changes into gas. The gas is lighter than water.
SS049	(Task 4) I think the mass will change. Increase. I have the feeling lead iodide is heavier than lead nitrate.
SS057	(Task 5) The mass will decrease. When there is heat in there, it decreases. ... I think maybe when the heat goes up, then indirectly, the mass of the zinc will decrease ... When it dissolves with hydrochloric acid, it reduces and produces energy and the gas. And mass of gas lesser than liquid.
SS058	(Task 4) I think it will increase. The mass is more than one hundred fifty eight point two because the product is solid. For sure, the solid will increase the weight.
SS059	(Task 5) Increases. Because there is chemical reaction also. So, the air maybe heavy. The air in the conical flask is heavy, so it is something to do with the air in it. Maybe there is increase of oxygen or the air. (Task 4) Because I see that the yellow colour looks heavy.
UF009	(Task 4) The substances meaning only them [the mixture] are inside here. ... The solid is different from the liquid. [The mass will change]. Because it already changed. Now, one [of the solution] becomes solid. ... In terms of the precipitation, maybe it changes in weight.
UF010	(Task 4) I think it will change. Increases. I think because initially they are in liquid form and they are not compact. The arrangement structure of the element is not compact. When the solid lead iodide is formed, the arrangement becomes more closely compact.
UF011	(Task 4) Increase. Yes. It increases because it formed precipitation. The precipitation is solid. So, solid's [weight] is more than the liquid. ... (Task 5) It reduces. Because the zinc reacts and it produces hydrogen gas. So, when the zinc reacts, it becomes lesser. The gas has lower density. So, the readings in the balance cannot be read. ... It is lighter. Even it has weight; the weight won't be that much. Yes. It decreases.
UF012	(Task 4) It became heavier. Because it is not a reversible reaction and there solid formed. Solid was formed. ... (Task 5) Decreases. Because the zinc just now has changed into aqueous, it releases hydrogen. The gas is lighter. It decreases.
UF060	(Task 4) It will be a bit lesser, because the formation of the precipitation. When the potassium iodide and lead nitrate are mixed, the precipitation will be formed and the liquid become lesser. Because a lot of precipitation is formed. ... There is precipitation, so the liquid become lesser.
UO021	(Task 4) Based on the equation, because of it is solid the mass will change. I think it changes. Because, before the reaction, both the substances that are mixed in aqueous state. After the mixing, the lead iodide is in solid form. So, if it is solid, as you said and what I think, solid is heavier. It is heavier. That is the factors that causing the change of the mass after they are mixed. ... (Task 5) I think it [the mass] will also change. Because initially the zinc is in form of solid. When it is mixed into the hydrochloric acid, dissolved and after that hydrogen gas is produced. So, solid changes into aqueous. When mixed with hydrochloric acid, the mass change because the gas is lighter.
UO025	(Task 5) Meaning, the zinc solid will turns into zinc Cl, aqueous. So, zinc, it will disappear. Forming the solution. Of course the weight will change. ... it is from solid to aqueous, and gas. The weight will not be the same.
UO028	(Task 4) [The mass] Increase. Maybe because the solid is produced, so it [the mass] changes. [From] aqueous into solid although the number of its mole is still the same, Mass. (Task 5) The mass decreases. Because it produces the gas.

More substances formed	
SF038	(Task 5) The mass will increase. Because the gas does has weight, isn't it. So, it will increase a little.
SF042	(Task 4) It increases. Because there's solid [formed]. (Task 5) Increases. Because there's gas [formed].
SF051	(Task 4) I think [the mass] increase. ... Because there is new [substance] ... I think it become heavier. ... Particles in the lead nitrate, and potassium, increase the weight. Because they have combined. ... (Task 5) So, there is something that makes the balloon inflates. The thing, after the balloon inflates, it makes the mass lesser. ... I think, it increase. ... Because, as you say something is produced. That's because there is something that will increase the mass. ... The one [lead iodide precipitation] before this I think also increase. Because there is something new [formed].
SF053	(Task 4) It combines because its particles of the potassium is a bit bigger, the lead, its atomic size is a bit small. So, when they are mixed, its mass decrease because potassium is combined with lead. The mass decrease, the mass becomes lesser. Because, the mass of the lead is very much lesser while the mass of the potassium is medium. When they are combined, it becomes lesser.

More substances formed	
SF074	(Task 5) [The mass in the reaction between zinc and hydrochloric acid] Because the air content becomes more. The air becomes more, so the weight becomes more.
SO033	(Task 5) I guess the weight will increase. In our lesson, gas, has weight. So, when it produces hydrogen gas, I guess it will increase in weight.
SO037	(Task 4) It caused from the mixing the new liquid, the new chemical. So, when mixing the new chemical, it can be said that it becomes more. Before that, the yellow thing was not there. After that, there is the new thing. Therefore, its weight increases. ... (Task 5) Air has mass isn't it. If air has weight ... it [the weight] changes a little. Increased. Formation of the gas, the air.
SO054	(Task 5) I think it will become, its mass become more. Because, it is mixed with the zinc pieces. And then, there is air some more. It will increase. There is air formed, and the zinc pieces.
SO055	(Task 4) ... something has been formed. I think it increases. He mixed, then something else formed, like foam or something, maybe the weight is increased. ... (Task 5) I think, it will be a bit heavier.
SS048	(Task 4) Increases. Because the chemical reaction. Maybe there are different products.
SS058	(Task 5) The mass will increase. Before the zinc is dropped into hydrochloric acid, we have already weighed them. Then it produces hydrogen gas and zinc will combine with HCl. The volume in the conical flask becomes more and maybe the weight will also increase.
SS067	(Task 5) [The mass in reaction between zinc and hydrochloric acid will] Increase. Because the present of hydrogen gas.
UF008	(Task 4) The weight is either increases or decrease. Because it is already become new substance. So, the initial substance, reacts and either will disappear or increase. ... (Task 5) I mean it will increase. I feel that it will increase because the hydrogen filling the space and it has mass ...
UF018	(Task 4) It becomes more. Become heavier. Because initially it has one substance only, the lead. But when it is mixed with potassium iodide, it is like two substances. So, it will become heavier it term of its mass. Because of the two different chemicals. The one were produced causes it to be heavier. ... (Task 5) Is like the hydrogen molecule move randomly and causing the pressure of the balloon become higher. Maybe because the zinc combines with chloride. That's why its mass increases. The new substance's weight will be heavier compare to the initial one.
UO027	(Task 4) It will increase. The mass increase because the total mass is now is including the solid lead iodide. ... (Task 5) Just now, it just aqueous solution. Increases. The present of hydrogen gas. It is certainly light but it also has mass.
UO029	(Task 5) The mass increases. Because zinc reacts with hydrochloric acid will produce hydrogen and then the balloon become bigger and the mass increases. The release of hydrogen gas ... released. ... (Task 4) I think it is also increase. New substance. Lead iodide. The number of particles remain the same but the mass change.
UO065	(Task 4) I think it will increase. Since the ... the hydrogen gas release is quite, is quite a lot, and plus the zinc chloride formed.

Gas properties	
SF041	(Task 5) I think it change. Because, it releases gas, the hydrogen gas is released. So, it becomes lighter. ... If it releases hydrogen gas, so the weight becomes lesser. The mass of the gas. Because it is up there. This is the only thing that can be weighed. That is why it's lesser.
SF043	(Task 5) Gas also has no mass.
SF052	(Task 5) No .. I think air doesn't have mass. It doesn't affect the mass of the balloon.
SF072	(Task 5) Because the solution has turn into gas. So, the mass decreases. Because gas has no mass. It is not as heavy as the solution is.
SS030	(Task 5) The hydrogen would impart a bit of buoyancy on it, whereby reducing the weight slightly.
SS047	(Task 5) I think still decrease, because the air is like, the hydrogen is like at the top, so like cannot, how to say ... measure the mass. I mean so it decreases, because the hydrogen gas.
SS048	(Task 5) It [the mass] will change. Decreases. Because the gas is released. So the particles in the solution become lesser.
SS068	(Task 5) Thing change into gas would probably reduce the reading in the weight balance. Because, one thing is, gas is lighter than the solution.
UF013	(Task 5) The mass will change. Because the zinc is heavier. ... the hydrogen gas is a gas. And the gas will not influence the mass of the conical flask. The hydrogen gas is lighter. The zinc will become lighter. Because it exist as liquid and precipitate. ... (Task 4) And the liquid and precipitate have mass that is more concrete. But this one (Task 5), gas, the mass of gas, it is harder to measure with the balance. If the balance is sensitive, the mass will reduces a bit. There will be some different.
UF060	(Task 5) Mass will be still the same. Because what is produced is only hydrogen.
UF061	(Task 5) I think will slightly different. ... Because I mean here is the gas is release, is release obviously the substance inside the conical flask is decreasing. Then you need to measure the gas.
UO019	(Task 5) It [the mass] changes, decreases. Because the reactants have changed into hydrogen gas. That's why the weight decreases. Maybe because the hydrogen gas is lighter. Maybe it will lift up the flask. ... The stopper is not leaking. It also decreases. Because it has already change to gas. It started with solid and then change into gas. So, it is lighter.
UO026	(Task 5) I think mass will decrease. Because when the zinc reacts with the hydrochloric acid, the hydrogen gas is full and then the hydrogen escaped from the surface of the solution. That's mean the particles will change from the liquid state to solid state. And the volume of the gas increased. So, the ... when the particles are escaped from the surface of the liquid, causing the particles in the liquid is decreased. Therefore the volume decrease and the mass decreases.

Gas properties	
UO069	(Task 5) I believe it will change. Because as you say just now right, the ... balloon, expand because of the gas. Since the gas expand upward, I don't think the detector [balance] ... no ... I don't think the detector can detect the gas because, the detector depend on what is put on top, right. So the gas is like on top of the conical, in the balloon, so I don't think gas will affect ... The mass will decrease. ... even if that's why, even if we don't have the balloon right, we just put zinc metal and we put a cover inside, you still can't detect the mass accurately because the gas is travelling around ... it's travelling around, is not in one place right. Doesn't have a fix shape. ... Because weighing means we have to put it on, on a place, a fix place.
UO070	(Task 5) The mass decreases. Because some of the chemical composition in it has changed into gas. ... I think the mass of the gas cannot be weight.

Closed system	
SF039	(Task 4) I think it is the same. My opinion is that everything has mass. Although they have different masses, after being in the container, the mass will be the same, although there is change in the chemical. ... (Task 5) Will the mass change? I don't think so. Because the air just goes up and it is not becomes more. There nothing can come in or goes out.
SF043	(Task 4) The same. Because nothing goes out. No. Because it is balance. After all it is closed. Nothing goes out or been added. The mouth is closed, so nothing can go in or out. So, it is the same.
SF052	(Task 4) I think it stay the same. Yes, I think. Because ... volume ... I think volume doesn't change. Volume doesn't change because person didn't put something else, it's in the same place. He just shakes it. It won't change, I think the mass stays the same.
SO044	(Task 4) I think the mass is just the same. Because the content is the same.
SO045	(Task 5) I think it will remain the same. Because it does not release any molecules.
SS030	(Task 4) The mass is constant. This is a closed system. If this is not a closed system, masses of any type, associated with gas, liquid or solid might escape or they may enter, whereby changing the final mass. The formation this or that, is only involve its prior reactants. It doesn't rely any other sources. ... All of the products in the form of solid or aqueous inside close container which prevents anything to escape.
SS031	(Task 5) I think no changes. [It is] In a closed system. Everything in a closed system. The balloon covers the conical flask.
SS032	(Task 4) Overall mass. The same. Because. It is in a fixed container. So, after the reaction, it must be the same. Nothing goes in. Yes. The mass must be the same. But the component, not the component but the particle is still the same. The number of particles is still the same.
SS047	(Task 4) No change [in mass]. Because the solution, the chemical is still inside the conical flask. So, they cannot escape from the conical flask, so, logical I can say, is still remained the same although change, the one change into the solid and one remains as aqueous solution.
SS059	(Task 5) It seems not. It is closed. What's inside is the same
SS068	(Task 4) Although there's gas releases but there is a stopper and the reaction that contained the air remain there. Based on what I think the mass should be the same.
SS071	(Task 4) Remain the same because it's closed. There is no air or whatever went in, so it's originally there. So, just change within inside, nothing being add or being taken out.
UF007	(Task 4) There is no addition to the reacting substances. And, if we look at this, the apparatus is closed. If it decreases, it doesn't go anywhere. Meaning there is no mass decrease. But these are already inside the apparatus. There is no change in terms of mass. It is only in its property changed, the colour. It is only different substance. But there is no change in weight, its mass.
UF009	(Task 4) The substances ... only them [the mixture] are inside here. ... Reacting substance will produce reaction products. ... So, the mass must be the same. Maybe.
UF010	(Task 5) [the mass] The same. The air fills up the space. Gas. It seems the mass is still the same. There is nothing been added except that there is air formed. It will not change.
UF014	(Task 4) Because, nothing goes out and nothing goes in. That's why the mass is still the same. But the reactant and the product have to be the same.
UF015	(Task 4) The mass will not change. ... Since we weigh the conical flask, lead nitrate and potassium iodide. When we weight it again without anything been taken out, the weight might be the same. We weigh lead nitrate and potassium iodide in the conical flask and it weighs one five eight point two. After the reaction it is still inside there, there is nothing been taken out. The reacting substance and reaction product is inside, so the mass maybe remains the same. ... (Task 5) If there's change it will be small. The mass will also not change. Because, similar to the other case just now, the reacting substances and product is still inside, the same place. Nothing gets out.
UF016	(Task 5) It is the same like just now. It only reacts with different substance and form new product. But after the products are formed, it still maintain in the equipment, did not go out. The zinc has already turned to zinc chloride and it is in the water, still inside it. The hydrogen gas, even though we think gas is light, but actually gas is still the same quantity. The mass is still the same.
UF020	(Task 5) It will not change. Because it is still in there.
UF022	(Task 4) The same because that's the only substance involved. So, when all of the substances completely reacted, it gets ... even maybe ... in different form. Also hundred [number of lead remains the same]. ... (Task 5) It will not change also. Even there is gas formed, the zinc chloride.
UF060	(Task 4) Still the same. We know that all of it weighs hundred fifty eight. Even though we let, it reacts and the precipitation is formed, the initial substances are in there.
UF061	(Task 4) I think is still the same. Because it is a closed system. Obviously, it's a closed system, then actually there no other things added.

Closed system	
UF062	(Task 4) The mass will remain the same. Because this is basically a closed system ...
UF063	(Task 4) Because it is in a contained environment. Both of reactant and the product are in a container ...
UO017	(Task 5) The product is the gas right. When it expanded into the balloon, the gas also has its mass inside. I think no change.
UO021	(Task 4) I think it is the same. Why it does not change? Maybe because the test tube contains the lead nitrate and potassium iodide is weighed initially, after the mixing inside the same test tube. I think the mass will not change. Because there are no factors from outside.
UO023	(Task 4) In my opinion, the mass remains the same. Because it's a closed system. Even based on the equation, there are no changes in terms of addition from the outside. The lead iodide is formed from the reaction between lead nitrate and potassium iodide.
UO024	(Task 5) If the gas is not released, just in there, the mass remains the same.
UO025	(Task 4) Because it changes inside it ...
UO064	(Task 4) It should remain the same. Which, according to law of conservation of mass it should remain the same. Because we cannot create mass and mass cannot simply disappear, because this is sealed by stopper, nothing should escape from the conical flask. So, if the original mass is that around one five eight point two, it should remain one five eight point two. ... the mass before the reaction and after the reaction, should remain the same. ... how much of the lead iodide [is] depends on how many grams of lead nitrate we use, how many grams potassium iodide we use, and then after the reaction, which one actually limits the product of lead iodide. The mass should remain the same.
UO069	(Task 4) Still the same. Because ... you still get the same number of moles, I mean regarding state. So, it should be the same, because number of moles is the same. The number of moles of lead, iodide, and potassium [is still the same].
UO070	(Task 4) Maybe it will not change. Because there is nothing, becomes lesser. He did not take anything out.

Rearrangement of atoms	
SS068	(Task 5) Number of elements is the same.
UF013	(Task 4) The mass will be the same. Because, before the reaction happens, the mass of both of the chemicals remain the same after the reaction. ... the ions just exchange their places. But there is no new chemical added. It's just exchange its place. ... the elemental content is still the same. For example, in lead nitrate, its nitrate, it will use two nitrate ions, there are still have two nitrate ions. So, the mass is not changes, for the nitrate. Also with lead, lead before the reaction, it has one mole of lead, but after the reaction, it will not increase also. It exists in one mole of lead. The same with iodide, for iodide before the reaction, it has two moles of iodide ion, after the reaction, the iodide still two moles.
UF014	(Task 4) See, one lead here, one here [referring to the chemical equation]. Two iodide, over there also two. Nitrogen also two, K two and six O. The same. So, I think the mass will not change.
UF015	(Task 4) Because the lead nitrate has reacted with potassium iodide. The bonding between lead nitrate and potassium iodide have been broken, they form different bonding with different substances.
UF016	(Task 4) In this situation, it will be the same. ... Meaning that, it is only interchanging the ions with other ions. It just like changing partners and form new products. But, all of the ions or composition does not reduce. Still inside the conical flask. So, when we weigh, it is still the same.
UF020	(Task 4) I think the mass before and after the reaction will be the same. Because the lead will react with two ions to form new substance, it only exchanges. It just exchanges to form into the new substance, which is more stable.
UF062	(Task 5) Release of hydrogen. I feel the mass will remain the same. ... we can see through the reaction the bond broken and the formation of new compound. So, at same time the heat is absorbed to break bonds and heat is released when bond formed. So, that's why I'll say overall still balance [the same]...
UO017	(Task 4) It remains the same. Because the precipitate comes from the reactant. It only turned into solid. Actually, the mass is the same. Because what is reacted in the, reactants, the products come out the same. Only the mixture is different.
UO024	(Task 4) The molecules inside is not been added or reduced. Meaning that, they just mixing and changing chemically, its molecular mass should be the same. And the mole is the same. So, the mass does not change. That's what I know. Because, that thing is just exchanging, it just reacts. ... (Task 5) ... it just reacts with the one that is more reactive. The number of moles is not been added or reduced. So, the weight is still the same.

Particle collision

Internal arrangement	
SF038	(Task 5) The particles will become gas. ... when mixed, it becomes active and flies here and there. ... move randomly and gather energy to become gas.
SF040	(Task 5) The molecules or atoms go in to the space. After that, it will release heat, and something releases the gas. After that, the balloon inflates. It moves randomly.
SF043	(Task 5) The zinc particle will be corroded, because of the acid. Acid and metal will produce hydrogen. The particles are corroded. It is solid isn't. It is like the particles come off and it forms into liquid and gas.

Internal arrangement	
SF052	(Task 5) I think the particles moving faster. Because the state is changing from solid to gas, so I think the particle move more randomly. So, that's why we can see, kind of full of bubbles, producing hydrogen gas. ... I think the movement become rapid, causing it change the state, to gas and liquid.
SF053	(Task 5) When the zinc reacts with hydrochloric acid, it will move very fast, and change into gas. Because the zinc, release the gas. ... So, the zinc changed into gas.
SF072	(Task 5) Maybe it knocks. ... The pieces are knocking each other. Because zinc mixed with acid, it turns into gas.
SF073	(Task 5) At first, the particles are close together. When there is acid, it will be separated and become gas. The zinc has turned into gas.
SF074	(Task 5) The particles become more ... so the space become more until it goes in the balloon.
SS057	(Task 5) After it is mixed, the particles collide randomly, strongly. So then, when it is close when the gas collide then it increase the temperature, then it seem boiling like just now. Then ... when the temperature increases, it produces air ... gas. ... Zinc with the hydrochloric acid, the zinc will mix, become closer. When they collide, the movement become faster, producing energy. Then they produce heat energy and hydrogen gas is released. Chloride ... when it moves randomly ... it will collide, then the space between them become more, eventually turned into the gas.

Movement of particles	
SF040	(Task 5) Because it moves more random.
SF041	(Task 5) ... when we heat it up, we excite the particles. It vibrates more. To each other. On heat, after that it vibrates.
SF043	(Task 5) Become faster. Because when it is hot, the particle move faster and goes out from ... They move faster.
SF052	(Task 5) [Rate of reaction] I think it will be faster. Because of the temperature. I think the higher the temperature, the rapid the movement become. I think because it is moving faster due to the temperature when we heat it up. The particles vibrate faster. ... I think the particle move further.
SF053	(Task 6) The butane's particles will move very fast, and combine with the heat and oxygen, too fast, producing heat. And the butane if it combines with the three things, the particles move very fast, chafing each other, it will produce heat and light, the spark. So, the flame is produced.
SF072	(Task 5) [Rate of reaction] Faster. Because there is heat. The particles become faster ... The heat makes the molecules move faster.
SS030	(Task 5) If we heat the mixture up, therefore the rate of reaction will increase. As the particle, the zinc and hydrochloric acid particles will have more energy, therefore, they move at higher velocity.
SS031	(Task 5) If we heat it up the rate of reaction, faster because the molecules, zinc and hydrochloric, will gain higher kinetic energy to move faster, and then will collide faster to react, to form the zinc chloride.
SS032	(Task 5) Heating it up, they will collide faster. Because the energy is high isn't it. It acquires energy, and moves faster. The frequency of collision also become more and the reaction become more.
SS048	(Task 5) Because it gained kinetic energy.
SS049	(Task 5) Heat it up then it will be faster. Because high temperature cause high reactivity. High reaction. Because of high temperature, right, so, the reaction will occur faster. Molecules more active because of the kinetic energy. Increase of kinetic energy.
SS071	(Task 5) I think so, it will [increase the rate of reaction]. When the temperature is higher, the particles will move faster, maybe the reaction become much faster, than when in room temperature.
UF007	(Task 5) We can add a little heat so that the heat will make the matter to vibrate. If we add more heat, maybe the movement of the atoms become faster. It can be the factor that makes the reaction become faster. ... the heat causes the particle to vibrate faster. When the particles vibrate faster. ... It moves, vibrate also the similar. In terms of kinetics, the kinetic energy increases. Indirectly, the zinc atoms and the hydrochloric acid will react faster. So, it is faster.
UF011	(Task 5) Become faster [Rate of reaction]. Because we supply heat energy to the zinc and the compound. So, the particles will move faster, so the reaction becomes faster. The kinetic energy becomes higher so it moves faster. So, become faster.
UF012	(Task 5) This zinc when we heat it up, the movement becomes faster. The collision tends to happen. The collision between zinc and HCl happens more.
UF015	(Task 5) If we heat it up, it will become faster [rate of reaction]. Because the heating causes the HCl and zinc particles move faster. Because when the zinc move faster, more zinc atoms, and the faster they breaks the bond and combines with Cl. The hydrogen gas will be release faster. Reaction becomes faster.
UF016	(Task 5) [Rate of reaction] Become faster. When it is heated, it will receive the heat energy and the ion inside will move faster and collide more frequently.
UF018	(Task 5) The heat will make the reaction process between the zinc and hydrochloric faster. With less heat, the reaction of the zinc is less. ... with the help of heat, the molecule to move faster to combine with the chloride. It will attract faster. It helps in the process of disengagement of the molecules. And then the heat is used for it to move faster.
UF022	(Task 5) The reaction happens faster. Become faster. But all of the particles moving fast.
UF060	(Task 5) If we heat it up, we supplied more energy. So, the atoms will move faster and more collision will happen. Then the reaction will happen.
UF061	(Task 5) After heat is provided, then the molecule will maybe vibrate more frequently, so the chance of collision is more.

Movement of particles	
UF062	(Task 5) When you heat the substance, the atoms inside the atoms of the molecules inside the substance tend to move faster due to the supplied, transfer of energy from the increasing temperature. So, they will vibrate and move very quickly.
UO019	(Task 5) If it is heated, yes, it [rate of reaction] will be faster. From the heat, the kinetic energy of the particles become higher, so it moves faster, and more collision. After that, it produces the product.
UO023	(Task 5) If it is being heated, the production of the product will be faster. Because the particle get more energy, and when the energy is increased the kinetic energy also increased. The movement is faster. So, the particles become faster.
UO024	(Task 5) [Rate of reaction] Faster. Because, the kinetic energy in the molecules is faster. So, the reaction becomes faster.
UO025	(Task 5) Because it is moving.
UO026	(Task 5) Reaction will become faster. When the solution is heated, the particles vibrate vigorously and then move faster. ... Because when we heat the particles, the atoms in the solution will vibrate vigorously and then try to escape to the surface. In contrast, if we do not heat the solution, the molecules at the solution may be ... just escape slowly, through its own. But when we heat it, then they will escape faster.
UO027	(Task 5) [heat] Causes the kinetic energy of the molecule more vigorous. So the reaction becomes faster.
UO029	(Task 5) Become faster (when heated). [Rate of reaction] Faster when it is been heated, the rate of reaction higher. Because the atoms move faster. ... At the higher the temperature, the higher rate of reaction.
UO064	(Task 5) Slightly higher temperature, this will increase the rate of reaction because higher temperature give a higher kinetic energy to the molecules or the atoms inside the system
UO065	(Task 5) The particle in the zinc and hydrochloric acid will moves rapidly to form the product.

