MISCONCEPTIONS ON CHEMICAL BONDING AMONG FORM FOUR PUPILS

QUAH MEI LING

FACULTY OF EDUCATION
UNIVERSITY OF MALAYA
KUALA LUMPUR

2020

MISCONCEPTIONS ON CHEMICAL BONDING AMONG FORM FOUR PUPILS

QUAH MEI LING

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE EDUCATION

FACULTY OF EDUCATION
UNIVERSITY OF MALAYA
KUALA LUMPUR

2020

UNIVERSITY OF MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: Quah Mei Ling

Matric No: PGJ140008

Name of Degree: Master of Education (Science Education)

Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):

Misconceptions On Chemical Bonding Among Form Four Pupils

Field of Study: Science Education

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original;
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date:

Subscribed and solemnly declared before,

Witness's Signature Date:

Name:

Designation:

ABSTRACT

The learning of chemical bonding in chemistry is an abstract concept for all students. The process of learning chemistry can be classified into three levels which are macroscopic, sub-microscopic, and symbolic levels. Students have problems correlating all three levels in learning chemical bonding. During the transition of these three levels, students face difficulties in relating the macroscopic and sub-microscopic levels which lead to misconceptions. Therefore, the purpose of conducting this study was to explore the misconceptions of chemical bonding which includes ionic bonding and covalent bonding among Form Four students. This study aimed to answer two research questions; 1) what are the misconceptions (if any) of chemical bonding among Form Four students and 2) how is the misconceptions on chemical bonding among Form Four students. A mixed-method design was applied to this research. The type of mixed method design starting with quantitative method and followed by qualitative method. In the first phase, which was the quantitative method, the participants were selected by convenient sampling where a total of 36 participants were selected. All the participants selected were given a two-tier diagnostic test to answer within 20 minutes. The data collected was analyzed descriptively to answer research question one. The second phase was the qualitative method, where 7 students were selected based on their diagnostic test scores to be interviewed in-depth on their misconceptions. These students were purposively selected for having the lowest scores. The findings showed that students have conceptual misunderstanding and factual misconception on chemical bonding and these misconceptions are students unable to differentiate ionic and covalent bonding, students failed to identify the type of particles in ionic and covalent bonding and students unable to construct the structure for ionic bonding.

Lastly, students failed to apply proton number and valency of electron of an element which needed for students to interpret the chemical bonding.

MISKONSEPSI IKATAN KIMIA DALAM KALANGAN MURID TINGKATAN EMPAT

ABSTRAK

Pembelajaran ikatan kimia dalam kimia adalah konsep abstrak untuk semua murid. Proses pembelajaran kimia boleh diklasifikasikan ke dalam tiga peringkat iaitu makroskopik, sub-mikroskopik, dan simbolik. Murid menghadapi masalah dalam mengaitkan semua tiga peringkat dalam pembelajaran ikatan kimia. Semasa peralihan ketiga-tiga tahap ini, murid menghadapi kesukaran dalam mengaitkan tahap makroskopik dan sub-mikroskopik yang menyebabkan miskonsepsi berlaku. Oleh itu, tujuan menjalankan kajian ini adalah untuk meneroka miskonsepsi ikatan kimia yang merangkumi ion dan ikatan kovalen dalam kalangan murid Tingkatan empat. Kajian ini bertujuan untuk menjawab dua persoalan kajian; 1) apakah miskonsepsi (jika ada) mengenai ikatan kimia dalam kalangan murid tingkatan empat dan 2) bagaimana miskonsepsi ikatan kimia dalam kalangan murid tingkatan 4. Reka bentuk kaedah campuran telah digunakan dalam kajian ini. Jenis reka bentuk kaedah campuran yang dipilih adalah bermula dengan kaedah kuantitatif dan diikuti dengan kaedah kualitatif. Fasa pertama adalah kaedah kuantitatif, sampel dipilih dengan persampelan yang mudah, sebanyak 36 peserta dipilih. Semua peserta yang dipilih diberi ujian diagnostik dua peringkat untuk menjawab dalam masa 20 minit. Data yang dikumpulkan dianalisis secara deskriptif untuk menjawab persoalan kajian pertama. Fasa kedua ialah kaedah kualitatif, di mana 7 orang murid dipilih berdasarkan skor ujian diagnostik mereka untuk ditemuramah secara mendalam atas miskonsepsi mereka. Murid-murid ini dipilih secara bertujuan kerana mendapat skor terendah. Hasil kajian menunjukkan bahawa pelajar mempunyai miskonsepsi konsep dan miskonsepsi fakta mengenai ikatan kimia dan salah tanggapan ini adalah pelajar tidak dapat membezakan