Collisions of particles	
SS030	(Task 5) I imagine zinc as simple as simple sphere, and hydrogen chloride as another sets sphere. So these two, will undergo collision, and meantime transfer electron will occur, so, hydrogen, hydrogen, will transfer two of these, transfers over electron from zinc. ... Rate collision will decrease. Therefore, the rate of effective collision will also decrease. If we heat the mixture up, therefore the rate of reaction will increase. As the particle, the zinc and hydrochloric acid particles will have more energy, therefore, they move at higher velocity. When they do so, they can hit each other more often, and with this increase of rate collision, rate of effective collision will increase. ... (Task 6) Oxygen molecules will collide with these butane molecules. Not necessary all at the same time, but look at it one in my undergo collision; break this up, and in the process the break the rest.
SS031	(Task 5) They need to collide first. This is zinc. And then inside, the HCl, of course it is a molecule. So, molecule in an aqueous form the element inside, the particle inside move ... if we heat it up [the mixture of zinc and hydrochloric acid] the rate of reaction, faster. ... the molecule inside, inside this element, zinc and hydrochloric, the molecule will gain higher kinetic energy to move faster, and then will collide faster to react, to form the zinc chloride.
SS032	(Task 5) Zinc will in contact with HCl. Since HCl particles moving around in water it will collide with zinc. The reaction occurs on the surface of the zinc. When there is enough energy, collide to each other, with a correct orientation, the reaction will occur. ... [The rate of reaction between zinc and hydrochloric acid] Because it finished already. The reactants become lesser. When the reactants are less, the frequency of collision between reactants also decreases. So, the reaction also less. ... Heating it up, they will collide faster. Because the energy is higher.
SS047	(Task 5) [The rate of reaction between zinc and hydrochloric acid] May be they, the zinc ion needs to find the hydrogen ions. Harder, so it will be slow. ... Find each other because less concentration means, less hydrogen ions inside so, I think, harder for the zinc ions to react with them.
SS048	(Task 5) [The rate of reaction between zinc and hydrochloric acid] It becomes slow because of the collision between the particles become lesser. So the reaction become lesser and the product become lesser. [When the mixture is heated up, the rate of reaction] Become faster because more collision. More products will be formed. Because it has gained kinetic energy.
SS057	(Task 5) the particles collide randomly and strongly. ... first the particle will collide then the movement become faster, producing energy.
SS068	(Task 5) There is collision inside there. ... [When the mixture of zinc and hydrochloric acid is heated up, the rate of reaction] It suppose be faster. ... Lower temperature, substance react together ... seem to be lower and higher temperature seem to react faster. ... If the collision is an effective collision ... much more active, thus the reaction much faster.
UF011	(Task 5) They need to meet. When it moves, collides to each other and faster. It is like when H ... zinc collide with Cl, and after that it is bonded.
UF012	(Task 5) Zinc when we heat it up, the movement becomes faster. The collision tends to happen. The collision between zinc and HCl happens more.
UF013	(Task 5) [The rate of reaction between zinc and hydrochloric acid will reduce] Because the place [site] for it to reaction become lesser. ... (Task 6) When the friction happened, oxygen and butane molecules will collide to each other. And the collide will form the spark. Molecular collision. It has to have ... active [effective] collision. Only fifty. So, fifty and fifty eight, the bonding is still stronger. So, the collision will not produce the intended reaction.

Collisions of particles	
UF014	(Task 5) Probability for effective reaction or effective collision. There must be collisions for reaction to occur. ... Zinc, it collides with HCl. They form zinc Cl two. So, more collision will happen, and if more collision happened, the probability of effective collision is higher. ... The heat will increase the kinetic energy. ... For example this zinc collide with H, that's not effective. And then, if zinc collide with chloride, got collision, something formed, transfer and reaction. So, that's called as effective collision. ... If the concentration of HCl, the rate of reaction increases. Because we increase the number of particles. So, more particles, the higher probability of effective collision. So, it is faster, the rate of the reaction. Faster. ... (Task 6) let say, C collide back with other C after they are broken, there are not effects, not effective collision. If C collides with O, so, it will form CO ₂ . So, I think there is collision.
UF015	(Task 6) When the collision occurs, the bonding between the molecules is broken and atom from butane will combines with oxygen.
UF016	(Task 5) Molecules will always collide to each other but not all collision will produce something. To form the new product, it needs the more energy called the activation energy. Effective collision means that the collision provides the energy more than the activation energy for the formation of the new product. If the energy is not enough, although it collides, nothing will happen because the more ions inside the more chances of collision between chloride ions and zinc. So, the chance of effective collision will increase and the rate of reaction will also increase. ... If it is an effective collision, exceeding the activation energy, it will form the intermediates and after that, it will separate to form carbon dioxide and water. ... [The rate of reaction between zinc and hydrochloric acid will reduce] Once zinc and chloride ion form the new product, the ions and zinc become lesser. For them to react, they need to collide. So, when the reactants become lesser, the collisions also become lesser as well as the effective collision. Therefore, the chemical reaction also become lesser, and the rate of reaction also become slower. ... [When the mixture of zinc and hydrochloric acid is heated up, the rate of reaction] When it is heated up, it will receive the heat energy and the ion inside will move faster and collide more frequently. And the effective collision will also become more frequent and the rate of reaction will increase.
UF018	(Task 5) There is collision. Maybe because they have similarities that make them combine.
UF020	(Task 5) Effective collision happened between the ions. ... When the surface of area is bigger, the correct orientation of collisions between ions is easier.
UF022	(Task 5) The rate of reaction decreases. After that, it will stop. [This is] because it became lesser and the zinc particle and free moving HCl. For it [reaction] to happen, they need to collide. Decreases [the collision] is, lesser.
UF060	(Task 5) If we heat it up, we supplied more energy. So, the atoms will move faster and more collision will happen. Then the reaction will happen. Faster ... Similar when we have eaten, after eating, we are more active, and more active we are in one place, more collision happens. So, in chemical reaction is also the same. When we supplied the kinetic energy to the solution, the movement will be more and collision will happen more frequent.
UF061	(Task 5) To my understanding, it is just like if there is a lot of people in a system you can meet people more frequently ... you collide, more frequently than the reaction more easily, than if you have three or four persons in the room, it is hard to make collision ... [When the mixture of zinc and hydrochloric acid is heated up, the rate of reaction] After heat provided, then the molecule will maybe vibrate more frequently, so the chance of collision is more.
UF062	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] The reaction becomes speed up [faster]. ... when you heat the substance, ... the atoms of the molecules inside the substance tend to move faster due to the supplied, transfer of energy from the increasing temperature. So, they will vibrate and move very quickly as compare if you don't applied any energy source. So, ... there are more chances for the atoms and molecule to react with the incoming like for instant zinc. So, the reaction become faster. The chance of contacting the ... molecules is higher.
UO019	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] If it is heated, yes, it will be faster. Particles' become higher, so it move faster and more collision. After that, it produces the product. ... (Task 6) There is collision. ... they are rubbing to each other. After that, it explodes and collision happens.
UO021	(Task 5) Zinc atoms will collide. ... [The rate of reaction between zinc and hydrochloric acid will reduce.] Why is it slow? ... when zinc and HCl collides, the zinc which is initially a lot, become smaller and smaller. That's why it becomes slower.
UO023	(Task 5) Based on the kinetic theory, the particles will collide and new product will be formed when there is effective collision. So, zinc and hydrochloric acid particles will collide and producing new products. As you can see here, it needs two moles. ... [The rate of reaction between zinc and hydrochloric acid will reduce.] Become slower. Because, when we follow the effective collision, the particles that available are not reacted yet. The reactants particles before the reaction, there are a lot of them. So the frequency effective collision is higher.
UO024	(Task 5) In terms of the effective collision, [when it] becomes more, that means it becomes faster. Effective collision, in terms of collision ... it hit correctly ... (Task 6) When they collide they will change. ... Maybe oxygen is stronger than butane. ... when they collide, they will break.
UO025	(Task 5) the lesser the ions, the slower for it to find ... to attract. Meaning that they are colliding.
UO026	(Task 5) And for a product to form the collision must be the correct orientation. If, it is the wrong orientation, the product will not be form also. In conclusion, for the product to form the collision must be in the correct orientation and the energy must be able to overcome the activation energy
UO027	(Task 5) there is something to do with the collision. ... [When the mixture of zinc and hydrochloric acid is heated up] Yes. It is faster at one point. Because the present of heat causing the molecules collides faster, so the kinetic energy is faster, so the reaction becomes faster.

Collisions of particles	
UO028	(Task 5) [The rate of reaction between zinc and hydrochloric acid will reduce] Because, when it is lesser, the effective collision occurs lesser. The molecules collide lesser and then the possibility for correct orientation is also lesser. ... They collide at the correct orientation. ... [When the mixture of zinc and hydrochloric acid is heated up] If it is heated, the rate of reaction becomes higher. ... (Task 6) The collision will lead to the bond formation ... the energy that is released will form heat, from the collision of the molecules.
UO064	(Task 5) For a reaction to occur, collisions have to occur, specifically effective collision. Even though collision can occur, but some are ineffective, the reaction will not occur. ... Yea, so, of course for the molecule to collide. ... [The rate of reaction between zinc and hydrochloric acid will reduce.] ... when zinc is almost used up, rate of the reaction decreases because the molecule need to find, I mean the molecule will have lower change bumping into the zinc atom, to start the reaction ... So, the chances is getting lower, so, the chance of collision between the zinc atom and hydrogen, H plus to, to bump into each other, decrease the rate decreases. ... [When the mixture of zinc and hydrochloric acid is heated up] So it start move faster so ... frequency of collision increases and then frequency of effective collision will also increases, ... according to Boltzman Distribution graph that molecules that have higher energy is double up in every ten degree Celsius, so rate of reaction is increases because each molecules that have higher energy that can compensate the activation energy or higher than activation energy is increases.
UO065	(Task 5) The gas will collide, I think. So, hydrogen gas formed and zinc chloride formed at the same time.
UO069	(Task 5) ... molecules collide right, if I'm not mistaken ... Put it this way. ... since you have to molecule colliding right, you need a certain amount of energy for it to bond. ... when you collide the particles that are colliding, have more energy, have more energy content of itself. Collision but as how the collision work ...
UO070	(Task 5) ... so the reaction is fast because the zinc and acid hydrochloric are like close together, the collision between the particles is very frequent ... there are more reactions happen the concentration of zinc and hydrochloric acid become lesser and the collision is not as frequent as it in the beginning.

Site of reactions	
UF014	(Task 3) If it is in powder form, the powder for will dissolve faster because the total surface area compare to the cube is smaller. ... From the rate of reaction. Its total surface is more, the surface that reaction occurs.
UF020	(Task 5) The surfaces where they are contacting become lesser when the substance become lesser. Effective collision happened between the ions. When the surface of area is bigger, the correct orientation of collisions between ions is easier.
UF060	(Task 5) [The rate of reaction between zinc and hydrochloric acid will reduce] Decreases. The site for reactions site has decreased.
UO021	(Task 3) If it is stirred, depend on the size of the particles. The size of salt and sugar. If it is small, it will easily disappear.
UO029	(Task 5) ... the rate of reaction increases when the surface of zinc ... becomes lesser. So, the rate of reaction eh ... but if the surface are become smaller ... the rate of reaction is high.

Probability for reactions	
UF014	(Task 5) For example there are twenty four atoms. First, it is fast because of high probability. High probability for reactions to occur. So, after a period of time, there more and more atom been used. Is like more get married, and lesser singles. ... the probability become lower, so the rate become lower.
UF015	(Task 5) If the quantity is doubled, the reaction will increase twice. ... [If the concentration of hydrochloric acid is greater] The reaction will increase (Task 5). Because the when the concentration of the zinc, the molecule of HCl will be more. So, the possibilities for zinc to react become higher.
UF016	(Task 5) The chance for them to react is lesser.
UF061	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] ... after heat provided, then the molecule will maybe vibrate more frequently, so the chance of collision is more.
UF062	(Task 5) Move faster. The chance of contacting the molecules is higher.
UO069	(Task 5) [If the concentration of hydrochloric acid is greater] if we increase HCl, of course the reaction will be fast ... if you say increase the concentration mean you have more number of mole of chloride, right, so, number of chloride attacking the zinc is more, so the possibility of having reaction occurring is higher as well.

Barrier to reaction

Energy initiates reactions	
SF038	(Task 6) The spark is needed for the gas to burn. ... when it's hot the particles will absorb the heat and ... and ... turns, and what ... gain more energy. More energy enables the particles to move.
SF039	(Task 6) [Spark is needed] To ignite the fire.
SF040	(Task 6) Heat is needed to produce the fire.
SF041	(Task 6) The spark, it got to, it starts the reaction between the gas and oxygen. Starts the reaction. Because just now, it provides heat isn't it. Because heating starts the reaction. With the spark, the heat make the reaction happened, these two. Oxygen and butane.
SF042	(Task 5) Become faster. There is heat energy. It makes it faster.
SF043	(Task 6) The reaction will happen. Because like other experiment, even though the reactants are mix, it will only react when it is being heated up. This one is also the same.

Energy initiates reactions	
SF051	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] ... the heat make it faster. Like making it becomes faster.
SF053	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] Become faster. Because you heat up the hydrochloric acid become more active, so the zinc, the reaction between the zinc becomes more, so the reaction becomes faster.
SF073	(Task 6) ... fire needs the heat. If there is no heat, it can't burn. Like if a candle is placed in a beaker, it will die out because there is no oxygen.
SF074	(Task 6) Maybe heat is hot so it will form the flame. When this is mixed with the gas, it will make the fire goes out faster.
SO033	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] May be the heat will alter some of the molecules, and make it regenerate and the reaction start over faster, the initial reaction will, that's just my guess. ... (Task 6) We need the spark to light up the fuel. The fuel inside this canister.
SO035	(Task 6) So that it can ignite the fire. ... So that the fire ignites.
SO037	(Task 6) it enables the fire to ignite. Starts the burning. Ignited like that.
SO055	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] I think. [the reaction is] Faster. Normally, when it is hot, it will reduce. If it [temperature] is increase, it will become stronger.
SO075	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] become faster. The heat ... the heat helps. ... (Task 6) [Spark is needed] so that the fire can start.
SS030	(Task 6) And then release of gaseous and ignited by the spark released by the flint. Therefore, causing oxidation will occur or combustion.
SS031	(Task 6) [Spark in combustion of butane] To trigger the reaction. Between butane with oxygen.
SS032	(Task 6) [Spark in combustion of butane] the spark causes it to react. It makes the reaction or burning to happen. So, when there is spark, butane will gain the energy and then the reaction will occur. ... Maybe the butane at first has not enough energy, so when there is spark, it supplies heat
SS047	(Task 6) To activate the, the combustion [of butane] to happen. May be to break the bonds between the butanes and the CH or the CC so that they can react with the oxygen to form the carbon dioxide and water. If the energy can break the bond between them, the butane, combine
SS048	(Task 6) For the combustion [of butane] to occur, heat is needed. So, the friction can produce the heat.
SS049	(Task 6) The spark will start the fire because for combustion [of butane] to occur, usually it's start with the spark. ... the small spark will trigger oxygen and then make it burn.
SS057	(Task 6) [Spark in combustion of butane] Combustion needs energy ... heat energy that will mix with the oxygen to produce the flame.
SS058	(Task 6) [Spark in combustion of butane] To produce the fire. It can form the spark and there is oil inside here and mixes with oxygen and lastly it produces the fire.
SS059	(Task 6) [Spark in combustion of butane is needed] Because heat triggers the fire. ... it is hot, it has energy.
SS067	(Task 6) [Spark in combustion of butane is needed] Maybe it wants to break the bond.
SS071	(Task 6) [Spark in combustion of butane is needed] because before you need to start fire, you need to spark, to ignite it.
UF007	(Task 6) [Spark in combustion of butane is needed] Without the spark, no rubbing, it does not produce the flame. The flame will not be formed. Only the carbon dioxide will be released. The water also formed but there is no burning happen.
UF011	(Task 6) [Spark in combustion of butane is needed] To initiate the burning.
UF012	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] Heating the mixture. Maybe the reaction become faster. I feel it become faster. Because the particles have more energy to work. ... (Task 6) [Spark in combustion of butane is needed] To initiate the burning, ignite it. ... To enable it to start the reaction between oxygen and butane. I feel there certain point, maybe, maybe the spark supplies heat to butane for the reaction. Maybe butane burns at certain point of temperature. That's the function of the spark.
UF013	(Task 6) [Spark in combustion of butane is needed] The spark is important in producing the fire. The spark can be considered as potential energy to produce the flame. Because it needs something to auxiliary [assist] it to react. If there is only butane and oxygen, it will not produce the flame. It needs one more ah ... friction to produce the flame.
UF014	(Task 6) [Spark in combustion of butane is needed] To initiate the combustion.
UF015	(Task 6) [Spark in combustion of butane is needed] To induce the flame formation.
UF018	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] Become faster. Because there is extra help from outside. When the heat is been used up, it will activate the molecules. ... (Task 6) [Spark in combustion of butane is needed] Maybe to activate it. To activate the hydrocarbon gas so that it reacts with the oxygen in the air. After that then it produces fire. Because it can't react by itself. ... To my point of view, because the bonding in butane is stronger. So, it needs help from the spark to produce the product. The flame is just by-product of the reaction.
UF020	(Task 5) [Activation energy is] The energy of the reactants for it to produce the product. (Task 6) [Spark in combustion of butane is needed] To initiate the reaction, the burning.
UF063	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] Most probably, the rate will increase. ... I mean the reactivity of the atom inside. So the more reactive it goes, the faster the reaction. ... the energy of the atom. The energy of the atom inside the matter. So, when we added heat into the matter. (Task 6) [Spark in combustion of butane is needed] To initiate the burning.

Energy initiates reactions	
UO019	(Task 6) [Spark in combustion of butane is needed] The spark is the trigger. Triggers the burning. Without the spark it will not burn, although there is gas. When the heat mixes with butane and oxygen, it becomes hot. When it is hot, it will ignite and burning happens. The reaction between butane and oxygen need triggers to occur. Other reactions happen naturally.
UO023	(Task 6) [Spark in combustion of butane is needed] The spark is to ignite the butane gas. To ignite the butane, it needs heat from the spark and oxygen. The butane gas cannot burn by itself. It needs spark to ignite. ... it needs a suitable temperature. But I don't how much heat the spark to cause [the burning]
UO025	(Task 6) [When the mixture of zinc and hydrochloric acid is heated up, the reactants] Become stronger.
UO065	(Task 6) [Spark in combustion of butane is needed] to initiate the reaction. So, like the equation shown the butane, the butane and the oxygen. So, oxygen is present but without the like the help from the spark ... We have the two element there but we have to do something to make sure the reaction to occur.
UO069	(Task 6) [Spark in combustion of butane is needed] We need something to initiate the burning process. So, in this case, would be, if I'm not mistaken, spark ... spark is light. Light has energy. It might be possible for the breaking. For breaking of bond because when the gas goes up, right, the gas contain this butane but if you don't have anything to break the bond, to let the oxygen coming does it work, it doesn't occur as how the reaction show here.

To lower the activation energy	
UF008	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] When we heat it up, there are two things that I know will happen. The activation energy will become lower or it will receive energy to achieve the activation energy for it to react.
UF014	(Task 6) [Spark in combustion of butane is needed] To lower the activation energy ... It lowers its activation energy. It is needed to initiate. To initiate the reaction. So, without the spark, this will not happen. It lowers its activation energy.
UO021	(Task 6) [Spark in combustion of butane is needed] When there is spark, the catalyst, the activation energy become lower and makes it burning. It is because there is catalyst ... so the activation energy is lowered. So the reaction becomes faster.

Energy as catalyst	
SS057	(Task 5) When If we heat it up, the balloon inflates. It [heat energy] is a catalyst.
SS067	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] It will be faster. Because it is like catalyst, the temperature is catalyst to make it faster to make the product. To make the process goes faster.
UF008	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] When we heat it up, there are two things that I know will happen. ... In the zinc, it will receive energy and it is faster, stronger to break the HCl bonding. But for the hydrochloric acid when it receives energy, it will break its bond. It became faster. That's what I said just now, it will receive energy ... like a catalyst for the reaction the happen.
UF009	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] High temperature. ... it [the temperature] make the reaction faster. ... It is like catalyst. Because, the catalyst can lower the activation energy. If the activation energy is lower, the reaction is faster. ... it combines faster.
UO021	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] ... the heat is like catalyst. ... [heat] speed up the dissolution of zinc in the HCl. It makes the reaction faster. To my understanding, the catalyst makes the reaction become faster because it is something like giving the energy.
UO021	(Task 6) [Spark in combustion of butane is needed] The spark is the catalyst of the flames. But what I think, when the spark is not present, there no catalyst yet, the activation energy is high. That's why it is hard to burn.
UO065	(Task 5) temperature is a common catalyst in reaction.

Energy as a part of reactions	
SF039	(Task 6) [Spark in combustion of butane is needed] ... because it needs chemical reaction for it to form the fuel. It is not only the spark able to form the fire. Like methane and oxygen when mixed, it will burn.
SF042	(Task 6) When it [butane gas] is with the heat and the oxygen, then there is combustion process.
SF052	(Task 6) [Spark in combustion of butane is needed] I think to react with oxygen, to produce the flame. When the spark comes out, it react with oxygen and produce the flame, I think.
SF053	(Task 6) [Spark in combustion of butane is needed] So that the gas inside reacts with oxygen. ... to get the flame, oxygen, fuel and also heat energy should present. So, that's why. It must have the spark. If there is none, oxygen and fuel only, the flame will not ignite. It must have heat energy, so that it produces the flame.
SF072	(Task 6) because there is gas ... it reacts with the heat.
SO033	(Task 6) [Spark in combustion of butane is needed] Because I think, the fire wouldn't start without the spark. And it also won't start without oxygen, because it, oxygen is needed ...
SO035	(Task 6) [Spark in combustion of butane is needed] So, that the fire ignites.
SO037	(Task 6) [Spark in combustion of butane is needed] it enables the fire to ignite. ... starts the burning. Ignites like that.
SO055	(Task 6) [Spark in combustion of butane is needed] Because without the fire, the thing [butane gas] will not burn. Similarly, we need the gas. Without the gas, maybe the fire will not ignite. This one is the same, it is empty, and it can't ignite. It [the spark] has to be there, so that the fire comes out.

Energy as a part of reactions	
SO056	(Task 6) ... when open like this, the hole is opened. If this is not here, then there is no flame. Without this, the flame will not ignite. So, it needs ... the flame and the spark.
SS047	(Task 6) [Spark in combustion of butane is needed] Because, in the theory of combustion to happen, need have the in the presence of three components, which is the oxygen, fuel and heat. The spark, act as a heat, and the butane is the fuel. So, I think will happen in the presence of the three components.
UF008	(Task 6) It reacts with the spark, it will burn with help of oxygen.
UF011	(Task 6) ... the gas will go out with the heat energy and oxygen, it burns.
UF061	(Task 6) [Spark in combustion of butane is needed] You need the substances; you need the oxygen, and one more. I forgot the last one. Then only the burning process can sustain. Actually, the first part [spark] is still a burning, but due to the lack of substance or something [the heat energy].
UO023	(Task 6) [Spark in combustion of butane is needed] Part of it. It [the spark] is needed for the combustion. Butane will not burn without heat. So that it burns. It needs oxygen, like the matches, butane gas need heat to ignite. [The same with] The rust needs metal and oxygen.
UO028	(Task 6) [Spark in combustion of butane is needed] maybe the spark has to react first with air in the surroundings.
UO065	(Task 6) [Spark in combustion of butane is needed] when there is friction, the spark will be formed. And then, keep pressing [the gas match] to release the gas and the gas will release. When it combines with the spark with the aid of the oxygen from surroundings then the flame will be produced.

Activation energy	
SS030	(Task 6) [Spark in combustion of butane is needed] In my view, this butane has a certain flash point or activation energy. If the activation energy can be provided by the spark, ... some of these energy to initiate reaction with oxygen. Therefore, it burns. Because the initial, because of the property of the chemical, the initial activation energy are not very high. So, under room condition they can already undergo some form of reaction. Certain change in condition, in this case, a very high temperature, provide, as provided by the spark.
SS032	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] In the aqueous, the HCl will collide with zinc. So, HCl when energy is enough, activation energy it will break to H and Cl. There is collision, and also sufficient energy.
UF008	(Task 6) [Spark in combustion of butane is needed] when the gas lighter is flicked, some kind of energy is given to the butane. Butane will achieve the activation energy and at that moment, the reaction will happen, then it burns.
UF014	(Task 5) Activation energy. Maybe, for example ... a person that to jump ten meter high, it is hard. If we lowered it to maybe five meter, more people can across. When there are more people able to across ... just an example. ... more atom that can across, meaning more reaction can occur, compare to the ten meters. This is hard to jump over, isn't it? Maybe this is [drawing] ten. Maybe only two able to jump over. And then we lowered it to five meter, maybe all can jump over. Or just eight. So, more atoms able to go over the barrier. So, more reactions occur. Energy for the atoms to qualify to undergo reaction. ... (Task 6) [Spark in combustion of butane is needed] Because. When the activation energy is very high, meaning that the process should be very hard to happen. But then this process is common. Combustion. So, it I think it is between here.
UF015	(Task 6) [Spark in combustion of butane is needed] Because we need to increase the activation energy to produce the flame.
UF016	(Task 6) [Spark in combustion of butane is needed] Activation energy. If to relate it to activation energy, it need to receive enough heat energy from the surroundings to exceed the activation energy, in order for it to react with oxygen and transforms to new products. ... If the it is an effective collision, exceeding the activation energy, it will form the intermediates and after that it will separate to form carbon dioxide and water.
UF020	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] It is to increase the energy for it to react. That's why it is faster. The heat causes the activation energy for the reaction to happen become higher. ... When we heat it up, the energy for the reaction to happen becomes higher than the activation energy.
UF022	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] Need to overcome the activation energy then the reaction will happen. For the reaction to happen, the activation energy must be sufficient. ... (Task 6) [Spark in combustion of butane is needed] maybe this reaction [combustion] need higher energy. ... the activation energy for every reaction is different.
UF061	(Task 6) [Spark in combustion of butane is needed] Because I think the spark provides something like the activation energy ... my teacher told me ignition point is just like the activation energy.
UO017	(Task 5) just like zinc and the hydrochloric acid, will overcome the activation energy, E1 for the forward process, and then E2 for the backward process. So, when it can overcome the activation energy and then here will be at the activated complex, and then overcome, can overcome the activation energy, the product will be formed.
UO023	(Task 5) [Spark in combustion of butane is needed] Butane and oxygen, when they react, the flame will be produced. So, spark makes the butane and oxygen to reach the activation energy. ... It helps the reactants to achieve activation energy.
UO026	(Task 5) for a product to form according to the collision theory, for the product to form they must overcome a certain energy first. This energy called activation energy. If the reactants do not have enough energy to overcome the activation energy, therefore the product will not be form.

Activation energy	
UO027	(Task 5) ... when it reaches the peak, the activation energy. We measure it height of the activation energy. Maybe as you said, even though the paper is let to expose to oxygen, it will not burn until we heat it up.
UO028	(Task 5) [When the mixture of zinc and hydrochloric acid is heated up] When it is heated, more molecules will gain energy to achieves the minimum energy, the activation energy, that allow to initiate the reaction. When the kinetic energy is higher, the faster it achieves the activation energy.
UO064	(Task 6) [Spark in combustion of butane is needed] for butane and oxygen to react, they also need to overcome activation energy and each of them will not, so called supply the energy but it need something to start the reaction. So, that's why when we only release the gas, even though the oxygen gas is surroundings the environment, there is nothing no reaction. So, they need something make them react. ... that's the purpose of the spark. You need the spark, the reaction then start. They need to overcome the activation energy. Normal temperature is not enough.
UO069	(Task 5) Because if we say reacting, we have to think about activation energy, as to whether it's successful reaction or not. So, increasing concentration, more amount of chloride, so you have more amount, means probability of succeeding is higher as well.

Activated complex

Metastable species	
UF016	(Task 6) Butane and oxygen in the reaction will temporary combine first and later on, they will break to form the carbon dioxide and water. Yes. Collide first. If it is an effective collision, exceeding the activation energy, it will form the intermediates and after that, it will separate to form carbon dioxide and water.

Reaction mechanism

Transmutation	
SO033	(Task 5) May be the acid hydrochloric separate the atom in the zinc, to create hydrogen gas. Because, what I have learn, or observed in some part of my lesson, in atoms, they, atoms break up or they form more atoms, and combine to, create a new atom. Or multiplies.

Quantity dependent	
SF038	(Task 5) [The rate of reaction between zinc and hydrochloric acid] gradually, the reaction in the beaker becomes lesser. Because most of the things changed to gas.
SF039	(Task 5) [The rate of reaction between zinc and hydrochloric acid] I think it will be corroded slowly. At first it fast because there is a lot of reaction. Eventually, it becomes lesser. Because eventually the zinc become corrode and no more zinc [lesser]. The zinc is the one causes the production of the chemical reaction
SF041	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Become lesser. Become slower.
SF042	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Become slower. Because all of it [zinc] dissolved in it. So, the reaction become slower. Because maybe it is already finished. Finished reacting, there is no more substance.
SF043	(Task 5) [The rate of reaction between zinc and hydrochloric acid will reduce]. Solid and the water [acid], it becomes smaller. So it becomes slower because it became lesser.
SF051	(Task 5) [The rate of reaction between zinc and hydrochloric acid will reduce] Become slower. isn't something that happen got its end. Eventually, maybe, it already used a lot of the elements, so eventually it become lesser. ... normally in experiments is also like that. Yes, it seems reduced.
SF052	(Task 5) [The rate of reaction between zinc and hydrochloric acid] I think it becomes slower and slower. First it becomes fast and then slower later.
SF053	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Become slower. Because the zinc finished. Because its reaction become lesser. ... the zinc is nearly finished. ... it [is slow] because the zinc is finishing.
SF072	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Become slower. Because ... it [substance] become lesser. Become faster. If more acid is added, it becomes faster.
SF073	(Task 5) [The rate of reaction between zinc and hydrochloric acid] ... there is more zinc mixes with acid to produce the hydrogen gas. The more, the faster.
SF074	(Task 5) [The rate of reaction between zinc and hydrochloric acid] ... When the zinc is more, so the reaction becomes faster.
SO033	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Slow down. Because the chemical inside will be used up in some time, within a time. Because it's, because in chemical reaction, it needs, it needs one of the component ... if one of the component is used up. No reaction can be form.
SO037	(Task 5) To speed up the reaction. Ump ... increase the zinc. Yes. Increase it.
SO044	(Task 5) [The rate of reaction between zinc and hydrochloric acid] It [rate of reaction] will be fast and then slow. Because the water become lesser.
SO075	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Becomes more. Because zinc becomes more but the acid becomes lesser...
SO077	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Become slower. Because it's already gone. Become lesser.

Quantity dependent	
SS030	(Task 5) It will decrease over time. This is because, the concentration of hydrochloric acid available as it react throughout the reaction will decrease, therefore reducing the rate of reaction over time. [Low in] concentration, therefore reduce the rate of reaction over time, so at one point this equation reach, ... the concentration of HCl decrease as it will be reacted with zinc ions, and therefore, actual number of HCl which, is actually acidic because of H plus, will be decrease as it reacted away released as gas. So, all the remains is relatively inert solution. This one can no longer undergo any reaction. Thus, only thing that controlling either one, if either one is runs out, the reaction no longer occur. As will be no longer any reactant. ... [To the rate of reaction is by] increasing is either one of the reactants, be in concentration or mass.
SS031	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Decrease because the amount of the reactants will decrease. ... usually the amount of zinc more, and then after the time goes, the amount of zinc is completely used to react with hydrochloric acid, to produce the hydrogen gas. ... then as the time goes by rate of reaction, increase first and then decrease. ... the amount of reactant is high, rate of reaction high.
SS032	(Task 5) [The rate of reaction between zinc and hydrochloric acid will reduce] Because it finished already. The reactants become lesser. When the reactants are less, the frequency of collision between reactants also decreases. So, the reaction also less.
SS047	(Task 5) [The rate of reaction between zinc and hydrochloric acid] I think it becomes slower and slower. I think slower and slower because the concentration of the HCl becomes lower and lower, that's why they react with the hydrogen ion will be like slower, because less concentration of hydrochloric acid.
SS048	(Task 5) [The rate of reaction between zinc and hydrochloric acid will reduce] Become slower. Because the reactants become lesser. So, the particles for the reaction to occur will decrease. So, the product will also reduce.
SS049	(Task 5) [The rate of reaction between zinc and hydrochloric acid will reduce] It will decrease. It will be slower. Already been reacted. ... not much of molecules to react. ... zinc and hydrochloric acid right, so at first it's very fast, then as time pass, right, maybe zinc has finished displacing.
SS058	(Task 5) [The rate of reaction between zinc and hydrochloric acid] It will be faster. We know even one mole zinc will increase the process of hydrogen, it will be faster if add more zinc.
SS059	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Become slower. Because it has already reacted. ... there is no more to react anymore. It reacts slower. ... the substance that reacting become lesser.
SS067	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Slower. Because there is no more Cl. Why it is slower? Because there is no more particle, for example there are no more Cl for zinc to combine.
SS068	(Task 5) [The rate of reaction between zinc and hydrochloric acid will reduce] First the amount of zinc being reacted with the chlorine will be reduced, so there is none to react anymore, then there is nothing react. So, it get slower and slower as time goes.
SS071	(Task 5) [When the concentration of hydrochloric acid is increased] Faster reaction ... they react faster. ... [Higher] Concentration. Faster I guess. I can't remember why. Because, as far as I remember ... the factors that affect the reaction to become faster is temperature, concentration, catalyst ...
UF007	(Task 5) ... in terms of the concentration of both substances. We increase the concentration of hydrochloric acid, maybe it makes it faster. Increase its concentration. Increase ... maybe ... the hydrochloric acid ... the chlorine and the hydrogen molecule are more, so the reaction with zinc will be faster. And the gas produced is more.
UF011	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Become slower. Because the zinc eventually finishes. So, it becomes slow. ... there is not much of zinc ions in there. H, hydrogen ion is also become lesser, because it becomes molecules, so it becomes slower. Because not enough ions for the reaction. ... [If there is more reactants, the rate of reaction] Becomes faster. Because there are more hydrogen and chloride ions, so the zinc reacts even faster. Zinc chloride formed faster.
UF012	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Become slower. When all of the zinc and hydrochloric acid been combined or react, there is no more reaction when they [zinc and hydrochloric acid] have finished. Because the substance become lesser. ... It need both for the reaction. For example, we have a lot of zinc and hydrochloric acid ... we can visualise it like building a house. Imagine in building a house and the hydrochloric acid is the builder. The zinc is our cement or material. So, when the hydrochloric acid, the builder remain the same [amount], and eventually if the zinc is not been added, that we assume as cement or sand for the house, eventually become lesser and lesser, so the productivity become slower. Meaning that, when it [zinc] became lesser, it [the rate of reaction] becomes slower. If the zinc is a lot, the builder is a lot, so ... for example they are four of them, zinc as the cement is enough for building the house. They [the builder] can build the kitchen, and the living room. But when the cement is not enough, they only can build the living room. The kitchen cannot be built. [analogy]
UF013	(Task 5) [The rate of reaction between zinc and hydrochloric acid] It will become slower. In the beginning, maybe for the zinc, we have two gram of it. For example, we have two gram of zinc. When the reaction is happening, it will use up the zinc, but the more it uses the zinc, the zinc becomes lesser. So, maybe, at the end, the zinc perhaps is only left about zero point zero eight gram. ... [which] become lesser to react with hydrochloric acid. ... zinc or the hydrochloric acid become lesser, among them will limit to each other. [The reactants] becomes lesser.
UF014	(Task 5) [The rate of reaction between zinc and hydrochloric acid will reduce] because its mass has been consumed, been used up. Meaning, when the reactant is used and then the product is produced [will be lesser]. ... it will stop. So, the rate becomes slower.
UF016	(Task 5) [The rate of reaction between zinc and hydrochloric acid] ... [is] slower because in the process, zinc and ion chloride are being used up. Therefore, the zinc that will attack the chloride ions is getting lesser and therefore the reaction will become lesser. The chances for them to react are lesser. So, it will become slower.

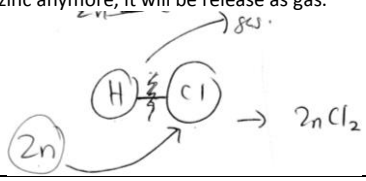
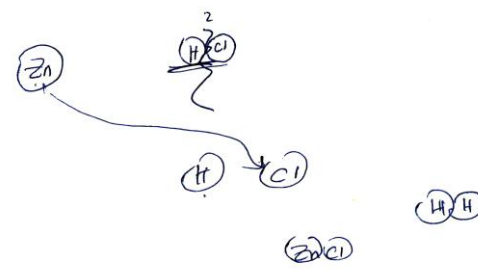
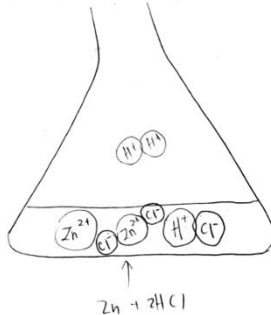

Quantity dependent	
UF018	(Task 5) [The rate of reaction between zinc and hydrochloric acid] The reaction will be slower eventually. It will be slower. Because, eventually the zinc is getting lesser and the acidity of hydrochloric acid also become lesser. So, the reaction becomes lesser.
UF020	(Task 5) [The rate of reaction between zinc and hydrochloric acid will reduce] Because the chemicals involved in the reaction become lesser, so the reaction becomes slower. ... the rate of reaction is influenced by the concentration of the reactants [since] the reactants has turned into products and the reactants become lesser.
UF022	(Task 5) [If the concentration of hydrochloric acid is increased], the [rate of reaction] also increases. The rate increases. more, presence more HCl ... so .. the probability for them to collide is more.
UF060	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Firstly, it is very fast, and then it became slower. It becomes slower and then stops. Because the reacting substances is finished.
UF061	(Task 5) [The rate of reaction between zinc and hydrochloric acid] It's become slower. ... after the chloride is finished then the reaction will slower, become slower and slower ...
UF062	(Task 5) [The rate of reaction between zinc and hydrochloric acid will reduce] because I think it depends on the amount of zinc and hydrochloric we put.
UF063	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Of course, in the end it becomes constant. The rate goes fast at the moment and then at the end of the reaction it will go constant. Because every reaction, there is a limiting reactant will determine the rate of reaction ...
UO019	(Task 5) [The rate of reaction between zinc and hydrochloric acid] If the concentration of HCl is increased, I don't think there is ... Yes. No effect. Because zinc is the limit. It's only in excess of hydrochloric acid. So, the reaction is as normal.
UO021	(Task 5) [The rate of reaction between zinc and hydrochloric acid] It becomes slow. I think it is the same with that Panadol [paracetamol]. Soluble. Because time goes by. Because the zinc become lesser. So, it becomes slower. It becomes slower because more zinc disappear.
UO023	(Task 5) [The rate of reaction between zinc and hydrochloric acid] The reactants eventually become lesser, then the reaction become slower.
UO025	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Slower. Because eventually zinc will finish combining with [chloride] ... Eventually, when it takes place, the ions become lesser. Yes. Because ... it's not the same ... When zinc and Cl reacts, the mole is not the same [anymore]. So, there must be a limiting reagent. When the limiting reagent finishes, the reaction finish. It becomes slower because the zinc becomes lesser. ... If zinc and Cl is a lot, it will fast. Become faster. If there are a lot of ions in it, Cl, Cl, so, the reaction will be faster ... it [zinc] reacts with Cl even faster.
UO026	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Become slower. Because the amount of the reactant decreases. So... no more reactant to react, therefore the reaction will gradually become slow. If the amount of the reactant is in a big quantity, ... they have the reactant to react, therefore the reaction will ... go on rapidly. ... So, finally no more reaction that ... The reaction will become faster. Because ... when the concentration of HCl is increased, that means the reactant [zinc] react with more HCl therefore the reaction id faster.
UO027	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Maybe slower. Because the usage of zinc and chlorine. What I mean, after the reaction happen eventually the molecules getting lesser and lesser. ... No more reactant to react. No more reaction. Because we didn't add [anything more].
UO028	(Task 5) [The rate of reaction between zinc and hydrochloric acid] Slower. Because the reactants become lesser. The concentration of the reactant becomes lesser.
UO029	(Task 5) [The rate of reaction between zinc and hydrochloric acid] ... depends on zinc. Meaning the longer [time], the slower. ... If there is no more zinc, how does it going to react?
UO064	(Task 5) [The rate of reaction between zinc and hydrochloric acid] the rate of reaction will still remain the same at some point but when the concentration of hydrochloride is less, or let say zinc is less, depend on which one is in excess, if anyone of them the limited, the process will cease when limit one is used up. For example, let say zinc chloride, I mean zinc pellets is the limiting reagent here, means it has a definite mass which going to limit the product hydrogen gas, so if zinc is used up, process is actually cease to continue. It became slower because there is no more zinc atom to react. Because hydrogen chloride, most of the time we use hydrogen chloride is excess. But, depends on the situation, my perspective is if zinc is almost used up, the rate will start to decrease.
UO065	(Task 5) [The rate of reaction between zinc and hydrochloric acid] when we observe from time to time the reaction will become slower because and at certain time it will become constant because the zinc and the hydrochloric acid have been reacted to become the hydrogen gas and zinc chloride. ... Initially it will rapid, go rapidly at a certain time it will slow down and then constant. Because there isn't any zinc or hydrochloric acid is to be consume to produce the product unless more zinc or hydrochloric acid is added.

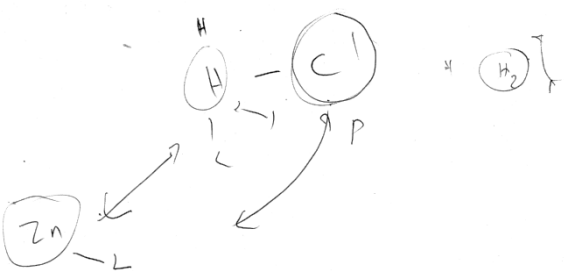
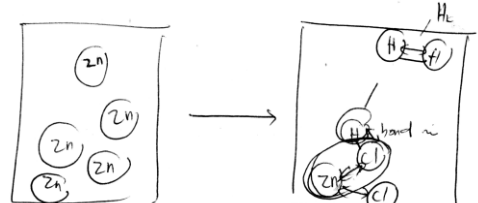
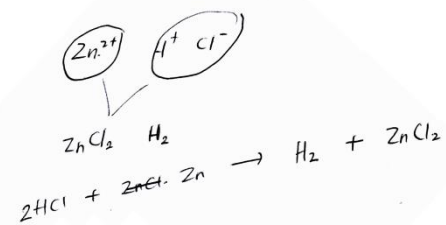
Quantity dependent	
UO069	(Task 5) [The rate of reaction between zinc and hydrochloric acid] It should be slower. Because when ... initially reacted, it has more reactants, so as time goes by, you have less reactant, with depends on the concentration of the amount you using, the reactants, so it will decrease, mathematically saying. It should decrease. Slower as in how much is produced per time unit. Rate of reaction, right. ... so, if it is rate of reaction, I would say slow, because as I say just now, the reaction depends on the amount of the reactant you have. Reactants become products, so you have certain amount of reactants, you can produce certain amount of products. So, the lesser you have, the less product you can get. ... So, as far I concern, mathematically saying, it is slower. Because comparing to the, to the ... let say time equal to zero to time two, let in second, so this ... within this period, you have more, you have more, what do you call, ah ... you have more product form, because you have more ... you have a larger amount of reactant. As time go by, let say, six to seven, eight, between this period maybe, during this period, most of the reactant gone. Let say it less than forty percent left, so have this amount, you have lesser product being formed.
UO070	(Task 5) [The rate of reaction between zinc and hydrochloric acid] the concentration of the zinc and hydrochloric acid is high, so the reaction is fast because the zinc and acid hydrochloric are like close together ...

Octet approach	
UF009	
UF011	(Task 5) Zinc is initially is solid. So, it is like this ... Zn Zn Zn Zn Zn Zn ... two plus ... not yet. After that, HCl is liquid. Aqueous ... its ion ... H plus and Cl minus. After that, when zinc is added into HCl, Zn will ionise into zinc two plus, after that surrounded by the other ions. After that, positive ion, negative ion will attracted to each other. So, it will form this one. Okay. This zinc, when it is mixed with HCl, zinc will ionise, so that it is more stable, it discards its valence electron. After that the HCl is in aqueous form, so it is in form of ions. ... zinc will discard its electron so that it is more stable. Cl will need one electron for it to be stable. So, for zinc and chloride to be stable, both them will combine. There are two of chloride atoms combine with zinc. They will form zinc chloride. The H, it only needs one electron, so H and H need one and one, so they will combine so that they are more stable.
UF014	(Task 5) Cl is the one receiving the electron, that's why it attracted to each other. Cl, for it to achieve stable noble electron configuration, it need one more extra electron, because it is a halogen, so it receive one electron. So, this one zinc, one zinc can donate two electrons. So, it will involve one chlorine, one chloride, so it will become zinc two. H, because it is left alone, actually H is also, among them, they will become H two, to form gas. This is covalent. ... H two. ... one electron share one electron, become duplet.
UO029	(Task 5) It [zinc] tends to donate electron because it wants to achieve stability. And this Cl is lack of electrons, so it wants to achieve stability, it need to receive electron. Its property is to receive [electrons]. This one likes [zinc] to give turns into this [zinc two plus].

Atoms rearrangement	
SF041	(Task 6) From here to here. They shift from here to here. Yes. Shifting. When the oxygen and butane react, changing their partners
SF043	(Task 6) The butane has carbon and hydrogen. So, the carbon will combine with oxygen to form carbon dioxide, and H will mix with oxygen to form water.
SS030	(Task 5) These electrons will go here, fill up the loophole, neutralise the charges [of the H of HCl], forming H2. Meantime, zinc will combine with Cl, which now considered as free. ... to form zinc chloride.
SS047	(Task 5) When the zinc dissolve into the mixture, and the zinc become the zinc ions, then the zinc ion will attack the hydrochloric acid and form with the chloride ion inside the hydrochloric acid and become the zinc chloride.
SS048	(Task 5) hydrogen in the hydrochloric will split apart, and then combined with zinc. Then, the hydrogen is left behind, to form hydrogen.
SS058	(Task 6) Butane, C four H ten. An alkane. Alkane, it has carbon. When carbon combined with oxygen for the combustion to happen.

Atoms rearrangement	
SS067	<p>(Task 5) As they break and then the zinc attracts the Cl. Then, they combine.</p> $2\text{Zn} + 2\text{HCl} \rightarrow \text{Cl}-\text{Zn}-\text{Cl} + \text{H}_2$
SS068	(Task 5) the zinc ... to bond with chloride. Thus, hydrogen is displaced
SS071	(Task 5) the particles of the hydrochloric acid split apart and the chloride connect [bonded] with zinc, then the hydrogen gas is released. So change in atom, compound like atoms split from hydrochloric acid, then the chloride, mix with the zinc. Then the hydrogen left alone, so it only left the hydrogen gas.
UF007	(Task 6) O ₂ has double bond. So, C ... will react with O ₂ to produce We ignore the number of atoms. CH ... CO ₂ ... this carbon will react with this, CO ₂ so ... CO ₂ and it will produce CO ₂ and water. Carbon will react with water but there is eight of it. There's 13 ... 13 more molecules oxygen that will react with every other carbons in butane. It will produce carbon dioxide and the hydrogen will react with oxygen to produce water.
UF008	<p>(Task 5) When zinc with the HCl, chlorine will react with the zinc. The chlorine will reacts with zinc ... the bond will be broken. There are two chlorine ... so it is easier to react. Zinc can hold two. Hydrogen, it turns into ions, but does not exist as a single atom. H plus with H plus will become one ... (Task 6) And then the reaction between oxygen and butane, will produce water and carbon dioxide. ... now, the carbon is eight. ... hydrogen is twenty, oxygen is ... this oxygen is twenty six. Water ... water that is produced is ten. But with H, with the two hydrogen for each. Carbon, got eight of it, oxygen, I think eighteen. When we add all of these, it will be balance, [i.e.,] the amount of oxygen, carbon, hydrogen and oxygen.</p> $2\text{Zn} + 2\text{HCl} \rightarrow \text{H}_2 + \text{Cl}_2\text{ZnCl}_2$ $8\text{C}_4\text{H}_{10} + 26\text{O}_2 \rightarrow 8\text{CO}_2 + 10\text{H}_2\text{O}$
UF009	<p>(Task 6) This one breaks first. ... it becomes ions. This one becomes ions. [i.e.,] HCl. ... it meets with this [zinc]. ... When it breaks, then it meets with zinc. Since H is not stable, so it will change to H₂. It is stable, share with H.</p> $\text{Zn} + \text{HCl} \rightarrow \text{Cl}_2\text{ZnCl}_2 + \text{H}_2$
UF010	<p>(Task 6) I think it mixes and then the zinc will combine with chlorine. Hydrogen will combine and released. H₂ because it [H plus] is not stable. Because of the electron arrangement, it needs to form diatomic. So it form H₂. The attraction forces ...</p> $\text{H}^+ + \text{H}^+ \rightarrow \text{H}_2$
UF011	<p>(Task 5) So, it is like this ... Zn Zn Zn Zn Zn Zn ... two plus ... not yet. After that, HCl is liquid. Aqueous ... its ion ... H plus .. and Cl minus. After that, when zinc is added into HCl, Zn will ionise forming two plus, after that surrounded by the other ions. After that, positive ion, negative ion will attracted to each other. So, it will from this one.</p> $2\text{Zn} + 2\text{HCl} \rightarrow \text{H}_2 + \text{ZnCl}_2$
UF012	(Task 5) ... the zinc ion tend to combine with hydrochloric, because zinc ions is positively charge, so it will tend to combine with the negative charge, which is chlorine, Cl ... so ... like this ... become Cl two. And hydrogen gas will combine, zinc combines with chlorine, released as hydrogen gas, H ₂ gas.