ikatan ionik dan kovalen, pelajar gagal mengenal pasti jenis zarah dalam ikatan ionik dan kovalen dan pelajar tidak dapat membina struktur untuk ikatan ionik. Akhir sekali, pelajar gagal mengaplikasikan nombor proton dan kekuatan elektron unsur yang diperlukan bagi pelajar untuk mentafsirkan ikatan kimia.

ACKNOWLEDGEMENT

My sincere gratitude to my supervisor Associate Professor Dr. Rose Amnah Abd Rauf for her support, encouragement and patience in guiding me through all stages of my work. I would like to thank to Dr. Renuka A/P V Sathasivam and Dr. Chua Kah Heng for their constructive feedback.

My sincere thanks to the Heads of Academics and Principals of the schools for allowing me to carry out on my research in the schools.

I would like to thank my parents and my uncle, Mr Quah Chong Soon for their unconditional support, love and encouragement throughout my life. Lastly, I would like to thank Pn. Doreen Da Costa for her help and my friends for their motivation and support throughout this time.

TABLE OF CONTENTS

CHAPTER 3: METHODOLOGY

CHAPTER 4: FINDINGS

CHAPTER 5: DISCUSSION, CONCLUSION, IMPLICATIONS AND SUNGGESTIONS OF THE STUDY

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.0 Introduction

Everything that happens around us is related to chemistry; in order to have a better understanding of our surroundings, learning Chemistry in school is necessary (Tumay, 2016). It is vital as we can use chemistry concepts to solve problems that exist in our daily lives. In our country, students begin to learn chemistry concepts at lower secondary level where they start to learn the concept of matter, and are introduced to matters such as atoms, elements, compound and mixture (Ministry of Education, 2002). The learning of these concepts will continue to upper secondary level, which is Form Four, where they will be exposed to other basic chemistry concepts such as chemical bonding.

The learning of Chemistry is known to be difficult because it involves abstract concepts. These concepts can be classified into three levels – the macroscopic level, sub-microscopic level and symbolic level. In order for students to fully master basic chemistry concepts, they should have the ability to link these three levels. The learning of the concept of chemical bonding involves learning of fundamental concepts such as to differentiate types of particles such as atoms, ions and molecules before students learn more in-depth concepts such as the process of bond formation in a compound and stoichiometry.

According to Johnstone (2000), the study of chemistry can be described in a triangular model which includes macroscopic (description), sub-microscopic (explanation) and symbolic (representation) levels. All these three levels in the model should correlate in the students' learning of chemistry (Perez et al., 2017; Reid, 2019). The learning of the macroscopic level involves the process of students observing phenomena happens during laboratory work (Talanquer, 2011). Analyzing, differentiating and explaining the chemical theories and models of matter such as chemical bonding is classified as sub-microscopic, whereas the symbolic level is the visual language, such as formula used to show the chemical processes involved in chemistry (Kamariah & Daniel, 2017; Treagust, Chittleborough, & Mamiala, 2003).

Learning this fundamental concept is the pre-requisite for students to be able to further their studies in chemistry. However, when they partially understand the concept or have learnt the wrong concept, misconception happens. This will affect the students' progression in learning topics related to chemical bonding, such as carbon compounds (Pabuccu & Geban, 2012).