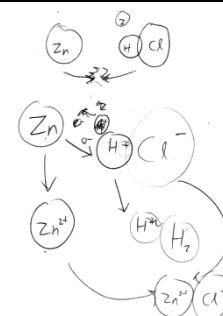
Atoms rearrangement	
UF015	<p>(Task 5) ... This is the H atom, this one is Cl atom, with the bonding. When the zinc is added, it will break the bond between hydrogen and chlorine. So, zinc will react with chlorine and forms zinc chloride. Since the hydrogen has no partner like the zinc anymore, it will be released as gas.</p> 
UF018	<p>(Task 5) The zinc has one atom, and the hydrochloric acid has hydrogen and chloride. Then, when they are mixed up, the zinc will combine with chloride and hydrogen will be released to the air. ... they will come together, like they are combined.</p>
UF020	<p>(Task 5) Based on the electrochemical series, chlorine is easier to couple with zinc compare to hydrogen. So, zinc displaces hydrogen and then zinc chloride will be formed. ... (Task 6) The same with the previous one; formation of ions and exchanging of the ions.</p>
UF060	<p>(Task 5) since zinc is stronger, the hydrogen will react with the chlorine. Hydrogen is been separated and without partners. Therefore, it will form into gas. Since it [zinc] is higher, it able to remove H from Cl. [drawing] So it will be removed. This one will not have any friend, but it can be alone, it needs friend. So, we have two hydrogen.</p> 
UF061	<p>(Task 5) In my imagination ... For me, it's really simple, just like, zinc is another guy, and the hydrogen chloride is a couple. The zinc comes, and snatches the girlfriend and the hydrogen will be become alone. [analogy]</p>
UF063	<p>(Task 5) when we add zinc it into acid hydrochloric they will displaces the position of hydrogen ... so ... the zinc will combine with chloride and then leaving hydrogen alone, forming diatomic atom.</p>
UO019	<p>(Task 5) Okay, it [zinc] is strong, so it pulls [attracts] the Cl. After it pulls that, it forms a new one [substance]. The hydrogen is left as hydrogen plus and it will form hydrogen gas.</p> 
UO021	<p>(Task 5) ... zinc reacts with HCl, one mole of zinc react with two moles of HCl, it will produce one mole of hydrogen gas and one mole of zinc chloride. ... The [zinc] atom will combine with chlorine.</p> $\text{Zn}(\text{p}) + 2\text{HCl}(\text{at}) \rightarrow \text{H}_2(\text{g}) + \text{ZnCl}_2(\text{at})$
UO023	<p>(Task 5) As you can see here, it needs two moles. ... two moles of hydrochloric acid combine with zinc. When they collide, two chlorine atoms will combines with zinc. The hydrogen will form to hydrogen gas.</p> 

Atoms rearrangement	
U0024	<p>(Task 5) That's mean zinc is more reactive than hydrochloric acid. So, zinc snatches off hydrogen from HCl. So, that's why zinc reacts with. If the zinc is human, means HCl is a couple, H and Cl. This one is the man and this the women [analogy]. So, when this Zn, another man, the Zn is more handsome than H, it is easy for Zn to snatch Cl from H. So, H has to go away, like Cl doesn't want him anymore. Meaning here, Zn is more reactive than H, so Zn will snatch Cl from H. We are left with H alone but there is no atom H, so we have balance it, so we got H two. ... (Task 6) And interexchange ... and Think so, yes. That's why oxygen can get in to carbon to form CO two. With hydrogen, turn into water.</p> 
U0026	<p>(Task 5) The zinc atom reacts with the molecule, hydrochloric molecule, the hydrogen and the Cl bond ... they will break, causing the hydrogen atom to be left alone, and then form hydrogen bond ... and the zinc atom will combine the chloride, to form the molecule ... zinc chloride. And the zinc will replace the position of the hydrogen. Therefore, the zinc chloride is formed. ... (Task 6) C-C bond in the butane is break. The oxygen atom is replace into to form carbon dioxide.</p>
U0027	<p>(Task 5) The zinc Cl two is form because H two ... Zinc will react with Cl to form $ZnCl_2$. Because of the charges. ... Leave the hydrogen behind.</p> $Zn \rightarrow Zn^{+2} + 2e^{-}$ $Cl^{-} + 2e^{-} \rightarrow 2Cl_2$ $2HCl + 2e^{-} \rightarrow H_2$
U0028	<p>(Task 5) Zinc and Cl will react and the bonding between this two will become further apart. This H will be released as gas molecules. Zinc with chlorine will form new bonding.</p> 
U0065	<p>(Task 5) zinc will combine with the chloride ion and hydrogen ... exist as its most stable compound ... Hydrogen gas will collide, I think, while in the reaction. So, hydrogen gas formed and zinc chloride formed at the same time. ... zinc will replace the hydrogen in the, in the hydrochloric acid. Then it will become zinc chloride and the hydrogen, it cannot stand as H. So, the most stable is the H two. So, the reaction will be completed when the hydrogen gas is formed and the zinc chloride formed.</p> 
U0069	<p>(Task 5) we can see this displacement reaction, ... zinc is more electropositive, if the positive side is stronger, because hydrogen can only release one electron forming what we call H plus, only one plus. But zinc can release two [electrons], so, it's two plus. In other words, because in aqueous right, hydrogen and chloride are not actually bond together. They are two separate things, but of course in the reaction, in the solution, two of them present. ... But since, put in zinc, it comes with both hydrogen and chloride, so depending in this case hydrogen and zinc ...it's not they cannot react but in preferably it's chloride. So, chloride goes in forming zinc chloride and ... since hydrogen left, hydrogen-hydrogen mix together, bond together, forming the gas.</p>

Atoms rearrangement	
UO070	

Bond breaking-formation	
SS030	(Task 5) Zinc will donate electrons, forcing H become H, H plus, Cl minus to recombine with zinc, to form zinc chloride. ... (Task 6) Many of them a time, oxygen and when it does this, bonds will break, the CH bond or CC bond will break. Therefore, leaving behind free C or H as intermediates, as it does this oxygen also may break or may not break, and therefore, mostly, actually no, it will all break, and reform with these free atoms, and therefore form the products and the process release heat.
SS031	(Task 5) These HCl dissociate to form one hydrogen, and then hydrogen ion and chloride ion
SS032	<p>(Task 5) When they collide, the bond in HCl will break. After it reacts with zinc. Zinc and Cl will form new bond. H with other H since it needs to be H two. Yes. There are bond breaking and then bond formation.</p>
SS047	(Task 6) ... break the bonds between the butanes and the CH or the CC so that they can react with the oxygen to form the carbon dioxide and water to break the bonds between the butane and also oxygen also, so that they can react with each other. They break the bonds ...
SS049	(Task 6) I don't know whether breaking or forming. Undergo the breaking of bonds. Formation of bonds.
UF008	(Task 5) When zinc with the HCl, chlorine will react with the zinc. The chlorine will reacts with zinc ... ah ... the bond will be broken. There are two chlorine ... so it is easier to react. Zinc can hold two. Hydrogen ... because this process is ... it turn into ions, but doesn't exist in single atom. H plus with H plus will become one ... It will break its bond. In this process, this oxygen will reacts with butane and will break the bond. Here the heat is produced.
UF009	(Task 5) This one breaks first [hydrogen chloride]. When it breaks, then it meets with zinc.
UF010	(Task 6) It [chemical bonds] will break. CH will break and meet with oxygen ...
UF011	(Task 6).. the bond breaks. The bond breaks. ... CO ₂ is formed because the carbon reacts with oxygen. ... formation of new bonds. ... It breaks here because it does not ionise, so it will break.
UF013	(Task 6) ... if the bonding between carbon and hydrogen is stronger than carbon-carbon bonding, because carbon and hydrogen, the distance between their centroid is much, much closer. ... if the energy that is supplied by the kinetic energy, the movement is not strong enough, only some parts of it will break. ... this bonding, only one carbon will be broken. And this one will wait other oxygen to collide. Every bonding will have an oxygen molecule that will collide with it.
UF014	(Task 6) ... for the reaction to form CO ₂ , bond is broken and new bonding will be formed. This will break first, this H is left. CO ₂ and then, oxygen is in excess. ... It [energy] has to be in excess so that it provide enough energy for oxygen atom for the C and also H. It will break first, so H will take two oxygen. And then, C will also take two oxygen.
UF015	(Task 5) This is the H atom, this one is Cl atom, with the bonding. When the zinc is added, it will break the bond between hydrogen and chlorine. So, zinc will reacts with chlorine and forms zinc chloride. Since the hydrogen has no partner like the zinc anymore, it will be release as gas. HCl is in liquid form. So, there are spaces between the atoms so zinc can move towards Cl and breaks the bond between H and Cl. When the collision occurs, the bonding between the molecules is broken and atom from butane will combines with oxygen.
UF016	(Task 6) it [butane] may undergoes substitution ... it is not substitution but elimination. The hydrogen is been discarded and oxygen comes in and forms the new product. And then they will break ups and this is left.
UF020	(Task 6) The bond will break. It is the same with the previous one.
UF022	(Task 5) HCl, the zinc attracts the chlorine atom. ... (Task 6) it seems that the butane ... its bonding breaks first. Break into its components.
UF060	(Task 5) The bonding in hydrochloric acid, HCl will break up first. After that, since zinc is stronger, the hydrogen will react with the chlorine. That's hydrogen is been separated and without partners. Therefore, it will form into gas.


Bond breaking-formation	
UF063	(Task 5) how to imagine? ... because this thing has been studied through molecular orbital so ... to imagine is quite hard. I mean ... the atomic number of zinc, and then I need to know the s-p-d-f of the zinc ...
UO019	(Task 5) The zinc will be ionised. And the hydrochloric acid will break up into hydrogen plus and chloride negative. The zinc has stronger attraction compare to hydrogen, so chlorine will be attracted to zinc. Since the zinc is two plus, so it will pull two chlorine ions. What is left is hydrogen. Since it is positive change, it will combine with another ion to form H two. ... Zinc two plus. For hydrochloric, H and chlorine negative. In the solution, there is a lot of ions. During the reaction, zinc is stronger. ... (Task 6) It [butane] breaks immediately. Its bonds ... The oxygen will also break. It react with this carbon to produce CO ₂ .
UO023	(Task 6) It [butane] is like been broken.
UO025	(Task 5) when it is in the liquid, of course the positive one will attracted with the negative one. ... zinc two plus will react with Cl, negative. It will form zinc Cl two. Because, when Cl reacts with zinc, H will release from the bonding, from Cl. So, H will be single. But hydrogen gas does not exist as single. It must be in molecule. ... (Task 6) This carbon will separate first. After that the carbon will bond with oxygen. There is CO two.
UO026	(Task 5) The zinc atom react with the molecule, hydrochloric molecule, the hydrogen and the Cl bond, they will break, causing the hydrogen atom to be left alone ... form hydrogen bond and the zinc atom will combine the chloride form the molecule, zinc chloride. ... (Task 6) C-C bond in the butane is break. The oxygen atom is replace to form carbon dioxide.
UO027	(Task 6) Bond breaks. It will form the new one because the bonds have broken.
UO028	(Task 5) Zinc and Cl will react and the bonding between this two will become further apart. This H will be released as gas molecules. Zinc with chlorine will form new bonding. It will become further apart, the carbon will react and will form bonds with oxygen.
UO064	(Task 6) this is going to be complete breaking all of the covalent bonds, with the C four H ten. CH bond and the CC bond they are all going to breaks. So, the bond breaking is an endothermic reaction, it absorb energy from the surroundings, ... CC bonds is still consider as a strong covalent bond, we need absorb energy first, to break the bond. Then after absorb energy, the bond breaks. ... first thing to happen is the CC bond and the CH bond, is going to change into radical, which is a homolytic fission And then when the oxygen comes in ... it forms the double bond by this joining here, double bond, and then this joining here, double bond
UO069	(Task 5) when you break bond, you release energy ... if you want to bond two atoms, you need energy ... Break release, you break release, if you want to bond it, you have to use energy. ... (Task 6) oxygen ... you have energy to break it down ... CO two and H two O ... carbon, hydrogen mix with these oxygen CO two ... oxygen ... take the hydrogen double bond C-C ... C-C one two. One two three ... (()) H ... H ... so ... one two three four, one two three four ... one two three four H, H, H,

Transfer of electrons	
SS030	<p>I imagine zinc as simple as simple sphere, and hydrogen chloride as another sets sphere. So these two, will undergo collision, and meantime transfer electron will occur, so, hydrogen, will transfer two of these, transfers over electron from zinc. ... zinc will donate electrons, thereby forcing H become H, H plus, Cl minus to recombine with zinc, to form zinc chloride.</p> 
SS031	Zinc undergoes reduction, by releasing its electron. The electrons received by the chloride ion to form the chloride. Receive by this chloride to form this [zinc chloride].
SS047	Zinc dissolve into the water, and form the zinc two plus ions. And release the electron into the mixture and ... the HCl also dissociate become H plus and Cl minus.
SS048	(Task 5) It has to do something with its number of electrons. But I forgot already the number. What I know is, it has two extra electrons. It donates, so its oxidation number is two plus.
UF007	(Task 5) it [zinc] will receive electron ... maybe two electron ... eh .. no .. it [zinc] releases electrons
UF011	(Task 5) It [zinc] release electron. It release electron to Cl ... Cl will take it. Zinc discards its valance electrons. ... later, Cl will take them [electrons].
UF012	(Task 5) when the zinc is mixed into acid hydrochloric, it [zinc] changes into two plus ... It [zinc] releases two electrons. It becomes ions. HCl in the aqueous form, it is already in its ions. Hydrogen has charge, H plus. So, the zinc just now releases two electrons. These H plus combine with the electron.
UF013	(Task 5) When the zinc is added, it will release two electrons, because will release two type, two electrons. So, zinc, will become zinc two plus. Adding two electrons and zinc two plus will move to stabilise the chloride. So, it will produce zinc chloride. H plus has less electrons. To stabilise it, H plus will accept two electrons. And two H plus, will need two electrons. Electrons will produce hydrogen gas.

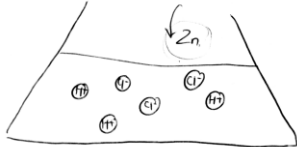
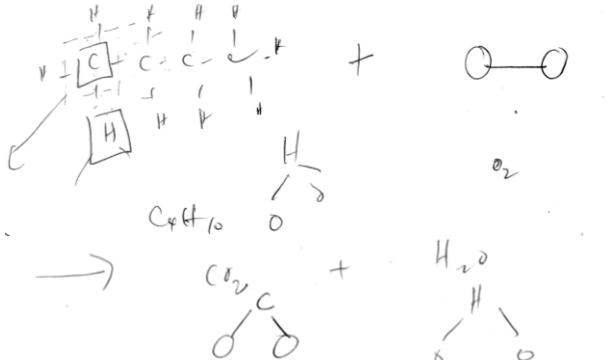
Transfer of electrons	
UF014	<p>(Task 5) zinc, it actually with two plus, if it is broken down the other atoms will achieve stable electron configuration. So, it will for, it will react, like male and female [analogy] attracted to each other. So, it will form an ionic compound, zinc Cl two. From zinc to zinc two plus, from zinc to zinc two plus, it will donate electron. It has access of two electrons, so it will donate two electrons.</p>
UF016	<p>(Task 5) Zinc will tend to donate electron. And the ions will tend to accept the electron from chloride ions. So, they will react to each other to form zinc chloride. And the hydrogen will change to positive hydrogen ion will combine to each other to form hydrogen gas. The hydrogen will accept the electrons.</p>
UF020	(Task 5) Electrons go to the hydrogen.
UF062	(Task 5) There's a transfer of electron.
UO019	(Task 5) from zinc to zinc two plus
UO025	(Task 5) the zinc gets the electron. From the ions of HCl. So, the electron, it is not the electron remains one only. So, the zinc later will get the electron from the solution.
UO027	(Task 5) Zinc will release the electrons.
UO029	(Task 5) It [zinc] donate the electron to HCl. It [zinc] tends to donate electron because it wants to achieve stability.
UO064	<p>(Task 5) So, undergo reduction by receiving the electron from zinc, and then forming hydrogen gas. Zinc solid become zinc two plus aqueous, plus two electrons. Then H, the real one that is happening here is H plus aqueous, plus two electrons, to form a H two gas, two electron, two H plus. So this is the oxidation process.</p>
UO069	<p>(Task 5) if the positive part is stronger, because hydrogen can only release one electron, forming H plus ... But zinc can release two, so, it's two plus. In other words, because in aqueous right, hydrogen and chloride are not actually bond together.</p>

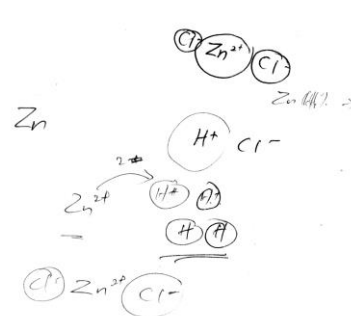
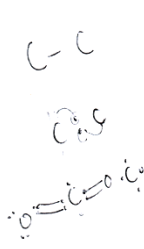
Redox	
SS030	<p>(Task 1) I understand that this iron, this is iron undergoing oxidation, forming rust ... (Task 8) The hydroxide ion, will undergo oxidation, whereby donating electron to dichromate, which therefore undergoes reduction. This reduction would change the oxidation number of chromate, into different oxidation number ...</p>
SS031	(Task 5) Zinc undergoes oxidation, and then the chloride undergoes reduction.
SS048	(Task 5) ... the metal undergoes oxidation. What I know is, it has two extra electrons. It donates, so its oxidation number is two plus.
SS068	(Task 1) Metal corrosion involves redox.
UF007	(Task 1) It is a reaction called as oxidation and reduction. Whereby, it involves oxidation and reduction.
UF014	<p>(Task 1) From ferum to ferum oxide. It is a redox process and oxidation. ... (Task 6) Combustion, one of its requirements is oxygen. So, it is oxidation. ... it form carbon dioxide and H₂O. This is redox. It means that something has accepted oxygen and release hydrogen. ... But this is not ionic. This is covalent.</p>
UF062	<p>(Task 1) [Rusting] Redox reaction happened here. Involves the oxidation and the reduction process. The iron been oxidised because of the exposure to air. So there is an oxidation occurred. And reduction occur the same time due to the oxygen. So, there's a transfer of electrons. (Task 5) Zn, this is zinc two plus and Cl minus, so, it's basically it is a redox reaction also.</p>
UO019	(Task 1) Maybe there is oxidation happened.
UO023	<p>(Task 1) In my opinion, it happens because of redox reaction. The metal reacted with water and oxygen. So, when these three components are present; the metal, water and oxygen. So the reaction that is called redox reaction happened and causing it to rust.</p>
UO024	<p>(Task 1) Rusting is a chemical reaction, i.e., redox reaction. So when the iron or metal is mixed with water or reacts with water, it will produce the rust. The chemical substances mixed with water, called as redox reaction. There is something being oxidised and reduced.</p>
UO029	(Task 1) The rust is from the iron. It undergoes the oxidation process; it undergoes rusting.

Redox	
UO064	(Task 1) [Rusting] is an auto-oxidation, as long as expose to air which contain water vapour and oxygen gas, ... whereby the Fe atom will become Fe three plus. Right, if it is metal ion, ion metal oxide, let say FeO, mean Fe two plus auto-oxidation will also occur because the send the electron ... reduction potential Fe three plus is much more stable than Fe two plus. So, oxidation occurs. ... (Task 5) this is an oxidation-reduction process, whereby zinc itself oxidised by the hydrogen because zinc is having a ... much negative standard electrode potential,
UO065	(Task 1) [Rusting] the metal corrosion is about oxidation reduction reaction
UO070	(Task 1) This metal undergoes corrosion. Its surface has undergone oxidation process. So, it [rust] is an oxide formed on its surface.

Attraction between charges	
SF041	(Task 5) They shift from here to here. ... the attraction, like it is the positive negative charge atoms, for this one, the zinc, I'm not sure how many positive. Like this, zinc will attract the two, chlorine, two chlorine particles, the charge is different isn't it.
SS030	(Task 5) ... zinc will donate electrons, thereby forcing H become H, H plus, Cl minus to recombine with zinc, to form zinc chloride.
SS067	(Task 5) As they break and then the zinc attract the Cl. ... Because zinc is positive right. The zinc is positive, so it attract the Cl negative.
UF010	(Task 5) It tries to find partners like I said. Zinc is positive and Cl is negative. Attraction forces between this one and this one.
UF011	(Task 5) So, it is like this ... Zn Zn Zn Zn Zn Zn ... two plus ... After that, HCl is liquid. ... its ion ... H plus and Cl minus. After that, when zinc is added into HCl, Zn will ionise forming two plus, after that surrounded by the other ions. After that, positive ion, negative ion will be attracted to each other.
UF018	(Task 5) There is positive and negative, combining them. Maybe the zinc is negative and hydrogen is positive, and the attraction of the hydrogen is stronger than Cl, so zinc will attract to the chloride.
UF022	(Task 5) HCl, the zinc attracts the chlorine atom. 
UO019	(Task 5) The zinc has stronger attraction compare to hydrogen, so chlorine will be attracted to zinc. Since the zinc is two plus, so it will pull two chlorine ions. What is left is hydrogen. Since it is positive change, it will combine with another ion to form H two. Zinc two plus. For hydrochloric, H and chlorine negative.
UO021	(Task 5) The atom will combine with chlorine. Zinc two plus.
UO025	(Task 5) when it is in the liquid, of course the positive one will be attracted with the negative one. So, ump ... this is its name ... okay ... zinc two plus will react with Cl, negative. It will form zinc Cl two.

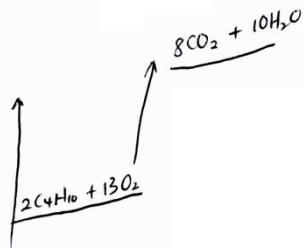
Intermediates	
SS030	(Task 6) Oxygen molecules will collide with these butane molecules, many of them a time, oxygen and when it does this, bonds will break. The CH bond or CC bond will break. Therefore, leaving behind free C or H as intermediates, as it does this oxygen also may break or may not break, and therefore, mostly, actually no, it will all break, and reform with these free atoms, and therefore form the products and the process release heat.
SS047	(Task 5) ... zinc dissolve into the water, and form the zinc two plus ions ... (Task 6) the butane will break their bonds, one form the C atom, and one is the hydrogen atom and the C atom will form together with the two oxygen atom to form the carbon dioxide
SS048	(Task 5) hydrogen in the hydrochloric will split, and then combined with zinc. The hydrogen is left behind. Then, they form hydrogen gas.
SS071	(Task 5) Like the hydrochloric, the particles of the hydrochloric acid split and the chloride bonds with zinc, then the hydrogen gas is released. ... atoms are split from hydrochloric acid, then the chloride, mix with the zinc. Then the hydrogen left alone, so it only left the hydrogen gas.
UF009	(Task 5) This one breaks first. ... maybe becomes ions. This one becomes ions.
UF011	(Task 5) After that, when zinc is added into HCl, Zn will ionise forming two plus, after that surrounded by the other ions. After that, positive ion, negative ion will be attracted to each other. So, it will from this one.
UF012	(Task 5) It [zinc] releases two electrons. It becomes ions. HCl in the aqueous form, it is already in its ions.
UF013	(Task 5) zinc, will become zinc two plus. Adding two electrons and zinc two plus will move to stabilise the chloride. So, it will produce zinc chloride. ... (Task 6) If the colliding, this bonding, only one carbon will be broken. And this one will wait other oxygen to collide.
UF014	(Task 5) From zinc to zinc two plus, from zinc to zinc two plus, it will donate electrons.
UF020	(Task 4) It will form ions first then it will react. ... (Task 5) The same with the previous one. Formation of ions. It just exchanging the ions. ... (Task 6) For combustion, carbon dioxide and water will be produced. That's all I know all this while.
UO026	(Task 5) the hydrogen and the Cl bond will break, causing the hydrogen atom to be left alone ... form hydrogen bond and the zinc atom will combine the chloride.

Intermediates	
UO064	(Task 6) ... when CO ₂ , I mean C radical and oxygen atom come together, so they will start their bonding formation, whereby they form a C double O, and then for H two O also form a single bond O. The C for example like this is a single bond, so each of them will take back what the original they have, C radical, C radical ...
Mechanistic approach	
UF012	<p>(Task 5) Hydrogen ... Cl ... hydrogen ion ... hydrogen added with Cl. ... chlorine is negative charges. So when the zinc is added into the [conical flask] ... Conical flask, the zinc ion tend to combine with hydrochloric, because zinc ions is positively charge, so it will tend to combine with the negative charge, which is chlorine, Cl ... so this become Cl two. And hydrogen gas will combine, zinc combines with chlorine, released as hydrogen gas, H₂ gas. Hydrogen has charge, H plus. So, the zinc just now releases two electrons. These H plus combine with the electron.</p> $\begin{aligned} \text{Zn} &\rightarrow \text{Zn}^{2+} + 2\text{e}^- \\ 2\text{HCl} &\rightarrow 2\text{H} + \text{Cl}_2 \\ \text{Zn}^{2+} + \text{Cl}^- &\rightarrow \text{ZnCl}_2 \\ 2\text{H}^+ + 2\text{e}^- &\rightarrow \text{H}_2 (\text{g}) \end{aligned}$
UF013	<p>(Task 5) in the hydrochloric acid, there are two types of ions. H plus and Cl minus. There are a lot of them. The H plus and Cl. ... when the zinc is added, the zinc will react with Cl ... When the zinc is added, it will release ... release two electrons, because will release two type, two electrons. So, zinc, will become zinc two plus. Adding two electrons and zinc two plus it will move to stabilise the chloride. So, it will produce zinc chloride. ... H plus, it is less electrons. To stabilise it, H plus will accept two electrons. And two H plus, will need two electrons. Electrons will produce hydrogen gas. Only parts of it will break. If the colliding, this bonding, only one carbon will be broken. And this one will wait other oxygen to collide. Every bonding will have an oxygen molecule that will collide with it.</p>  $\begin{aligned} \text{Zn} &\rightarrow \text{Zn}^{2+} + 2\text{e}^- \\ \text{Zn}^{2+} + \text{Cl}^- &\rightarrow \text{ZnCl}_2 \\ 2\text{H}^+ + 2\text{e}^- &\rightarrow \text{H}_2 \end{aligned}$
UF014	<p>(Task 6) There is bond breaking [in butane]. And then, for the reaction to form CO₂, bond is broken and new bonding will be formed. ... This will break first, this H is left. CO₂ and then, oxygen is in excess. It got to be in excess so that it provide enough oxygen atom for the C and also H. It will break first, so H will take two oxygen. And then, C will also take two oxygen. Step by step, like that. It is not after colliding, all break up.</p> 
UF015	<p>(Task 6) When butane and oxygen collide, the bonding will break. Oxygen bonding and bonding in butane. This carbon, it breaks step by step. After the bond breaks, the atoms will combines. CO will form double bond, CO₂. After that, hydrogen with oxygen.</p>

Mechanistic approach	
UF016	<p>(Task 5) Since H is positive, it needs to accept electrons and zinc is tend to donate two electrons. Zinc will turn to zinc two positive. The hydrogen will accept the electrons, achieving the octet state and will form hydrogen molecules. Once the zinc become zinc two plus, it will react with two chlorine ions to form zinc chloride.</p> 
UF020	<p>(Task 5) Electrons go to the hydrogen.</p> $\text{Zn}^{2+} + 2\text{H}^+ + 2\text{Cl}^-$ $\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$ $2\text{H}^+ \rightarrow 2\text{H} + 2\text{Cl}^-$ $2\text{H}^+ + 2\text{Cl}^- \rightarrow 2\text{HCl}$
UO064	<p>(Task 5) Then H, the real one that is happening here is H plus aqueous, plus two electrons, to form a H two gas, two electron, two H plus. ... this is, this is the oxidation process. This is a reduction process, so, when we say the real, so called as we say real reaction is the one which actually takes place in the reaction is zinc, so there are two H plus to give us a, zinc two plus aqueous and a H two gas. Cl remains the same. ...</p> $\text{Zn(s)} \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$ $2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g})$ $\text{Zn(s)} + 2\text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{H}_2(\text{g})$ <p>(Task 6) when CO two, I mean C radical and oxygen atom come together, so they will start their bonding formation, whereby they form a C double O, and then for H two O also form a single bond O. they formed a stable molecule, so they will release much higher energy when they form the bond. ... after the reaction, released and energy that is absorb during the reaction is compensate, overall give us a negative value. Combustion is always a negative value, releasing of energy actually. ... the CC bond and the CH bond, is going to change into radical, whereby it is a homolytic fission. The C for example like this is a single bond, so each of them will take back what the original they have, C radical, C radical. Because C is bond to four different atom, it will form back itself. And then when the oxygen comes in, we have oxygen here and then it form the double bond by this joining here, double bond, and then this joining here, double ... so, this what actually happen.</p> 
UO069	<p>(Task 6) ... step by step, if it a straight away reaction, of course it might be a straight away reaction, with chemistry having its own explanation, ... I can only think step by step because organic chemistry normally come to step by step.</p>

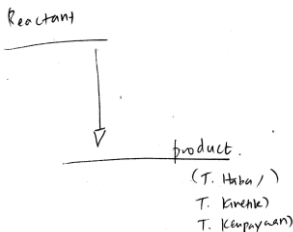
Conservation of energy

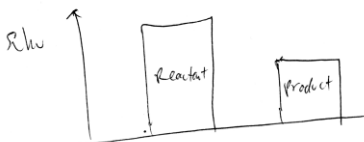
Energy gain and loss	
SF038	(Task 6) ... reaction normally absorb heat... So, when absorb heat, the thing will be hot as well.
SF040	(Task 7) The heat is already being released. To the surroundings.
SF041	(Task 6) maybe the heat ... released. Out from the beaker. But I'm still not sure why does it becomes so cold. Even though it releases the heat.
SF042	(Task 7) It releases heat. It became liquid. Because the heat is release.
SF051	(Task 7) I think it went to somewhere else. It goes to different place. Different place. As long it is not in there.
SF052	(Task 7) Dissolve may be in the air. I think the heat is release, so the temperature went down. Release to outside. Spread out.
SF072	(Task 7) So, the heat drop. Because it is already released to the air.
SF073	(Task 7) The heat is lesser. ... Where the heat goes? I don't know. The heat is released, maybe. From the beaker released into the air.

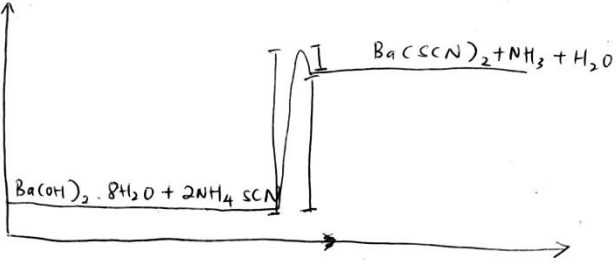
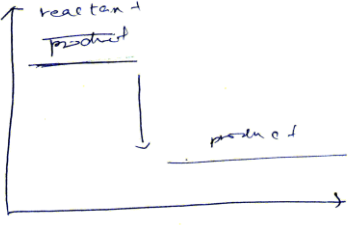
Energy gain and loss	
SF074	(Task 7) The heat is like been absorbed from the air in the surroundings. It is absorbed. Absorbed to where? [into]The air outside. The heat is from inside to outside.
SO033	(Task 7) May be, because it expels heat from the surroundings. ... it absorbs heat. ... I think it absorb heat. It absorbs to surroundings. Because in our lesson, we didn't learn much about freezing, but we learn about heat. ... When you heat a substance, and leave it at room temperature, the surroundings will become hotter. The heat is absorbed to surroundings.
SO044	(Task 7) ... the heat is been removed out.
SO045	(Task 7) The heat goes out.
SO046	(Task 7) ... the heat maybe it is already disappeared. It goes to the air.
SO056	(Task 7) The heat goes out. Losing the heat. But it is difficult to say like that.
SO077	(Task 7) Cold. Because it releases heat. From inside the beaker to outside.
SS031	(Task 7) Heat released.
SS048	(Task 7) Released to the surroundings. This is an endothermic reaction. It releases heat to the surroundings.
SS057	(Task 7) Maybe it releases heat. ... Release the heat, after that become negative. It produces heat and it releases the heat.
SS058	(Task 7) Surroundings! Released into the air. It is like going out. To the surroundings also.
SS059	(Task 7) Goes to the surroundings. Surroundings. The heat goes out.
SS071	(Task 7) Loose to the surroundings.
UF011	(Task 7) The temperature change when barium reacts with the ammonium thiocyanate, it releases energy. ... If it releases energy, it becomes cold? Because the energy is released.
UF012	(Task 7) It releases heat to the surroundings. But the one inside, it involves of particles, the one inside there, loses heat energy. The outer part received the energy. The temperature maybe dropped. Here, it releases energy. Yes. From the temperature, it releases energy. But the energy is higher. Heat energy. The heat energy is higher. But the heat energy discarded because in here its ... it involves particles, the heat energy is lesser but outside is higher, it releases heat.
UF016	(Task 7) Because this process is also an exothermic reaction. So, once the reaction occurred, it will releases the energy to the surroundings and it becomes very cold. Because it has already lost the energy to the surroundings. It releases heat to the surroundings. Therefore, the energy content become lesser and also become cold.
UF020	(Task 7) ... releases heat. To the surroundings. So, the reactant's temperature will go down because it releases heat to the surroundings. ... The temperature of the product.
UO017	(Task 7) Surroundings.
UO021	(Task 7) The heat gone [disappeared]. Surroundings. It goes out ... yes. The heat is released, the temperature drops.
UO026	(Task 7) Heat is given off to the surroundings. Therefore, the reactant itself becomes cool. It [heat energy] is being given off.
UO029	(Task 7) Heat is released.
UO064	(Task 7) Drop of temperature is from twenty-five to negative, that's mean, energy is released. Energy is released from there. Energy is released from there, that's mean barium thiocyanate is much stable than barium hydroxide. We can see the barium thiocyanate is stable, and we know that ammonia and water both are stable, that's why when they formed a much stable product, just like combustion they form much stable product, they release much energy to the surroundings.
UO065	<p>(Task 6) Since butane is organic compound, then when it is burned, carbon dioxide and water is formed oh yeah, when such as, you know, the small gas stove that we use to cook, we're not using the gas we're using the ... not like the ... we're not using the big the gas cylinder. We're only use the one like ... a hairspray can in size, it is butane gas, right. When we cook with it so, after we use the, the gas, right. When we take out the can, the outer of the can we can feel like watery. ... it is the water produce when the butane plus the oxygen but the carbon dioxide. ... I think this combustion is endothermic, I think. ... But as I say the, the can just now the butane gas canister something weird because it is cold but the fire is hot ... the butane inside the canister, it absorb the heat, absorb the heat from surroundings to produce a hot fire. When it absorbs heat, the surroundings will become cooler, but the substance is hot but the surroundings is cooler. Just like the can just now it is cool because all the heat has been absorb. ... (Task 7) ... the temperature drop from the actual temperature because the energy has been release to the surroundings, so the product is cold. ... the product inside is cold, so it is exothermic reaction.</p> 
UO070	(Task 7) It breaks, and energy is released. So, the temperature will drop. [Heat energy goes to the] surroundings

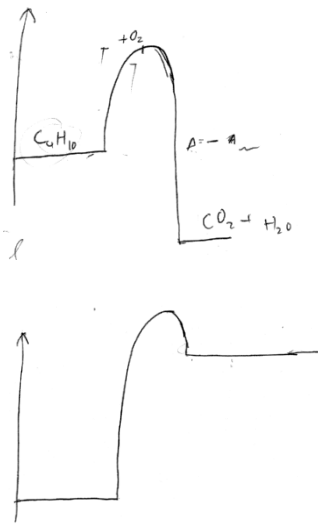
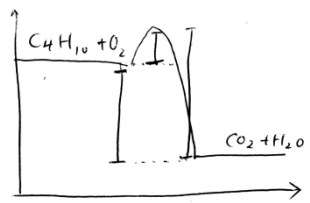
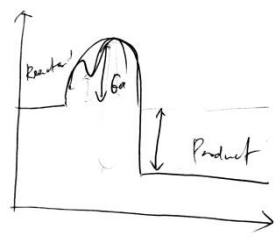
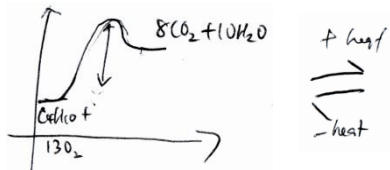
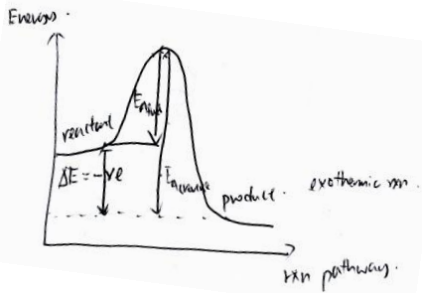
Change in form of energy

SF041	(Task 6) Chemical reaction produces energy. Because, maybe when the oxygen and butane react, ... their particles collide to each other, maybe that is where the energy is produced.
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Change in form of energy	
SF053	(Task 6) Because, maybe its particles ... its particles move very fast, after that it produces heat energy. ... The butane's particles will move very fast, and combine with the heat and oxygen, too fast, producing heat. And the butane ... if it combines with the three things, the particles move very fast, chafing each other, it will produce heat and light, the spark. So, the flame is produced.
SF072	(Task 6) Heat is hot. We also rub it.
SO045	Because of the friction.
SO056	(Task 6) Chemical reaction with ... flame, friction. Actually, it is not the flame that produce the spark. Actually, it is just like the stone with stone, the spark.
SO075	(Task 6) Maybe because of the gas and oxygen ... they rubbing to each other ... It rubs, and become hot.
SO076	(Task 6) The heat is from the friction.
SS059	(Task 6) Chemical energy [changed] into heat energy.
SS068	(Task 6) Atoms are collided
UF008	(Task 6) ... chemical energy change into heat energy. Energy change. But there are two different kind of energy. I feel ... in this one bar ... this is activation energy, active level. This energy ... chemical energy, it exceeded the from the activation energy, it becomes into heat.
UF010	(Task 6) Energy change ... chemical energy, heat energy and light energy. Chemical energy form butane and oxygen, after that the fire is formed, there is light energy and we feel hot because of there is heat energy.
UF011	(Task 6) Because the change of energy from one form to another form.
UF012	(Task 6) Energy from the kinetic energy, it changes to heat energy. When it is released outside. ... energy can't be created, it is only tend to change. Change. Change in form. 
UF018	(Task 6) Why fire is hot? I think the atoms are moving very fast and the friction between them will create the heat. That's why fire is hot.
UF063	(Task 6) As we know it, the energy cannot be destroyed and cannot be created. So, energy can be transformed. So from the movement of atoms, from the kinetic energy of atoms, it change into heat energy.
UO019	(Task 6) When the burning happen, reaction of butane and oxygen from the collision will produce the heat.
UO021	(Task 6) Maybe because of the collision is very strong ... its energy ...
UO027	(Task 6) The collision between the particles. The collision releases the heat. ... Maybe because of the collision of the particles.
UO029	(Task 6) From the collision.

Energy content	
SF040	(Task 6) The heat is from butane.
SF042	(Task 6) Because there carbon dioxide. Carbon dioxide is hot.
SF043	(Task 6) Because it has heat.
SF051	The thing inside, in the gas, that makes it hot.
SF053	(Task 6) Because it has heat energy. Heat comes from the flame. Heat, because flame has heat energy and also light energy. So, the heat is from the flame.
SF073	(Task 6) Because fire has heat. The heat is from the fire.
SF074	Because it [butane] has heat isn't it.
SO037	(Task 6) This gas, the air, there's hot air. It is hot
SO045	(Task 6) What inside it is fuel that a substance that causes the reaction and produces heat.
SO054	(Task 6) Because the heat of the fire. When gas is turning to fire there is something that forms the fire.
SO075	(Task 6) The heat accumulates in there [butane].
SS071	(Task 7) Because when it is in solid form, it's like certain temperature trap inside the solid. And when it turns into liquid [the temperature] is released.
UF007	(Task 7) I feel, if the reaction is endothermic, the product of the reaction will drops [in terms of energy] because the temperature goes down. The temperature goes down and its energy goes down because it is an endothermic reaction. Endothermic, its energy goes down.
UF008	(Task 7) the reactant with the higher temperature, and the other side, the product. The product with lower temperature. 

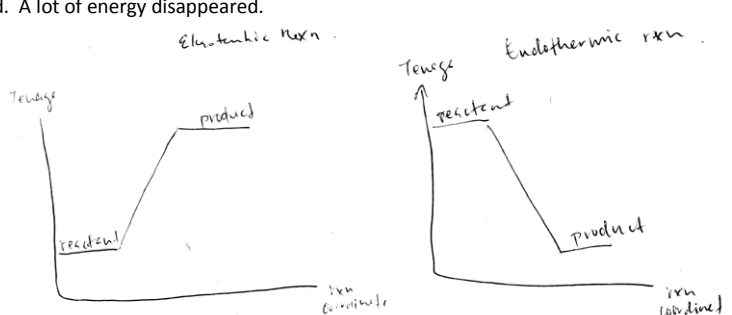
Energy content	
UF010	(Task 6) The heat is from the burning of butane as the fuel. The property of fuel is hot. Heat formed from the combination of the fuel and oxygen and fire will be produced. Exothermic will release heat.
UF011	(Task 7) Its energy becomes lesser.
UF013	<p>(Task 7) ... bonding is formed in barium thiocyanate, it absorb heat, higher. So, temperature goes down because the energy content is absorb to become energy content of barium thiocyanate. Before the reaction happen, the energy content for barium hydroxide and ammonium thiocyanate is lower. [drawing] It is lower. Reaction will happen. And the energy content for barium thiocyanate is higher. The amount absorbed is the same. The amount of energy absorbed is here. Activation energy needed is higher compare to the energy absorbed.</p> 
UF014	(Task 7) Higher than the reactant. But it is not stable because the energy content is higher.
UF015	<p>(Task 6) Energy level change. Becomes higher. If compare between the reactants and the product, which one has higher energy level? The products. Heat released because the lower energy level goes to higher one. So, the heat is release ... Heat is formed from the reaction between butane and oxygen. Heat need for the energy to form new bonding between the atoms from butane and oxygen. It supposes to be lower. ... (Task 7) Reactants higher, product is lower. The reactant is low, the product is high.</p>
UF016	(Task 7) This is an exothermic process. And from higher energy level to lower energy level. After it releases the heat into the surroundings, it becomes cold, less in energy. So, the products have less energy.
UF018	(Task 6) Because fire is hot.
UF060	<p>(Task 6) The product has higher energy. Here it went down, released. It should be like this. [drawing] The exothermic product is here. ... Reactants. Here is the product. We know that there is the energy reduced.</p> 
UF061	(Task 7) The heat used is here. It's for bonding, activation energy higher. Endothermic ... it take a lot of heat, then you form the new product is actually is higher in potential energy
UO024	(Task 7) If it is endothermic, the reactant is less energy than the product.
UO028	(Task 7) [the energy] for the product is lower than the reactant.
UO064	<p>(Task 7) That's why the energy drops. Why it drops such a large scale [of energy] is because barium thiocyanate, from this process we can see the barium thiocyanate is stable, and we know that ammonia and water both are stable, that's why when they formed a much stable product, just like combustion they form much stable product, they release much energy to the surroundings, that's why itself has negative temperature. So that's why it release energy to surroundings, so itself is lower energy.</p>

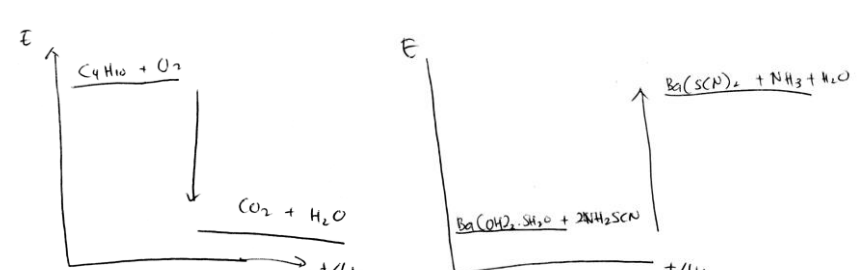
Net energy transfer	
SS030	<p>(Task 6) The heat required to be absorb for reaction to occur is less than heat release due to the formation of the new bonds. ... this energy is absorb use to break the bond and initiate reaction with butane. As time progresses, this energy used up, and this energy become negative energy, as is released due to bond formation. ... As the bond formation in carbon dioxide and water collective are stronger in butane. ... The heat release will be significantly higher than the heat energy that was absorbed, whereby forming the product, therefore meantime releasing a lot of heat. ... Stability, carbon dioxide and water are more stable than butane, because the heat released is significantly compare to the heat absorbed. Therefore, it get imply than the bonds that's formed after the reaction are stronger than the bonds present, before the reaction. ... (Task 7) The heat goes ... for the bond breaking. Because bond formation is always releasing heat. So, from the drop of temperature, we can imply that the energy required to break the bonds is significantly higher than the energy required to form, reform the bonds. From this you can imply that the salt produce and the product produce, overall have ah, I say, ... have weaker bond, as compared to the initial, initial reactants. However, the total energy will be higher, as they have absorbed more energy than they have released.</p> 
SS032	<p>(Task 7) At first the energy acquired to form the bonding of the reactant is less. But when it forms the product, it need more energy, so it takes in energy from outside.</p>
UF013	<p>(Task 6) ... taking in the energy from outside and during it is reacting to form carbon dioxide, the carbon dioxide bond formation and water, it will release heat which is higher form ... the energy to break the bond. ... (Task 7) It absorbed, it absorb by force. The energy is absorbed and this energy is release. ... Yes. A bit only. The differences will make this up.</p> 
UF015	<p>(Task 7) Bond formation releases heat. But the heat is used in the bond breaking.</p>
UF016	<p>(Task 6) Because in this process, maybe it receive energy and also release energy, but the energy that been released is more that been accepted. So, overall it releases the energy to the surroundings. ... Normally it is for breaking or to eliminate something or breaking a big molecule to smaller molecules. ... Breaking the bond. Normally energy is needed for the bond breaking. It accepts the energy. ... Normally it is formed when new products are produced.</p> 
UF062	<p>(Task 7) I think is an endothermic reaction. After mixing, there is drop in temperature. So, basically heat is absorb more than heat is release. ... The heat absorbed it to break bonds. The heat released is when bonds are formed. ... the previous reaction (Task 6), heat is released more than the heat absorb but this one is the heat absorb is more than the heat is released.</p> 
UO025	<p>(Task 7) This is an endothermic [reaction]. ... when products are produced ... it the same ... heat is needed up to here.</p>
UO027	<p>(Task 7) Heat is absorbed. For formation of bond, maybe release the heat.</p>
UO028	<p>(Task 6) Maybe because from the change of energy happen when the breaking of bond and formation of bond. Heat is evolved here. ... It needs the heat to break first. And when formed, then the energy is evolved.</p>
UO064	<p>(Task 6) this is absorbed, this is released, a higher released minus a lower absorb, so it results a negative value. We say this is an exothermic reaction. ... in my point of view is, it undergoes homolytic fission, absorb energy; they break. ... one of them start to form the CO two or H two O, heat energy is release, and the, I mean energy is released to surroundings ... (Task 7), when they need to release the aqua, they take in energy. So, they take in energy, but then after the reaction, since they form a much stable, the energy that they absorb already is release again, so that's why it release energy to surroundings, so itself is lower energy.</p> 

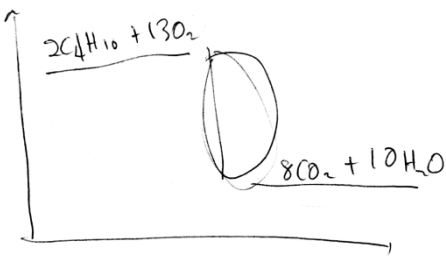
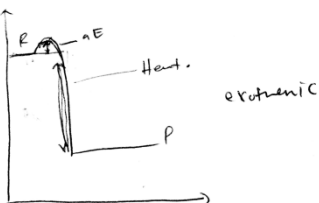
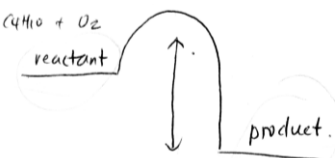
Energy change

Change of physical state	
SF039	(Task 6) Like in the experiment of ice changing to water. Because when the ice releases energy, it also releases heat that will cause the ice to change into water. The butane. It is in liquid form but when the reaction between the liquid and the spark ...
SF042	(Task 7) It changes into liquid. Because the heat is released.
SF043	(Task 7) It liquefies the solid into liquid. Because from solid to liquid, it needs heat energy. Because the energy is already been used to form the liquid.
SO035	(Task 7) Colder than before. Because it is mixed with ice. Not sure.
SO055	(Task 7) if we want to cool water, we need to put inside the fridge. Maybe it gone like, maybe like the mixture's temperature. It became cold. And then for this one, it combined and became cold.
SS071	(Task 7) From solid mixed with another solid. Become a liquid. Then the temperature drop, drastically. But ice itself, just with temperature with the surroundings heat and it will become liquid. But this one, need two different solid it forms the liquid, the water and other component. Because when it's in solid form, ... some certain temperature trap inside the solid. So, when become liquid, releases some energy.
UF012	(Task 6) because it is gas, the particle ... the energy in the particle is higher, the kinetic energy is high because its heat energy is high. So, when change into water, the energy of the particle become lesser and it release this. Meaning that, the kinetic energy becomes lesser when it release the heat. That's is how the change of the matter. Yes. Water or water vapour, the matter need, when changing from one state to another state, for example from gas to liquid, it needs to release heat. I feel like that, in terms of the environment is hot, in terms of matter. The state of matter changes and causing it to release heat. ... (Task 7) Maybe because of the change (Task 6) just now. From solid to liquid.
UO024	(Task 7) So, like the ice, it needs energy to hold the molecule so that they are arranged properly.