In the classroom, the lessons conducted mostly focus on the connection between sub-microscopic level and the symbolic level. This means students are mainly taught how to solve chemistry questions that involve mathematical calculations, so that they are capable in answering calculation-related questions. However, more in-depth questions regarding explanation (sub-microscopic) on phenomena observed (macroscopic) and correlation with symbolic levels (chemical formulae) are rarely taught. Students face problems in understanding the concepts, for example, when explaining and differentiating the formation of ionic bond and covalent bond, students are unable to use correct terminology to describe the ionic and covalent compound. Students often apply the term "molecular" in their explanation of ionic bonding. This example shows that students may be having misconceptions in the use of terminology describing ions or molecules (Gilbert & Treagust, 2009; Prodjosantoso, Hertina, & Irwanto, 2019; Talanquer, 2011; Vladusic, Bucat, & Ozic, 2016). The consequence is, students are unable to explain ionic and covalent bonds using the correct terminology (Chu & Hong, 2010; Luxford & Bretz, 2014).

In learning ionic bonding, students have to identify how electrons are transferred through gaining or losing in order to form ions (Levy Nahum, Mamlok-Naaman, Avi Hofstein, & Taber, 2010; Jazilah Othman, 2008). When students are unable to understand the concept and engage their prior knowledge, they most likely will re-construct the concept to their own understanding based on their daily life experiences or explanations commonly used by people. Hence, it may causes a misconception on chemical bonding. It is important then to rectify the misconception as chemical bonding is a basic concept in chemistry, and forms the foundation for the organic chemistry (Gkitzia, Salta, & Tzougraki, 2019; Melrafina, Wiji, & Mulyani, 2019; Sen, Varoglu, & Yilmaz, 2019).

In the past few years, studies on the misconception of fundamental chemistry concepts have been conducted. In those studies, the researchers listed all the general misconceptions that happened but they failed to explore the causes of misconceptions of chemical bonding. The causes of these misconceptions have to be identified especially the difference between covalent and ionic bonding (Taber, 2002a; Talanquer, 2006; Tumay, 2016). The misconception of differentiating chemical bonding exists in classrooms especially when students learn chemical bonding concepts such as ionic and covalent bonding (Levy Nahum, Mamlok-Naaman, & Hofsein, 2013; Melrafina et al., 2019; Jazilah Othman, 2008; Pabuccu & Geban, 2012; Perez et al., 2017; Tsaparlis, Pappa, & Byers, 2018). Thus, exploring the causes of misconceptions of chemical bond among students is important as the study of chemical bonding will not just stop at Form Four; it will proceed to more advanced concepts such as polymer chemistry, organic compound and hydrocarbon. To understand these concepts, students need to first comprehend chemical bonding. If the students' understanding of chemical bonding is weak, eventually this confusion will lead to other problems in their future studies (Ouellette & Rawn, 2018; Ozmen, 2004). Therefore, this study focuses mainly on exploring the misconceptions of chemical bonding among Form Four students. In the exploration, the researcher would like to find out whether these misconceptions of chemical bonding are due to the failure in understanding the fundamental concept.

The learning of chemical bonding is one of the important fundamental chemistry concepts that students need to master before progressing to organic chemistry, polymer and other topics (Perez et al., 2017). The difficulty faced by students in learning chemical bonding is that they are unable to identify the ionic and covalent bonding. Students are unable to classify the compound given into ionic and covalent bonding. They face difficulty in answering the questions given by teachers or questions in the reference books. When students analyze the questions given, they have difficulty in identifying whether the compound given is an ionic compound or covalent compound. They would mix up the two, using "ionic" to describe a covalent compound and "covalent" to describe an ionic compound (Luxford & Bretz, 2014; Prodjosantoso et al., 2019).

Misconception in chemistry happens when students failed to construct the correct concepts linked to an existing concept (Levy Nahum et al., 2013). They will construct concepts based on their own understanding or common explanations used by people (Eggen & Kauchak, 2004, 2010a; Melrafina et al., 2019; Prodjosantoso et al., 2019; Sen et al., 2019). One of the studies on misconceptions in chemical bonding was conducted by Ganasen and Karpudewan (2017). They used computer-assisted instruction (CAI) to improve the students' understanding in chemical bonding. However, there is hardly any research exploring and describing how the misconceptions of chemical bonding occurs. The study of misconception of chemical bonding is prevalent overseas but more exploration on the misconception of chemical bonding in Malaysia should be conducted.