Heat as a reactant or product	
SF041	(Task 6) Fire is hot. ... because chemical reaction also produces energy.
SF043	(Task 7) It liquefies the solid into liquid. ... Changes from solid to liquid, it needs heat energy. ... [The drop of temperature] Because the energy is already been used to form the liquid.
SF051	(Task 7) It becomes cold because ... Maybe the heat is used ... It used the heat ... if it takes in the heat, it [should] become hot ...
SF052	(Task 6) Because of the heat produced. ... Because of the heat and the gas. ... Because everything that is burning produce heat. Besides carbon dioxide and water, also produce heat, from the reaction.
SF053	(Task 6) The reaction of butane, oxygen and heat energy. That's where it's from, producing the flame. ... (Task 7) Disappeared. It has lesser heat. So, it is cold. ... It reacts with barium and ammonium. ... The heat is part of it substances.
SF073	(Task 6) Because fire has high temperature. That's why it can produce heat.
SF074	(Task 6) Because fire produces heat because there is oxygen from the surroundings. So the fire blazed and become hot.
SO033	(Task 6) Because anything burning produces heat. ... It comes from the burning object.
SO045	(Task 6) It is produce by heat.
SO075	(Task 7) The heat change to cold the heat movement become heat. ... The heat goes in (()) the heat is recycled to become cold. ... It is like it been recycled into different substance.
SS031	(Task 6) The energy formed from the reaction between butane and oxygen. ... Because heat of combustion.
SS032	(Task 6) Fire is hot because the heat energy is produced.
SS057	(Task 6) ... the flame produces heat. That's why we felt it hot. ... heat is produced.
SS059	(Task 6) Friction of the flint. Produces heat.
SS068	(Task 7) Absorb, possibly for the formation of barium thiocyanate.
UF007	(Task 6) the product that produced will produce more energy.
UF008	(Task 6) the energy is used to produce the gas. ... it produces energy. (Task 7) The energy in form of heat. ... But this process, barium and ammonium, the energy is used to produce other thing.
UF009	(Task 6) So, it produces heat. ... to make the new compound. So, it reacts, it needs energy.
UF010	(Task 6) So, butane is considered as the fuel. The oxygen is need for the fire to be form based on that triangle [fire triangle]. When these three are present, then the fire will be formed. The fire is from the heat. ... Heat formed from the combination of the fuel and oxygen and fire will be produced. ... This one absorbed the heat and after that combines with other substances.
UF015	(Task 6) Because the reaction produces heat.
UF061	(Task 7) ... it requires heat, or something like, energy form and they will absorb from the environment, absorb from the environment, then ... absorb from environment then the new thing will be formed. So the temperature of the environment will drop.
UF062	(Task 6) The heat is released ... the heat is released at the same time carbon dioxide is formed. ... when water vapour is formed.

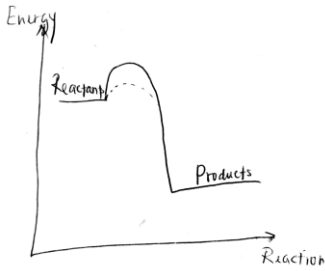
Heat as a reactant or product	
UO019	<p>(Task 6) The reaction that produces the heat. ... Before the reaction, the energy of the reactants is lesser. In the reaction process, the endothermic reaction, during the product is produced; it also produces a lot of energy. That's why it is hot. ... (Task 7) The energy is disappeared, used up to separate them. When the reaction happens, they combined to form new product. At this, the energy is already lessen because a lot of it been used. A lot of energy disappeared.</p> 
UO024	(Task 7) So, like the ice, it needs energy to hold the molecule so that they are arranged properly.
UO025	(Task 7) For it to produce the product.
UO028	(Task 7) ... all of it is used to produce the product.

Energy transfer	
SF039	(Task 6) Releases heat. ... it is hot because it releases heat. Anything that releasing energy will form something hot. That's my opinion. ... The butane. It is in liquid form but when the reaction between the liquid and the spark, it change into gas and at the same time it also releases heat
SF053	(Task 6) Formed from the combination of butane and oxygen and the heat, that was released ... (Task 7) Temperature drops ... because it absorbs heat. ... Heat from the surroundings. ... It absorbs heat, after that, the surroundings becomes cold. ... The heat from the surroundings is absorbed to change it to water.
SO055	(Task 6) ... when it is burning, it becomes hot. Maybe it gives out heat, so maybe it is hot.
SS031	(Task 6) Combustion, it releases heat; exothermic process. ... Exothermic process is the release of heat, is the release of heat, when one element of or another element combine, during combustion with oxygen. ... Combustion, so they release heat. Release heat, so it is exothermic. The amount, if exothermic, the amount of reactant, is more than amount of product. ... [For exothermic reaction] it releases heat to the surroundings. So, the temperature of the surroundings increases.
SS032	(Task 6) It gives off heat energy. ... Yes. There is excess of energy. So, the excess is given off as heat energy. ... Extra energy is released. ... (Task 7) ... it takes in energy from outside to form it compound. So it takes in energy from outside. ... Yes. From outside. So, the temperature drops.
SS047	(Task 6) ... carbon dioxide can give the heat energy to the surroundings ... of course inside the molecule will release their own energy to the surroundings, so the surroundings' temperature will be high. ... (Task 7) Absorbed by the reactant. So that, they can use [the energy] to form all the three products. From outside [the surroundings].
SS048	(Task 7) The heat is absorbed from the surroundings. So, the temperature of the surroundings drops.
SS049	(Task 6) ... it releases heat. Because the butane and oxygen releases heat.
SS068	(Task 6) Burning release heat. ... In this case, it is exothermic. Because it releases heat. When there is chemical reaction beside they release heat as well and possibly light.. ... (Task 7) As the chemical react together they involve of the process called endothermic. Where ... heat is absorb that result in temperature drop. ... Absorb, possibly for the formation of barium thiocyanate.
UF007	(Task 7) To my observation, this reaction caused the temperature drops. When reaction absorbs heat, it is called endothermic. Endothermic reaction absorbs heat from the surroundings causes the temperature drops. ... The one just now that releases heat is exothermic.
UF009	(Task 6) Heat released. ... (Task 7) Heat is absorbed.
UF010	(Task 6) ... exothermic releases heat. ... Exothermic will release heat. ... (Task 7) After the two substances are mixed, the temperature drops because heat is absorbed from the surroundings. ... Heat from the surroundings is absorbed to the substances. ... This one (Task 6), exo releases heat energy spread to the surroundings. This one (Task 7) it absorbed the heat and after that combines with other substances.
UF011	<p>(Task 6) ... it releases energy. Because it is an exothermic [process]. It releases energy. ... (Task 7) Endo ... it absorbs heat. So, this one it absorbs energy.</p> 

Energy transfer	
UF012	(Task 6) When ... the reaction produces carbon dioxide and water, production of water, they combined to produce the water [and] releases heat energy. That's why the surroundings is hot.
UF014	(Task 6) ... it releases heat. ... (Task 7) Meaning, heat is absorbed. The reaction absorbs the heat. ... So, surroundings become cold. Heat absorbed.
UF015	(Task 6) Release of heat energy. ... Heat released because the lower energy level goes to higher one. ... (Task 7) The reaction receives the heat. ... Receives the heat from the surroundings. So, the surroundings become cold. ... When the reactant changing into product, it need a lot of energy. So, the energy is absorbed by the reactant. ... Why does it been absorbed? To break and to form the bond. To break the bonding in barium and ammonium. So, when the energy is absorbed by the reactants, the heat becomes lesser. When the heat becomes lesser, the temperature becomes cold.
UF016	(Task 6) Why it is hot? Because the process is an exothermic process. It will release energy to the surroundings, so we feel hot.
UF020	(Task 6) Exothermic, heat is released to the surroundings. ... When the product is formed, the heat is released. That's why we feel hot.
UF022	(Task 6) it releases heat to the surroundings. ... It releases heat. ... (Task 7) this is an endothermic reaction. ... It absorbs the heat for the reaction to happen, it absorbs heat from the surroundings. ... the heat is absorbed ... for the barium to react so ... it seems used it, maybe.
UF060	(Task 6) Because as we know, when butane is oxidised, the energy will be given out. So, when the heat energy given out, we feel hot. So, this is an exothermic reaction. ... (Task 7) The energy is absorbed from the surroundings to form the bond.
UF061	(Task 7) it requires heat, or something like, energy form and they will absorb from the environment, then the new thing will be formed. So the temperature of the environment will drop.
UF062	(Task 6) exothermic. ... heat released. ... with more energy released from an atom, the temperature will rise. So, that why it is hot. ... (Task 7) so when as we know, when an endothermic occurs, it absorbs energy from the outside [surroundings] and does not release energy. So, the energy is inside the barium thiocyanate. ... Sort to say. It is contained inside the reaction, not release to the environment.
UO019	(Task 6) This one is exothermic. Because it gives off heat. ... releases heat. ... (Task 7) It is absorbed. ... [Heat energy absorbed] To the reactants. When the reaction happens, the heat is absorbed so that the reactants will react.
UO021	(Task 6) ... heat released.
UO023	<p>(Task 6) We say that burning of butane is exothermic. So, it releases heat. ... Like this butane and oxygen, when it is burning, from the combustion, it releases heat in the fire. That's why we feel hot. ... The energy that been released. ... Formed. ... (Task 7) The heat energy is not been formed but it is been released. ... The energy from outside is used to make the reaction between the reactants to happen. That's why the temperature goes down.</p> 
UO024	(Task 6) Because it gives off heat.
UO025	<p>(Task 6) It put out heat. ... heat release, right. Here, that's why it is hot. ... Release by the combustion. That's why it is hot. ... (Task 7) endothermic, meaning that it absorbs [heat]. So, it need a lot of energy. ... The reactants absorb it [heat] for the reaction to happen it needs heat.</p> 
UO026	<p>(Task 6) Because heat is given-off.</p> 
UO027	(Task 6) It releases energy. ... The release of heat energy. ... Because this process releases heat. Exothermic reaction. ... (Task 7) Heat is absorbed, endothermic reaction.
UO028	(Task 6) the heat is evolved. ... (Task 7) Absorbed. By the reactants.
UO029	(Task 6) Because it releases heat.
UO064	(Task 6) when CO two and H two are formed, they release high energy. They release high energy, so, ump ... the energy that release will be formed into light, so we can see red, or orange glow, and then we can also feel the heat, and then we can also hear the sound. ... That's why we can feel specifically the heat. Because this a combustion process, we can feel the energy that exist as a heat energy.

Energy transfer	
UO069	(Task 6) ... because you form a product, we have what we call energy dissipated ... If I'm not mistaken heat dissipated, that's the term ... heat dissipated when you form something, it uses part of the energy and it becomes heat. That's why we feel hot. ... (Task 7) ... just now the temperature drop because it absorbs energy right for the reaction

Reverse energy transfer in chemical bonding	
SS032	(Task 6) [Burning is hot] This is because of the breaking of bond. When butane turning into carbon dioxide and water, from a big compound, it breaks into smaller compounds. So, energy is released and that's why it is hot.
SS049	(Task 6) ... the breaking or forming of bonds cause heat. ... exothermic. ... breaking forms heat. ... So, it is breaking of bonds, release heat. ... A bond breaks, that's why release heat. That's why we feel hot.
SS067	(Task 6) It breaks down. ... butane and oxygen. ... It releases heat. ... From the breaking [of bonds].
UF008	(Task 6) In this process, this oxygen will reacts with butane and will break the bond. Here, the heat is produced.
UF009	(Task 6) Maybe it breaks the bonding in it, this butane. ... Maybe breaks up. Because, what I learn, release of a lot of heat energy is for the bond breaking. So, maybe the breaking [of bond] cause the heat given off. Maybe. ... This energy is bigger. Lower than this one. That's why it produces.
UF013	(Task 7) ... bonding is formed in barium thiocyanate, it absorbs heat, higher. So, the temperature goes down because the energy content is absorbed to become energy content of barium thiocyanate.
UF015	(Task 6) ... between this molecule, there is bonding. Between the bonding, there is energy that bond. When the bond break the heat is released. ... (Task 7) Bond formation needs energy. It accepts energy.
UF060	(Task 6) ... butane is a big molecules. So, when its bonds are been broken, the energy is released. This is because it stored a lot of energy for it to be bonded. So, when it is broken, the energy is released. ... (Task 7) This is barium and this is ammonium. So, firstly, the ammonium is positive twenty five and when it is added [with barium hydroxide], it will be reduced. When the barium hydroxide wants to bond with ammonium thiocyanate, it need energy. The energy is absorbed from the surroundings to form the bond. So, that's why the temperature is negative.
UF061	(Task 6) ... burning process is actually is breaking bonds ... break everything from the molecule than ... as we know the breaking bonds is a ... endo ... er exothermic process, then it provides heat. ... By breaking the bond. ... they will produce heat. ... for me, breaking bond, then they will produce heat. ... (Task 7) It [heat energy] is used to form new bond.
UO024	(Task 7) If it is hot, it needs a lot of energy to "open" the molecule. For this one eh ... this ... oh! It needs strong energy in the molecule to form bonding between the molecules ... So, like the ice, it needs energy to hold the molecule so that they are arranged properly. So, when it needs to change, energy from outside to release the particles to move freely inside the solid.
UO025	(Task 7) When forming [bond], it needs heat.
UO069	(Task 7) ... when you break bond, you release energy. ... if you want to bond two atoms, you need energy. ... you break, energy release; if you want to bond it, you have to use energy.

Enthalpy of formation comparison	
SS031	(Task 6) Release heat, so it is exothermic. The amount, if exothermic, the amount of reactant, is more than amount of product.
SS032	(Task 6) To my understanding, the energy of bond in the reactants is higher than the energy of bond formation in the product. ... What I mean is the energy required in formation of the reactants' compound is higher than the energy required in the formation of the product. So, energy released.
SS047	(Task 6) ... increase in their energy level. I mean the, the product will have higher energy than the reactants. So, they need to absorb the outside energy, so the outside energy, the surrounding energy ... the temperature will decrease. ... increased in their energy and the enthalpy change is positive. Because increase in their energy, but the surrounding temperature decrease.
UF013	(Task 6) the energy content become lower because it releases energy. Here, the energy is released and this energy will be felt hot.
UF014	(Task 6) Because it is exothermic, so, means its reactant's energy is higher. It releases heat, so this one is exothermic. The product is lower. Energy level.
UF020	(Task 6) The energy that been used by the reactant is more than when the product is formed. The energy inside the product for it to react and the energy contained in the product become lesser. 
UF022	(Task 6) The reactant [has higher potential energy] and the product is lower. Because the energy level has

Enthalpy of formation comparison	
	<p>lower down. ... (Task 7) Product [is higher energy level].</p>
UO064	<p>(Task 6) when CO two and H two are formed, they release high energy. They release high energy, ... a combustion process is whereby the energy that absorb by butane and oxygen, when they form a lower energy stable of product, CO two and H two O, there is a much greater form energy. So they just simply releases to surroundings and exist as light, heat and sound. That's why we can feel specifically the heat. Because this a combustion process, we can feel the energy that exist as a heat energy.</p>
UO069	<p>(Task 6) Two C four H two, plus thirteen O two, gas, eight CO two, gas, plus ten H two O, gas. In chemistry, all these have its own, what we call energy contain. For example, C four H ten, to form the basic component of carbon and hydrogen, (forming these things), it requires a certain amount of energy. So, the energy of the process for making it [butane], is the energy it has. For example, we put it as A. Now, oxygen itself is formed from two oxygen, energy B. Then, the carbon, and oxygen, two oxygen, we have energy C. We have hydrogen two, one oxygen, let's say the energy used is D. As I say just now, B is insignificant right, let calculate the enthalpy change or the change in heat. It would be C plus D, minus A, since B is insignificant, so the amount heat here, let say it's negative, would mean that, there is extra energy, meaning to say that A is bigger that C plus D. So, energy is released.</p>

Energy transfer in chemical bonding	
SS030	<p>(Task 6) ... the bonds formation releases heat ... heat required, [i.e.,] to be absorbed for reaction to occur is less than the heat release due to the formation of the new bonds. ... this energy is absorbed, used to break the bond and initiate reaction with butane. As time progresses, this energy used up, and this energy become negative energy, as is released due to bond formation. ... As the bond formation in carbon dioxide and water collective are stronger in butane. ... bond formation is always releasing heat. ... (Task 7) ... from the drop of temperature, we can imply that the energy required to break the bonds is significantly higher than the energy required to form, [i.e.,] to reform the bonds.</p>
SS047	<p>(Task 6) When the carbon dioxide formed, heat will be released. That's mean when this reaction happens, this reaction is exothermic process, will release heat when carbon dioxide formed ... the bonds, when form the bonds, will release the heat. ... From the formation of the bond between the carbon dioxide molecules. And also water.</p>
SS049	<p>(Task 7) Breaking of bond. ... mostly breaking of bonds. ... the barium thiocyanate is displaced but I think mostly breaking of bonds, compared to forming [bonds]. ... the heat is used up. That's why the surroundings becomes cold. ... [Energy] Used up, to break the bond.</p>
SS067	<p>(Task 7) ... [the reaction] absorbs the heat to break down all complex molecules.</p>
UF009	<p>(Task 7) This one need a lot of heat to breaks the bond. ... This one breaking the bond.</p>
UF013	<p>(Task 6) ... taking in the energy from outside and during it is reacting to form carbon dioxide, the carbon dioxide bond formation and water, it will release heat which is higher form ... the energy to break the bond.</p>
UF014	<p>(Task 6) ... we feel hot because heat is released, and there are new bonds formed. ... If there are new bonds formed, the heat [energy] need to be released. So, we feel hot. ... for the reactant to form new product. ... for it to reform, the energy need to be released. ... (Task 7) Heat is absorbed for breaking the bond. Looking at the barium hydroxide hydrated, from that it actually, it breaks the bond. So, it needs energy to break the bonding. This reaction absorbs heat, the surroundings becomes cold.</p>
UF015	<p>(Task 6) The bond formation will release the heat, so the energy becomes lower. ... the product will be formed. ... (Task 7) ... to break the bonding in barium and ammonium. So, when the energy is absorbed by the reactants, the heat becomes lesser. When the heat becomes lesser the temperature become cold. ... Bond formation ... releases heat. But the heat is used in the bond breaking.</p>
UF016	<p>(Task 6) Because in this process, maybe it receive energy and also release energy, but the energy that been released is more that been received [absorbed]. So, overall it releases the energy to the surroundings. ... Normally it is for breaking or to eliminate something or breaking a big molecule to smaller molecules. ... Breaking the bond. Normally it needs energy for the bond breaking. It accepts the energy.</p>
UF062	<p>(Task 7) I think is an endothermic reaction ... due to the drop in temperature ... basically heat is absorbed</p>

Energy transfer in chemical bonding	
	more than heat is release. ... The heat absorbed it to break bonds. The heat released is when bonds were formed. ... the previous reaction [that is in Task 6] the heat is released more than the heat absorbed but this one is the heat absorbed is more than the heat is released.
UO019	(Task 7) There is a lot of energy has been used to separate the compound.
UO027	(Task 7) It [energy] is used to break the bonding. ... For formation of bond, release the heat.
UO028	(Task 6) Maybe because from the change of energy happen when the breaking of bond and formation of bond. Heat is evolved here. ... It needs the heat to break first. And when formed, then the energy is evolved.
UO064	(Task 6) to my point of view, it undergoes homolytic fission, absorb energy, [i.e.,] they break. Once the process of breaking, one of them start to form the CO two or H two O, ... energy is releases to surroundings ...
UO069	(Task 7) For breaking the bond and then forming the bond.

Spontaneity

Reaction naturally happen	
SO033	(Task 7) I think, it has to do something with the molecules inside the chemical. And it reacts to each other.
SS030	[Task 4] Also the nature of the chemicals ... the nature of the chemicals that meant to react in such way.
UF007	(Task 7) It is ... the chemical law. ... it depends to the type of the substance itself.
UF008	(Task 6) Depends on the reactants.
UF010	(Task 7) I think it is because the properties of the substances.
UO017	(Task 1) ... the metal react with the oxygen then the chemical reaction will have happen. This is the nature substance. The nature of the ferum ... because the ferum is a metal, right. So, when it is mixed with oxygen, of course it will corrode. Naturally.

Presence of reactants	
SF038	(Task 1) Spark, then it [burning] starts and continues to burn. When there is more gas, it will continue, it won't stop until the gas is finished, the material for burning. Until the reaction finishes.
SF039	(Task 1) I found that it is a reaction. It happens when metal with water and oxygen in our earth.
SF040	(Task 1) It [rusting] continues [to happen] because there are still substances present. When there is none, there is no reaction. ... (Task 7) As long the substances are not finished, it still dissolving, [temperature] drops to negative. At certain stage, it will turn into water completely.
SF043	(Task 7) [the reaction continues] Because the component [the reactants] is still there.
SF052	(Task 6) [the reaction continues] Because butane keep reacting with oxygen.
SO055	(Task 6) [the burning continues] Because the gas is continuously been let go. When the fire is inflaming, it will keep on released out. It kept opened. Like this lighter, it has something that keep on releasing the gas out. So, it keeps on burning.
SS048	(Task 6) Because the valve is still open. So, the oxygen can go in to mix with butane inside the gas lighter.
SS049	(Task 6) I think it will continue to burn until finish up oxygen or butane. Access of oxygen. If no oxygen, it will stop burning.
SS057	(Task 6) ... as long there is oxygen and butane, the reaction will continue.
SS059	(Task 6) [the burning continues] Because there are substances for it to burn. ... Will react, because of the substance. If there is no substance, it can't react.
UF007	(Task 6) ... this is because the reacting substances. In burning, it needs oxygen ... enough oxygen ... the substance able to react with oxygen ... added with the heat ... and the burning happened.
UF008	(Task 6) When the condition is suitable. When all of the prerequisite is fulfilled, the reaction will happen. In this reaction, butane without oxygen, it can't react.
UF011	(Task 6) ... when it changes, with the presence of oxygen, it will reacts with oxygen ... with the flame, hot flame supply the energy ...
UF060	(Task 6) Because there is a lot of oil in here, isn't it and in environment also has a lot of oxygen. We just let the butane out and the oxygen is out there. (Task 7) ... the barium wants to react with thiocyanate.
UO027	(Task 6) If we just the butane alone, without the oxygen, even with heat, it will not reacts. If there is no other reactants present, just this reactant [butane], the chemical reaction will not happen.
UO069	(Task 6) Because you have these amounts, the limiting factor here, would be butane, as long the liquid butane here, ... as long the supply is here. After this [butane] is gone, it cannot burn.

Reacting agents	
SF038	(Task 6) The heat produced enables the reaction to continue.
SF040	(Task 1) For the metal corrosion, it is rusting. Caused by acid rain. It able to change colour because of the present of water and air, as I said just now, it [acid rain] can cause rust.
SF041	(Task 6) Because when it has started, when the spark started the reaction, the heat is there already. The heat energy will continue to be there. So, it doesn't need the spark anymore. Self-sustained. As long as the gas supply is maintained.
SF051	(Task 1) ... to me metal corrosion, it is caused, exposed to the air. That's why it is rusting.
SS047	(Task 6) Because I think, when the burning started, it will also produce heat, and provides for the butane to react again and again. I mean is continuous. It supplies the heat. To its own molecule.

Reacting agents	
UF007	(Task 1) When the surface of the iron is exposed to the surroundings like rain, water, and the environment That's what causes the iron to rust. ... So, the lead [referring to iron] is one of the metal will reacts with the non-metal, right. It is the properties of the elements itself to react. It [the reaction] is influenced by the substances itself. Like the iron, when it is added with water, it will rust. But when it is in contact with other element like oil element, it will not rust. Because it depends on what substance that it is reacting with.
UF009	(Task 6) There is agent that helping [it to react].
UF010	(Task 1) Because there is air in our surroundings. When there is air and water, even we put it in a container, the corrosion still happens. ... The properties of air and sun help the reaction to happen.
UF012	(Task 1) Metal has chemical properties, at certain temperature and environment that has water vapour and then it tends to undergo reaction. ... so the reaction happened. ... it depends on the environment ... it is not only depends on the environment, it also depends on what it is mixed with. Different kind of substance, different kind of product [will be produced]. ... The environment that causes that the ferum suitable to change into ferum three.
UF014	(Task 5) This is a reactive metal. It reacts with strong acid and it will release hydrogen gas.
UO021	(Task 1) External factors. ...The environment maybe [causing rusting]
UO025	(Task 1) When it is exposed to the environment, the reaction will happen. That's why rusting happens.
UO027	(Task 7) Why reaction happens? Because of the present of certain reactants causing the chemical reaction happens until the products if formed.
UO028	(Task 1) Because ... it is influenced by the condition ... influenced by its surroundings, present of oxygen and water. That's why rusting happened with the present of these two important elements. Water and air. The things in the surroundings.

Reactive reactants	
SS032	(Task 6) The reactant is more reactive turning into something not reactive, in stable form.
UF007	(Task 5) ... the reactivity series. When the molecule in the position ... depends on the series ... the position of the metal. reactivity series ... electrochemical series. ... depends on that. That's among factors that influence the reaction.
UF008	(Task 4) ... it happened because lead can react with iodide, because the Periodic Table ... lead, when it reacts, it chooses either potassium or iodide. Iodide is easier to react with lead.
UF011	(Task 7) Its reactivity. Maybe the barium has higher reactivity, it will take the thiocyanate.
UF015	(Task 1) Because ferum is reactive, so it reacts with the surroundings like humidity. It's not like other metals that are less reactive and does not react.
UF016	(Task 1) ... more reactive, whereby ferum ion three the position is more active. The metal is more active or reactive, it will turn into ferum three. But ferum three, it is already stable. ... after combining with other compound, it is more stable. And it will remain in that condition, will not change back.
UF018	(Task 5) It is because of the hydrogen, maybe its reactivity. The reactivity of the hydrogen is either lower or higher. ... zinc will combine with the two H. But if it is not H, say sodium, zinc will combine with sodium. Depends on the reactivity series. ... Because it need something to cause the reaction for it to happen.
UF020	(Task 5) Based on the electrochemical series, chlorine is easier to couple with zinc compare to hydrogen.
UF060	(Task 5) HCl, as we know it is like that It will break up because it [zinc] is higher.
UF061	(Task 5) we know zinc is more reactive than the hydrogen, because the zinc chloride is more stable than the hydrogen
UF062	(Task 5) Zinc is quite reactive metal. So, when it encounters with an acid, it will react vigorously ...
UF063	(Task 5) zinc has higher reactivity compare to hydrogen ... when it is reacting with a more reactive [substance] ... zinc has higher reactivity compare to hydrogen ...
UO024	(Task 5) zinc is more reactive than hydrochloric acid. So, zinc snatches off hydrogen from HCl. ... Meaning here, Zn is more reactive than H, so Zn will snatch Cl from H. We are left with H alone but there is no atom H, so we have balance it, so we got H two.
UO026	(Task 5) Zinc is the metal. And then hydrochloric is form of strong acid. When the metal react with the strong acid, the strong acid have a strong oxidising power, and then corrode the metal and produce the gas, hydrogen gas.
UO064	(Task 5) ... this is a oxidation-reduction process, whereby zinc itself oxidised by the hydrogen because zinc is having a much negative standard electrode potential ... zinc have a value of negative zero point six volt, and hydrogen is having zero point zero volt. By the concept of electrode chemistry, the more negative one will always be oxidised, oxidation one I mean as the reducing agent, so itself undergoes oxidation by induced by oxidizing agent, hydrogen, so it release two electron to the system, itself becoming a zinc ion. And then hydrogen itself in contras, at this point, H plus, alright, since it has electrode potential zero point zero volt, so it is an oxidising agent. So, undergo reduction by receiving the electron from zinc, okay, and then forming hydrogen gas. So, this is actually a process [similar] a voltage cell but itself in the cell, but this is not in the cell. We cannot [calculate] the volt, but it still applies. That's what actually happened there.
UO069	(Task 5) Zinc ... normally we can see this displacement reaction, ... more electropositive, if the positive side is stronger, because hydrogen ... can only release one electron ... forming what we call H plus, only one plus. But zinc can release two, so, it's two plus.

Stability driven	
SS030	(Task 6) Stability, carbon dioxide and water are more stable than butane, because the heat released is significantly compared to the heat absorbed. Therefore, it get imply than the bonds that's formed after the reaction are stronger than the bonds present, before the reaction.
SS032	(Task 5) Maybe because the product is more stable. ... (Task 6) Maybe its stability. The reactant is more reactive turning into something not reactive, in stable form. ... (Task 7) The products are more stable. ... But if it not stable, why does it happen like that.
UF011	(Task 5) the zinc will discard its electron so that it is more stable. Cl will need one electron for it to be stable. So, to form ... for zinc and chloride to be stable, both them will combine. There are two of chloride atoms ... combine with zinc. They will form zinc chloride. The H, it only need one electron, so ... H and H need one and one, so they will combine so that they are more stable. ... (Task 7) To achieve stability. Why these reactions tend to happen? Because, two different compound mixed together, react to each other. ... To achieve ... stability. Its reactivity. Maybe the barium ... has higher reactivity, it will take the thiocyanate. ... Because there is H ₂ O, NH ₃ , it is stable.
UF013	(Task 7) It is more stable because it releases heat.
UF014	(Task 7) More stable, the energy content is lower. Maybe it is not logic, because I think, because this one, the reactant's total energy is higher than the product. Its products are also two. ... So, in single, we see it is stable. That's why even this we look at it more stable because of its energy content is lower, but maybe if we consider in terms of energy individual energy content, maybe it is still lower than the reactants. But then, for this single barium hydroxide, its energy content is more when compare to each product. ... when the three is summed up, it is higher than that [reactants].
UF016	(Task 1) ... the metal is more active or reactive, it will turn into ferum three. But ferum three, it is already stable. ... after combining with other compound, it is more stable. ... it will remain in that condition, will not change back.
UF020	(Task 1) Because the iron's arrangement is not stable so it will take other compound from the surroundings to react so that it will become something more stable. It just exchanges but the new substance is more stable.
UF061	(Task 5) ... zinc chloride is more stable than hydrogen ... But because the product is more stable in this form. We have been told that the product is more stable in this form.
UF063	(Task 8) ... a stable compound when there are present of ... I mean present of reactive component, so ... both of these will react to form more stable [substances].
UO023	(Task 5) Zinc reacts with hydrochloric acid. Since these two substances are not stable, they will react to each other to form more stable compound. This is also influence by the differences in electronegativity.
UO029	(Task 7) Because it [the reactant] wants to become stable. ... the chemical reaction happens between these molecules because they want to become stable.
UO064	(Task 1) Right, if it is metal ion, ion metal oxide, let say FeO, mean Fe two plus auto-oxidation will also occur because ... Fe three plus is much more stable than Fe two plus. ... (Task 7) Energy is releases from there, that's mean barium thiocyanate is much stable than barium hydroxide. That's why the energy drop. While, why it [the temperature] drops such a large scale is because barium thiocyanate, from this process we can see the barium thiocyanate is stable, and we know that ammonia and water both are stable. That's why when they formed a much stable product, just like combustion they form much stable product, they release much energy to the surroundings, that's why itself is in negative temperature.

Electrostatic charges	
SS047	(Task 7) ... the barium hydroxide will break their bonds, ... into one barium ion and hydroxide ion. ... barium ion will combine with the SCN ion. And form the barium thiocyanate. ... then the OH will combine with the hydrogen of one of the ammonium ions, to form the water. And the remaining, NH ₄ reduce in the hydrogen number, so become NH three, the ammonia gas.
UF008	(Task 7) In the Periodic Table, barium with ammonium, with the thiocyanate ... it can reacts, it has some kind of attraction that make them ... break the bond ... with the ammonium and the thiocyanate, ... barium with the hydroxide and water.
UF011	(Task 4) Because lead is two plus. Because it is positive, and this one is negative. Yes. It is [nitrate is also negative] So, it make friend with this one.

Electronegativity differences	
SS030	(Task 7) ... the differences of electronegativity. But, from what I know because, the differences in electronegativity between this two are so great, that they are able to continue reaction, despite environment condition being actually counterproductive, because a decrease of temperature would obviously cause a decrease of rate of reaction, however rate reaction still continue, in fact accelerate despite the decrease in temperature.
UO023	(Task 5) Zinc reacts with hydrochloric acid. Since these two substances are not stable, they will react to each other to form more stable compound. This is also influence by the differences in electronegativity.

Energy driven	
SS030	(Task 4) This because the energy store within, store within the chemical are ready enough to initiate the reaction, almost spontaneous between the two.

Energy driven	
UF008	(Task 6) When the condition is suitable. When all of the prerequisite is fulfilled, the reaction will happen. In this reaction, butane without oxygen it can't react. Now, in this case, there are butane and oxygen presence, and the spark for the energy, and achieving the activation energy only then the reaction can occur.
UF014	(Task 7) the energy content is lower. So, it reacts.
UO064	(Task 6) it can itself act as the resource of the energy for the C four H ten, I mean C atom and H atom in the molecule to start the reaction. So, this reaction going on, the energy keep on released, so they keep on started, keep on started, until all of them is finished. That's why combustion process, normally if it is started, we cannot simply like put it off easily. ... when we have two ligands, so the ligands is thiocyanate and OH, ump ... the one that will lead to a lower ... the one that lead to a lower ... d-d transition, lower energy field, higher energy field ... But there is going to a change ligand because, one of them going to be more prefer which cause ah ... I kind of forgot the higher energy or lower energy, it should be the lower energy that will give a lower product, because this result in a lesser d-d transition.

Reversibility

Irreversibility presumption	
SF041	(Task 8) Some can, some cannot.
SF043	(Task 7) Maybe when it is already mixed, it is hard to divide them.
SF052	(Task 6) Because it's already mixed together. So, mixed together, so, it's hard to separate something mixed together.
SF072	(Task 6) ... if this one [butane] added with this one [oxygen] ... it produces this one [carbon dioxide and water] ... if we want to get this ... we need to break it again. Because ... it is already different.
SF074	(Task 7) The change has already mixed up. So, it is hard to reverse it to the original.
SO033	(Task 6) Carbon dioxide and water are heated. No [it will not change back to reactants]. I don't think so. Impossible.
SO077	(Task 6) Because, the liquid inside the lighter is natural; from the seabed, formed millions of years ago. So, it cannot be formed back.
SS059	(Task 6) ... it is already happened. So, this one is already changed to this.
SS067	(Task 7) Because like they already mixed, two different solid and then they mixed together, ... I think it is hard to get back the original one.
UF009	(Task 1) The surroundings make it to form ferum hydroxide. The ferum is pure metal, it reacts with the surroundings, so it is hard for it to revert. ... Because it is already mixed with other substance. So, it is hard to revert to the original thing. ... it has already combined.
UF011	(Task 6) It is a hydrocarbon, which is only can be obtained from the petroleum. So to get it back, it must be from petroleum.
UO021	(Task 1) Because when something had happened ... it's like when baby is born, how to unborn the baby. So, it is hard.
UO027	(Task 6) Because butane is not from carbon dioxide and water.
UO065	(Task 6) I think ... impossible. Because any organic compound if we burn with oxygen, we will get the carbon dioxide and water, so the reaction is irreversible. ... any organic compound if we burn with oxygen, we will get the carbon dioxide and water, so the reaction is irreversible.... I think it's slightly impossible. ... (Task 7) I think it's irreversible reaction ... [i.e.] non reversible, I think. ... because it is complex ion I think, hard, it is hard to reverse the reaction.

Physical state	
SF038	(Task 8) It releases, some absorb. Some become gas. This one, it remains as liquid. [Therefore, the reaction is reversible]
SF043	(Task 8) Because this one only involves water [liquid]. The same state.
SF052	(Task 8) I don't know, may be the reaction, liquid. Liquid state, so it is easier [to reverse]. Then they don't mix with another state of matter.
SS071	(Task 6) So, when you mix water and carbon dioxide together, carbon dioxide will evaporate also. So, it won't become this back. The CO two need to be contains and then to mix with the water. Just it becomes liquid.
UF012	(Task 8) Why it is reversible? It is reversible, because it is still the same thing. In the same form of state of matter. Still in form of liquid, it does not change into solid. Because it still in aqueous.
UF018	(Task 6) Because it is in gas form so, it is hard to get it back.

Matter is not conserved	
SF038	(Task 6) Because, chemical reaction, ump ... produce, produces different form of particles, carbon dioxide and water, probably cannot changed back.
SF040	(Task 7) Because it is in solid form. That one, it needs to be separated first, but it is quite impossible. Because it has turned into water. This cannot be reverted because hydroxide ... we have to put in oxygen again.
SF051	(Task 6) I think it can't be [reversed]. Because it is already burned. I think ... it is already change to that thing, so to get it back is hard.

Matter is not conserved	
SF053	(Task 6) Cannot, because, that's its products. The butane has carbon and hydrogen. Oxygen, only oxygen. So, if combined with heat, the oxygen and hydrogen is been used up, what's left is carbon and water. So, the carbon and water will not be used. So, if they are mixed, it cannot produce heat. ... some parts of butane is already been used up.
SO033	(Task 6) Because, carbon dioxide and water, when, butane is added with oxygen, I think it just by products. So, it, when you, mix carbon dioxide and water, heat up, I think it won't get, the initial component, like butane and oxygen. Because it's a by-product.
SO054	(Task 6) Maybe this, carbon dioxide with water, if we mix ... maybe butane has something more than one substance for that.
SS058	(Task 6) Maybe because in a reaction, the reacting reactant, when both of the reactant will react to form the product. When the product is formed, some of it, is gone. So, the products unable to form the reactant back.
SS059	(Task 6) ... the heat was released already. How it can be reverted to [the reactants] ... The heat is already been released. ... (Task 7) Maybe not. Because it is already became water.
UF010	(Task 6) Butane and oxygen have changed to carbon dioxide. Therefore, the properties have change. So, we cannot get the initial properties. The properties have changed.
UF015	(Task 7) It is like, initially there are two substances but when the reaction occurred there are three substances were formed. And ammonia was also released as gas. Therefore, few atoms from the earlier substances have been released.
UF016	(Task 3) But this one, chemical reaction has happened, some of the molecules have changes to form new products. Not all can be change back. It is hard because it's already undergoes chemical reaction.
UO024	(Task 7) Because the thing is already released to the air. It can but it is hard also. Because, it is hard to get the ammonia back. Maybe it is hard.
UO025	(Task 6) Because if the carbon dioxide is to be combine again, the product is not enough ... it is different already. It will not be butane anymore ... the product will be different. ... (Task 7) ... if A add with B produce C. How it can be [reversed] ... it will not form back to B and A. If it is to turn back, it is not reversible
UO028	(Task 6) It cannot, because ... because it has already formed to products. ... the bonding is already different. Atoms that making up the molecules are different. Chemically it is different.
UO029	(Task 6) ... the molecules have changed. The initial molecules break to form new molecules; carbon dioxide and water.

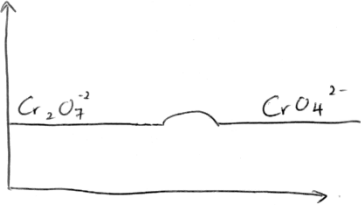
Through a different set of conditions	
SF038	(Task 8) Maybe it can be reversed by using different materials.
SF039	(Task 7) Yes [it can be reversed]. We can but through a different kind of reaction.
SF043	(Task 7) It needs to be heated to reverse it. It needs some process.
SF052	(Task 6) I'm not really sure, but I think ... we can do something like experiment to separate both elements. Require precise process. ... (Task 8) If we use correct method, we can get back the original material.
SF053	(Task 8) This one, initially orange in colour, when it is combines with this [HCl], it turns to yellow. After that, the yellow one when combines with this [NaOH], it turns to orange.
SO033	(Task 8) May be it involve the response of the two chemicals. The first chemical turns it to the by-product and the other chemical turns it back to the initial chemical.
SO037	(Task 8) .. some chemicals have colour. When other colour mixes with other colour, it produces different colour. First, it's orange, when mixed with the ion next to it, it becomes yellow. After that, when the one in other side put into the container, it becomes orange.
SO037	(Task 8) First, it's orange, when mixed with the ion next to it, it becomes yellow. After that, when the one in other side put into the container, it becomes orange.
SO055	(Task 8) If it is a lot, maybe it ... it belong to it. Like the master. All of that just follows.
SO077	(Task 8) ... it is added with the alkali [so it is reversible].
SS030	(Task 8) It might be some other process you can re-obtain the reactants but then it would be from other steps all together. Therefore, for it to return to this state, you'll need another set of reactions all together which can be very long.
SS032	(Task 8) Because NaOH has OH isn't it. So, when it is added, the dichromate ions turn into chromate ions. It turns into yellow. But when HCl is added, it has H plus, and Cl negative. After that, it will react with OH negative to form water.
SS047	(Task 6) Maybe catalyst is needed but I think it can [be reversed]. Can be combined together and form back to the butane, with other process. (Task 8) It is a reversible process. When added with the alkali solution, the dichromate ion will form chromate ion.
SS048	(Task 8) What I know is the reaction will undergo the process of product formation. If the concentration of the reaction is increased, the reaction will shift to the right.
SS058	(Task 8) Maybe because dichromate ion, when mixed with NaOH, it becomes yellow. But when the HCl is added more than the NaOH, it makes the properties stronger than the orange one. So, that's why it changes colour back. ... At first, the ion dichromate is orange in colour and when it is added with sodium hydroxide, the content becomes more. ... Although it is a little, it changes to yellow. When HCl is added, it increases the properties of the initial one, more than the sodium hydroxide. This causes it to change back to orange.
UF009	(Task 3) Because it has changed into a different form. So, for it to change to the original form, because it is already in liquid form, it needs an agent that helps it to revert. ... (Task 8) When OH ion is added, it will change to chromate. It is oxidation. But when HCl is added, the oxidation number change back to dichromate.

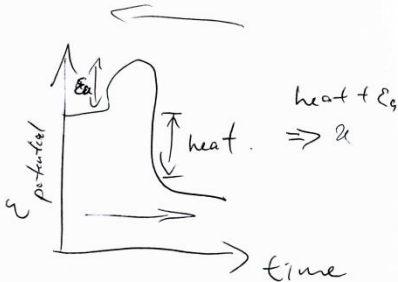
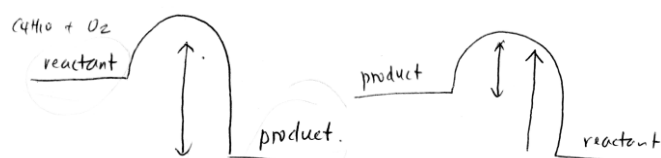
Through a different set of conditions	
UF010	(Task 8) Maybe it depends of it properties. There are certain properties that make it turn back to its original form without going through certain reaction. Like water turns back to ice, just either to add or discard the heat.
UF012	(Task 1) Because it depends on the environment ... it is not only depends on the environment, it also depends on what it is mixed with. Different kind of substances, different kind of product. Because of the environment. The environment that causes that the ferum suitable to change into ferum three. It [environment] stop it to reverse. The environment forbid the reaction.
UF016	(Task 8) Because hydroxide ion tends to accept electron and forms chromate ions. And when the chromate ions are formed and added with hydrochloric acid, it will tend to donate electron to the hydrogen ion from the hydrochloric acid to form back the dichromate ions. So, it is due to the present of hydroxide ions and hydrogen ions, which are the agents that reacts with them [the chromate and dichromate ions].
UF060	(Task 8) When hydroxide is added with acid, it will change colour. It is the same with chromate. When dichromate is added with hydroxide, it will reduce, and turn its colour to yellow. But when it is added with H plus, to counter the hydroxide, we get the dichromate back.
UF061	(Task 8) Reversible? Because the natural principle ... when it reaches the equilibrium ... and ... something new at the system ... it will shift to the other side. The right side and the left side. And something if you add to the right side, and you shift back to the right.
UO019	(Task 6) It is possible for carbon dioxide to turn back to oxygen it need the photosynthesis process. Plants use the carbon dioxide in the photosynthesis and it produces oxygen. Maybe we can if we heat it up. When we heat it up, we supply the energy, so it will reverse. Reverse to reactants. ... (Task 8) Why it is reversible? Because for dichromate to produce chromate, it need the NaOH as the trigger. It is the same for HCl, it is the trigger for chromate to change into dichromate. Yes. It is like from the reactants to products is hydration and to reverse it through dehydration.
UO021	(Task 8) Because when the dichromate ions react with strong base, it turns into yellow. When it reacts with strong acid, HCl, it turns orange. So, we can differentiate when the dichromate ions react with acid or base.
UO023	(Task 8) I think that it [HCl] will react with chromate ions for it to reverse back. The factor is the HCl. Because there are different reactants. Like the HCl, it reacts with the chromate ions to produce back this one [dichromate ions]. Without the HCl, it won't [reverse].
UO024	(Task 8) Meaning that, there is chromate. From dichromate. Meaning that, Na does not react to anything. OH only reacts with this, to form chromate. We put in HCl, meaning that H will take the OH, chromate formed ... [i.e.,] dichromate from chromate. That means, it will change to this, to orange back.
UO025	(Task 8) Why does it change into orange again? ... this is NaOH with dichromate, right. The HCl is added, it change back.
UO029	(Task 8) Dichromate ions mixed with hydroxide ions, chromate ions are obtained. After adding HCl, dichromate ions are obtained again. ... Meaning that, chromate ions when mixed with HCl, dichromate ion will be obtained.
UO064	(Task 7) If we have a barium thiocyanate and then we have a method, we can have method ... to put a lot of water into it. And then the recrystallisation process might occurs again, but this need to undergo a lot of filtration, and then we need a method take away the thiocyanate. We have to take away the thiocyanate, to form back. It's possible ... But, we need much more steps. Because step is going to reduce activation energy. Different path way. It cannot just simply go back. ... (Task 8) ... first, one is when it proceed to yellow, because the OH minus is dominant, when it reverse back, because the H ₂ O is much more dominant, so why does it only reverse when HCl is added because the excess of OH minus is reacted with the HCl, the H plus from the HCl to form more water, so this induce a much greater concentration of H ₂ O. So, the reaction will reverse back.

Stability factors	
SS030	(Task 4) More stable.
SS031	(Task 8) It is a reversible reaction. (Task 7) This is irreversible because the barium thiocyanate is in stable.
SS032	(Task 5) The product is more stable, so it will not change back.
UF009	(Task 6) Maybe already stable. This one [butane and oxygen] is less stable.
UF013	(Task 1) ... that new substance, the iron trioxide, is a stable chemical. More stable and it won't undergoes oxidation anymore. The original metal is less stable. It will when expose to air, it will reaction to form rust which is more stable. The rust is more stable.
UF014	(Task 1) So, it is more stable. ... (Task 3) Maybe because, NaCl compound is ionic, isn't it. So, it is more stable when in the ionic solution.
UF016	(Task 7) Because it is not stable. So, it is looking for a stable position. So, it tends to react to each other to form a very stable products and will not change back. ... (Task 8) I think they are almost the same in terms of stability. If they are not, it can change easily. The stability of the chromate and dichromate ion is almost the same.
UF020	(Task 6) ... the water and carbon dioxide is more stable forms. To turn them back to butane will requires a lot of energy. ... (Task 7) So, that's my opinion why it is hard to be turned back. The same. Because it becomes more stable. For these substances to form back require a lot of energy.
UF061	(Task 6) ... the product is CO two, [which is] more stable.
UF063	(Task 7) So, In these two reactions, the more stable, the product is this two. So, if a substance is in a stable condition does not go to the instable one.

Stability factors	
UO023	(Task 6) It will not [reverse]. Because it is already in a stable form. ... (Task 7) It is in a stable form, the product. Both of these, the reactants are not stable, but when these reactants are mixed, it will produce salt and water. Salt and water, the products are stable.
UO029	(Task 1) The Fe ions are more stable.
UO069	(Task 6) ... what struck my mind would be stability. May be because this one is more stable, and as you know, carbon and oxygen is double bond right. So, it might be more stable because you breaking a double bond is harder than breaking a single bond.
UO070	(Task 1) The rust is more stable.

Chemical structure factors	
SF038	(Task 8) This is because it is simpler than the others. It is not so complex, the reaction is not that complex.
SS030	(Task 4) I feel that in formation of KI, it is the chemical bonds Pbl, the bond formed between the ions are stronger than they would in water where, change, a simple change of temperature or pressure, can break down this bond from the water molecules, whereas this one, it requires more processes. ... (Task 6) And also for certain conditions, to be met because, butane is only consisted of two different elements, whereas these two already in total contrary different elements.
SS049	(Task 6) I think the atoms are bonded are very strong already. ... (Task 8) Because, the dissociation isn't very strong, I mean the bond is not very strong.
SS067	(Task 8) Because of the bond. It contains the hydrogen bond. Hydrogen bond kind like is weak. So, it can break down and form easily.
SS068	(Task 6) ... butane ... the formula structure is a bit complex, rather than the mixture of the carbon dioxide and water. So ... yes, I believe it's irreversible.
SS071	(Task 7) Because in its solid form, is like it's complicated [complex]. ... after it reacts, it became not that complicated.
UF009	(Task 3) Maybe, NaCl is already become compound. So, need a lot of energy to break them the bonding. ... (Task 8) Because it is still itself. Cr Cr still has O O. It just differs in terms of oxidation number.
UF011	(Task 6) It will not turn back into butane because it is a big molecule.
UF013	(Task 7) I think the bonding between barium and cyanate [thiocyanate] is stronger. Maybe the molecule is closer. We can't just consider the activation energy. Should also look at the chemical bonding.
UF015	(Task 7) It can't. It is not reversible. ... because of the bonding of the molecules. The bonding in the molecules is stronger. The products' bonding is stronger. After all, it seems already completely change into a different substance. ... (Task 8) It is reversible. Because the atom that forming the substances are the same. It just differs in terms of quantity. It is not the same with the previous reactions. The atoms' partners have already changed. ... It seems there are few factors. Maybe one of it is because of the difference of energy level and maybe because of the constituent atoms that forms the products.
UF062	(Task 8) ... the oxidation number of chromate ... oxidation number at different ... it changes oxidise or reduce ...
UO019	(Task 8) Maybe the bonding [of the products] is stronger.
UO028	(Task 6) ... the bond completely broken. If it is reversible, it is not completely broken. So, it can form back to the original substances. Like the ammonia [referring to Task 7]. They are not completely [broken], it is still similar molecule. But this one, it forms a different molecule.
UO069	(Task 6) So, it might be more stable because you breaking a double bond is harder than breaking a single bond. So, in this case, it might be stable, oxygen has two hydrogens, this one is can be considered more stable than ah ... carbon dioxide ... The chain here is harder to break, so it tends to be more stable.
UO070	(Task 1) maybe the strength of the bond of this one is much stronger than this one.

Energy factors	
SS030	(Task 6) ... my strongest reason, for it not being able to reform into butane, because it requires a lot of energy. ... my main reason I think it cannot work, is because the higher energy is involved and because this is a none reversible reaction. ... (Task 7) logically, it should be easier to reverse. This because ... they (the products) have a lot of energy contain between them, therefore we don't need to apply a lot of different ...
UF013	<p>(Task 6) [Irreversible] Because, the energy content for carbon dioxide and water is lower. If to go back to butane and oxygen, the activation energy becomes very high. Higher than that butane to carbon dioxide. To achieve activation energy, it needs higher energy. But if you want to make carbon dioxide to butane, the energy will be obtained from maybe butane to produce energy that will be supplied to carbon dioxide to form back. ... (Task 8) Because the activation energy is more or less the same. The energy content is about the same. Small. So, it is easier to shift it.</p> 
UF014	(Task 1) The energy content of the new substance is low. ... (Task 6) Because its energy is lower, it is lower than product. CO ₂ , H ₂ O is lower than the reactants.
UF015	(Task 6) Cannot. Not reversible. From low to higher energy is difficult. From high to low is easier. The reaction is not reversible because of the products have lower energy level of the reactants. It's like going against the energy slope.

Energy factors	
UF016	(Task 6) Here the activation energy is easy to be overcome to become the product. But when changing back from product to reactants it has to go through a higher activation energy.
UF020	(Task 1) The activation energy from metal to rust is lower than from rust to metal. The activation energy is higher. ... (Task 6) ... To turn them back to butane will require a lot of energy.
UF061	<p>(Task 6) ... we can see the activation of the product is lower. Then if you want to reverse that, if you reverse the whole process, then the heat and plus the different between the reaction, the activation energy will become the activation energy. Therefore, it is a lot more than what I draw. I draw here, if you want to reverse this way, if you want to reverse, then the heat will need to add with activation energy ... The heat, plus the activation energy then you need this amount is X amount in order to get back.</p> 
UF062	(Task 6) ... maybe due to the activation energy ... it's maybe it's too high to achieve. ... (Task 8) it is possible make it backward but it depend on the activation energy. ... it is hard for the product to get back the reactant. But your reactant can [easily] go to the product.
UO023	(Task 6) To produce butane, it needs a lot energy.
UO025	(Task 6) If it is like this, meaning that the reactant has higher energy (but) product lower energy. So, it means that it is easier to produce the product.
UO026	<p>(Task 6) Because ... to form the original if the reactant want the product it has to overcome the activation energy the activation energy ... if the product want to become the reactant, the activation energy will become higher.</p> 
UO064	<p>(Task 6) Reversal of the reaction is quite impossible when we study PMR, SPM or STPM, wherever we always say this process is irreversible. ... I actually read some of article and journals, found out that by a specific catalyst, ... we can lower down the activation energy for the reverse reaction, or we can also use biological enzymes [or] catalyst, ... naturally it won't happen [reversal process]. High in activation energy. Because both of them are stable. Once they become CO two and H two O, they exist [in] that [form] only. They cannot simply change back. ... (Task 7) It's possible, but if this process is release much energy right, is release fifty degree, ... reversal of this reaction is possible. But, we need much more steps. Because step is going to reduce activation energy.</p>

Equilibrium system	
SS030	(Task 8) Then from there, we can imply that a change of condition would change the concentration of either side of the reaction. From this we can safely assume that a change in condition would not significantly or not alter at all the concentration of either side because they will more, they will be more significantly altered by the reactants than the alter in condition.
UF013	(Task 8) When it is yellow, dichromate ion will become lesser compare to the yellow one, because the yellow colour is formed from chromate ion. ... if the hydroxide is added on, the dichromate ion will be used up. And all will change to yellow, chromate ion. The chromate ion, the yellow colour will become lesser, because it turns back to dichromate ion. The more hydrochloric acid is added, it will go to the left side.
UF014	(Task 8) And then, maybe it is not hundred percent disassociation, maybe partially only. The degree of disassociation is not hundred percent. Because actually, this process is not like the acid, when mixed with water, immediately the HCl breaks but it is similar to NH3. Mixed with OH. The electrons are still been released and accepted. It is like backward and forward. So, this is maybe partial disassociation, that's why there is some more left.
UF020	(Task 8) Maybe because it is only partial dissociation, so that it is reversible. It involves weak acid and weak alkali.
UF063	(Task 8) ... dichromate ion when added with hydroxide ion, the basicity of the solution increases ... the ionic change of the dichromate ion into chromate ion. So when added with more HCl, it becomes dichromate ion again.
UO027	(Task 8) Because it is not used completely. So, initially the dichromate ion turned into chromate ion when added with alkali. After that, when added with acid, it turned back to dichromate.

Equilibrium system	
UO064	(Task 8) There should be two factors, other reversible reaction, other reversible reaction is induce by the ... equilibrium, that depends on concentration, second condition, the ligands one of that, using the theory of concentration, and then if it is a gaseous, of course depends on the pressure and the number of molecule exist and all of the system of course is going to be induced by the temperature also. But some other reaction is only to proceed when lower energy, lower temperature. For example is the Haber process, H two and N two form NH three. Delta H is negative. ... if you want the reaction proceed in that way, the right hand side [that is] to produce more ammonia, we need to lower down the energy. Okay, but if we increase the temperature, the reaction will form back to reactants. So, these result in reversible change will occurs.
UO069	(Task 8) ... because it doesn't disassociate complete, it cannot releases hundred percent, of this thing [chromate].

Appendix D Thematic Codes Against the Students' Pseudonyms

[illegible]

Note. Shaded cells indicate the attributes were expressed by the corresponding student.

Appendix D



[illegible]

Note. Shaded cells indicate the attributes were expressed by the corresponding student

Thematic Codes Against the Students' Pseudonyms Codes

[illegible]

Appendix E Approval Letter From the Prime Minister Department

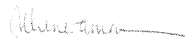
	<p>UNIT PERANCANG EKONOMI <i>Economic Planning Unit</i> JABATAN PERDANA MENTERI <i>Prime Minister's Department</i> BLOK B5 & B6 PUSAT PENTADBIRAN KERAJAAN PERSEKUTUAN 62502 PUTRAJAYA MALAYSIA</p>	 EPU <small>ECONOMIC PLANNING UNIT PRIME MINISTER'S DEPARTMENT, MALAYSIA</small> Telefon : 603-8872 3333
<p>Denis Andrew D. Lajium No.41, Lot I-79, Jalan Sepanggar, Lorong Gudon Utara, Taman Gudon Utara, Menggatal, 88450 Kota Kinabalu Email: denisadl@ums.edu.my</p>	<p>Ruj. Tuan: Your Ref.: Ruj. Kami: Our Ref.: Tarikh: Date:</p> <p>UPE: 40/200/19/2718 3 December 2010</p>	
<p>APPLICATION TO CONDUCT RESEARCH IN MALAYSIA</p>		
<p>With reference to your application, I am pleased to inform you that your application to conduct research in Malaysia has been <i>approved</i> by the Research Promotion and Co-Ordination Committee, Economic Planning Unit, Prime Minister's Department. The details of the approval are as follows:</p>		
<p>Researcher's name : DENIS ANDREW D. LAJIUM</p> <p>Passport No. / I. C No: 771212-12-6031</p> <p>Nationality : MALAYSIAN</p> <p>Title of Research : "STUDENTS' MENTAL MODELS ABOUT CHEMICAL REACTIONS"</p>		
<p>Period of Research Approved: THREE YEARS</p>		
<p>2. Please collect your Research Pass in person from the Economic Planning Unit, Prime Minister's Department, Parcel B, Level 1 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.</p>		

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

Fax: 88883961

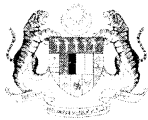
ATTENTION

This letter is only to inform you the status of your application and **cannot be used as a research pass.**

Cc:

Pengarah
Unit Perancang Ekonomi Negeri
Tingkat 8 dan 6, Blok B
Wisma MUIS
Beg Berkunci No. 2041
88999 Kota Kinabalu, Sabah

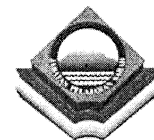
Appendix F Approval Letter From Sabah State Education Department



JABATAN PELAJARAN NEGERI SABAH

SEKTOR PENGURUSAN SEKOLAH
TINGKAT 1, BLOK C, BANGUNAN KWSP
88000 KOTA KINABALU

Pejabat Pengarah : 088-252224, Pejabat Am (SPS) 088-251720 / 251721,
Faks : 088-224585



Rujukan: JP (SB)/700/7/03 Jld. 20 ()

Tarikh : 8 Februari 2011

Denis Andrew D. Lajium
Sekolah Pendidikan dan Pembangunan Sosial
Universiti Malaysia Sabah
88999 Kota Kinabalu.

Tuan,

KELULUSAN UNTUK MENJALANKAN KAJIAN DI SEKOLAH, INSTITUT PERGURUAN, JABATAN PELAJARAN NEGERI DAN BAHAGIAN-BAHAGIAN DI BAWAH KEMENTERIAN PELAJARAN MALAYSIA

Dengan segala hormatnya, saya diarah merujuk surat tuan/puan mengenai perkara di atas

2. Sukacita dimaklumkan bahawa Jabatan Pelajaran Negeri Sabah tiada halangan bagi pihak tuan menjalankan kajian "*Students' Mental Model About Chemical Reactions*" seperti dalam surat Kementerian Pelajaran Malaysia. Walau bagaimanapun ianya tertakluk kepada syarat-syarat berikut:

- 2.1 Berhubung dan berbincang dengan pentadbir sekolah tentang pelaksanaan/ perjalanan kajian tersebut.
- 2.2 Penyertaan warga pendidik dan murid-murid dalam kajian adalah sukarela.
- 2.3 Proses pengajaran dan pembelajaran atau pelaksanaan aktiviti sekolah tidak terganggu atau terjejas semasa kajian dijalankan.
- 2.4 Tuan tidak dibenarkan menjalankan aktiviti di kelas-kelas peperiksaan awam sekolah.
- 2.5 Sebarang data / maklumat serta dapatan kajian hanyalah untuk memenuhi syarat-syarat kursus pengajian sahaja

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA"

Saya yang menurut perintah


[MADAILE HAJI BASRI, A.D.K.]
Penolong Pendaftar Institusi Pendidikan
b.p. Pendaftar Institusi Pendidikan dan Guru
Jabatan Pelajaran Negeri Sabah

s.k 1. Pendaftar Institusi Pendidikan dan Guru,
Jabatan Pelajaran Negeri Sabah

(Sila catatkan nombor rujukan apabila berurusan dengan kami)

JANGAN TERJERUMUS KE DALAM PERANGKAP DADAH

Web: www.moe.gov.my/jpnsabah

Appendix G Letter for School Principals and Research Consent Form

Denis Andrew D. Lajium

School of Education & Social Development
Universiti Malaysia Sabah
88999 Kota Kinabalu,
Sabah.
Email: denisadl@ums.edu.my
Phone: 088-320000 ext :2469
Mobile: 0168468595
Fax: 088-320268

Centre for Science and Technology Education
Research (CSTER)
The University of Waikato
Private Bag 3105
Hamilton, New Zealand
Ph: 64-7-838 4035 (Centre direct line)
Fax: 64-7-838 4272
Email: cster@waikato.ac.nz

4 March 2011

Principal

Dear Sir,

Application for Permission To Conduct Research at

With regard to the above matter, I am writing to formally request permission to conduct my research for my PhD study entitled "Students' Mental Models for Chemical Reactions" in your school. The study focuses on students' idea of chemical reactions concepts examined in form of mental models. I hope this study will gain better insights on students' development on scientific concepts of chemical reactions and enhance teaching and learning across educational level.

For the purpose of this study, data collection will involve interview of 60 minutes per students (or as permitted by the school) of your students from Form 4 (3 students) and Form 1 (3 students). For your information, students' participation is on a voluntary basis. Both the interviews 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.

The data collected will be kept confidential and securely stored. The data will be destroyed five years after research completion. Data obtained during the research will be used for the purpose of writing reports, published papers and making presentations. This data will be reported without use of name or identity of the school, principle, staffs, or students. Any self-identifying statement will be excluded.

Approval letter from Education Planning and Research Division (EPRD), Sabah State Education Department and the interview protocol are enclosed. I would be very grateful 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, Ph: 07 838 4100), Dr. Anne Hume (email : annehume@waikato.ac.nz, Ph: 07 838 7880) or Dr Chris Eames (email: c.eames@waikato.ac.nz, Ph: 07 838 4357) at the University of Waikato in New Zealand.

Thank you very much for your support.

Yours sincerely,

(Denis Andrew D. Lajium)

Borang kebenaran kajian – Pengetua Sekolah Menengah
Research Consent Form – Secondary School Principal

Saya telah membaca surat makluman berkenaan.
I have read the attached letter of information.

Saya faham bahawa:
I understand that:

1. Penyertaan sekolah saya dalam kajian ini adalah sukarela.
My school's participation in the research is voluntary.
2. Saya berhak untuk menarik penyertaan sekolah saya pada bila-bila masa.
I have the right to withdraw my school from the research at any time.
3. Pengutipan data melibatkan temu bual dengan pelajar Tingkatan 1 (___ orang) dan Tingkatan 4 (___ orang).
Data collection involves interviews of selected students from Form 1 (___ students) and Form 4 (___ students).
4. Data yang dikutip dari sekolah saya adalah seperti yang dinyatakan dalam surat iringan. Data ini sulit dan disimpan dengan selamat. Data ini akan dimusnahkan selepas lima tahun kajian ini tamat.
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 yang diperoleh akan digunakan untuk tujuan penulisan laporan, kertas kerja dan pembentangan tanpa menggunakan nama atau identiti saya, kakitangan sekolah, pelajar dan sekolah. Kenyataan yang boleh menjurus kepada identiti pihak saya, juga akan disingkirkan.
Data obtained during the research will be used for the purpose of writing reports, published papers and making presentations. This data will be reported without use of my name or identity, the names or identity of my staffs, my students and the school. Any self-identifying statement will be excluded.

Saya boleh mengemukakan sebarang pertanyaan atau keraguan mengenai kajian ini kepada Denis Andrew D. Lajium, di Universiti Malaysia Sabah atau University of Waikato (email: denisadl@ums.edu.my, Ph: 016-8468595).

I can direct any questions or concerns about the study to, Denis Andrew D. Lajium, at the Universiti Malaysia Sabah or University of Waikato (email: denisadl@ums.edu.my, Ph: 016-8468595).

Letter for School Principals and Research Consent Form

Jika terdapat isu yang tidak dapat diselesaikan saya boleh menghubungi Professor Richard Coll (email: rcoll@waikato.ac.nz, Tel: 07 838 4100), Dr. Anne Hume (email : annehume@waikato.ac.nz, Tel: 07 838 7880) atau Dr Chris Eames (email: c.eames@waikato.ac.nz, Tel: 07 838 4357) di University of Waikato, New Zealand.

For any unresolved issues I can contact Professor Richard Coll (email: rcoll@waikato.ac.nz, Ph: 07 838 4100), Dr. Anne Hume (email : annehume@waikato.ac.nz, Ph: 07 838 7880) or Dr Chris Eames (email: c.eames@waikato.ac.nz, Ph: 07 838 4357) at the University of Waikato in New Zealand.

Saya memberikan kebenaran untuk sekolah ini terlibat dalam kajian ni mengikut syarat yang dinyatakan di atas.

I give consent for my school to be involved in the project under the conditions set out above.

Nama/Name : _____

Tanda tangan/Signed : _____

Tarikh/Date : _____

Appendix H Letter for Deputy Vice Chancellor and Research Consent Form

Denis Andrew D. Lajium

School of Education & Social Development
Universiti Malaysia Sabah
88999 Kota Kinabalu,
Sabah.
Email: denisadl@ums.edu.my
Ph: 0168468595

Centre for Science and Technology
Education Research (CSTER)
The University of Waikato
Private Bag 3105
Hamilton, New Zealand
Ph: 64-7-838 4035 (Centre direct line)
Fax: 64-7-838 4272
Email: cster@waikato.ac.nz

17 February 2011

Deputy Vice Chancellor (Academic and International)

Universiti Malaysia Sabah
88999 Kota Kinabalu,
Sabah.

Dear Prof,

Application for Permission to Conduct Research at Universiti Malaysia Sabah

With regard to the above matter, I am writing to formally request permission to conduct my research for my PhD study entitled "Students' Mental Models for Chemical Reactions" in Universiti Malaysia Sabah. The study focuses on students' understanding of chemical reactions concepts examined in form of mental models.

For the purpose of this study, data collection will involve interview of approximately 60 minutes per student of Universiti Malaysia Sabah undergraduate students.

For your information, students' participation is on a voluntary basis. The interviews will be conducted as allowed by the respective Dean and at a time that is convenient for the students in order to avoid disruption of the teaching and learning activities

Approval from Economic Planning Unit (EPU) and the interview protocol 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, Ph: 07 838 4100) or Dr. Anne Hume (email : annehume@waikato.ac.nz, Ph: 07 838 7880) or Dr Chris Eames (email: c.eames@waikato.ac.nz, Ph: 07 838 4357) at the University of Waikato in New Zealand.

I look forward to hearing from you.

Yours sincerely,

(Denis Andrew D. Lajium)

Research Consent Form – Deputy Vice Chancellor

I have read the attached letter of information.

I understand that:

1. My university's participation in the research is voluntary.
2. I have the right to withdraw my university from the research at any time.
3. Data collection involves interviews of selected students only from first and final year undergraduate students.
4. Data may be collected from my university 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 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 university. Any self-identifying statement will be excluded.

I can direct any questions/concerns about the study to, Denis Andrew D. Lajium, at the Universiti Malaysia Sabah or University of Waikato (email: denisadl@ums.edu.my, Ph: 016-8468595).

For any unresolved issues I can contact Associate Professor Richard Coll (email: rcoll@waikato.ac.nz, Ph: 07 838 4100) or Dr. Anne Hume (email: annehume@waikato.ac.nz, Ph: 07 838 7880) or Dr Chris Eames (email: c.eames@waikato.ac.nz, Ph: 07 838 4357) at the University of Waikato in New Zealand.

I give consent for my university to be involved in the project under the conditions set out above.

Signed: _____

Name: _____

Date: _____

Appendix I Letter for Students and Research Consent Form

Denis Andrew D. Lajium

School of Education & Social Development
University of Malaysia Sabah
88999 Kota Kinabalu
Sabah, Malaysia.
Ph: 088-320000 ext :2469
Mobile: 0168468595
Fax: 088-320268
Email: denisadl@ums.edu.my

Centre for Science and Technology Education Research
(CSTER)
The University of Waikato
Private Bag 3105
Hamilton, New Zealand
Ph: 64-7-838 4035 (Centre direct line)
Fax: 64-7-838 4272
Email: cster@waikato.ac.nz

8 February 2011

Dear student,

I am writing to invite you to participate to my doctoral research study. This study involves investigating students' ideas about chemistry concepts which lead to an understanding on students' mental models about chemical reactions. I hope that this study will gain better insights on students' development on scientific concepts of chemical reactions and enhance teaching and learning across educational level.

I would like to interview you about your ideas about chemical reactions or changes. I expect the interview to last about 60 minutes but still depend on your school/university permission. During the interview, I will show few pictures and video clips, and we will talk about. I would also like to audio-record the interview and collect your drawings for later analysis. I undertake to return a summary of the interview to you to check or change any contents within a two week period after receiving the summary. This summary would be confidential to the persons interviewed.

If suitable to you, I would like to interview you in a private space in your school/college/university, 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 name or identity in any publications or presentations but your data will be reported as pseudonyms. All information gathered from you is confidential and will be stored 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 summary. If there is a withdrawal, I will destroy any data gathered from you.

I would appreciate your permission for you 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 the Denis Andrew D. Lajium (denisadl@ums.edu.my, Ph: 016-8468595). If you have a concern about the project that you wish to discuss with someone else, please contact Associate Professor Richard Coll (email: rcoll@waikato.ac.nz, Ph: 07 838 4100) or Dr Chris Eames (email: c.eames@waikato.ac.nz, Ph: 07 838 4357) at the University of Waikato.

If you agree to participate in the study, please read and sign the attached participant informed consent form. If you give consent to be involved in this study, I will meet you in school with permission of your principal to arrange a time and place for the interview. At the interview we will further explain the purpose of this study and ask for your signed consent on the attached form before proceeding with the interview. Thank you very much for your support.

Yours sincerely

Denis Andrew D Lajium

Borang kebenaran kajian – Peserta
Research Consent Form – Participant

Saya telah membaca surat makluman.
I have read the attached letter of information.

Saya memberikan kebenaran untuk ditemu bual dalam kajian ini. Saya faham bahawa:
I give my/our consent to be interviewed for this study. I understand that:

1. Penyertaan saya dalam kajian ini adalah sukarela.
My participation in this research is voluntary.
2. Saya mempunyai hak untuk menarik mana-mana atau keseluruhan maklumat yang saya sampaikan selepas dua minggu menerima ringkasan temu bual tersebut.
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 summary of the interview.
3. Data yang dikutip daripada saya adalah seperti mana yang dinyatakan dalam surat makluman. Data ini sulit dan disimpan dengan selamat.
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 yang diperolehi daripada saya semasa kajian dijalankan akan digunakan dalam penulisan laporan, penerbitan atau pembentangan mengenai kajian ini. Data ini dilaporkan tanpa menggunakan nama dan identiti saya. Kenyataan yang boleh menjurus kepada identiti saya, juga akan disingkirkan.
Data obtained from me during the research project may be used in the writing of 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.

Sebarang pertanyaan atau keraguan, saya boleh menghubungi Denis Andrew D. Lajium, di Universiti Malaysia Sabah atau University of Waikato (email: denisadl@ums.edu.my, Tel: 016-8468595).
I can direct any questions/concerns to the study, Denis Andrew D. Lajium, at the Universiti Malaysia Sabah or University of Waikato (email: denisadl@ums.edu.my, Ph: 016-8468595).

Jika terdapat isu yang tidak dapat diselesaikan saya boleh menghubungi Professor Richard Coll (email: rcoll@waikato.ac.nz, Tel: 07 838 4100), Dr. Anne Hume (email : annehume@waikato.ac.nz, Tel: 07 838 7880) atau Dr Chris Eames (email: c.eames@waikato.ac.nz, Tel: 07 838 4357) di University of Waikato, New Zealand.
For any unresolved issues I can contact Professor Richard Coll (email: rcoll@waikato.ac.nz, Ph: 07 838 4100), Dr. Anne Hume (email : annehume@waikato.ac.nz, Ph: 07 838 7880) or Dr Chris Eames (email: c.eames@waikato.ac.nz, Ph: 07 838 4357) at the University of Waikato.

Nama/name(s) : _____

Tandatangan/Signed : _____

Tarikh/Date : _____

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