With all the misconceptions, students may have the mindset that Chemistry is too difficult for them as they do not understand the concepts. Hence, when it comes to examinations, they will merely memorize all the notes given by the teachers. However, after the examination, the concepts they memorized would be forgotten as the retention of these concepts was meant for short term memory (Haidar, 1998; Levy Nahum et al., 2013; Ozmen, 2008).

In this study, the researcher would like to explore more on the misconceptions of chemical bonding among Form Four pupils and how these misconceptions happens when students learn on chemical bonding. This would enable the researcher to identify the main causes of these misconceptions. This area has been studied by other researchers in other countries (Levy Nahum et al., 2013; Levy Nahum et al., 2010; Melrafina et al., 2019; Ozmen, 2004; Pabuccu & Geban, 2012; Perez et al., 2017; Sen et al., 2019; Tsaparlis et al., 2018).

In Malaysia, the study of chemical bonding was on the use of technology and computer-assisted instruction (CAI) to identify the misconceptions of chemical bonding. One recent study conducted on the misconceptions of chemical bonding was the researcher applying computer-assisted instruction (CAI) to help students allay these misconceptions (Ganasen & Karpudewan, 2017). More studies on misconceptions of chemical bonding are needed to identify the root of the problem. This is because the theory of chemical bonding is a foundation for organic chemistry. Thus, the researcher hopes that the findings of this study can help to ease the students' learning of other chemical concepts as they progress.

1.1 Background of the study

Learning of Chemistry is important to students as chemistry concepts can be applied in our daily lives. In Malaysia, upper secondary school students in Form Four will be streamed after their assessment in Form Three, which is known as Pentaksiran Tingkatan Tiga (PT3) into science stream, commerce or art stream. Students who are enrolled into science stream can either take all pure science subjects such as Biology, Chemistry and Physics, or they could take a combination of any two subjects out of the three, such as Biology and Chemistry, Chemistry and Physics, or Biology and Physics. On the other hand, students who are in the Commerce or Art stream will take general science subject.

Chemistry is highly abstract subject as it can be expressed at three levels, the macroscopic level, sub-microscopic level (Gabel, 1999; Treagust et al., 2003; Tumay, 2016) and symbolic level (Johnstone, 1982, 1991, 1997, 2000; Reid, 2019). This makes chemistry complex and difficult for students to master the concepts as they must be able to relate all three levels in their learning process (Reid, 2019). When students have conceptual misunderstanding in any one of the level, the students would have the difficulty in relating the three levels (Treagust, 2003).

The learning of basic concepts in chemistry such as chemical bonding, chemical equilibrium, acid and bases, and electrochemistry is important in order for students to proceed in their learning of chemistry (Svinicki, 1994; Thomas, 2013; Levy Nahum et al., 2013). Students often have misconceptions about these few concepts (Al-Balushi., Abdullah, Ali, & Taylor, 2012). Most students memorize answers or key words used in certain questions in order to answer examination questions without having an in-depth understanding of the concepts (Committee on Undergraduate Science Education, 1997; Levy Nahum et al., 2013; Tsaparlis et al., 2018).

Throughout their learning of the chemical bonding process, students may or may not understand the concepts they have learnt. The concept of matter learnt in lower secondary level will become their prior knowledge in learning chemical bonding in their upper secondary (Milenkovic, Hrin, Segedinac, & Horvat, 2016; Papageorgiou, Markos, & Zarkadis, 2016). Therefore, if they have not understood the concept or partially understood the concept, they may construct their own understanding of it based on their daily life experiences or explanations commonly used by people. This can lead to misconception when they learn chemical bonding (Chakraborty & Mondal, 2012; Vladusic et al., 2016; Yasri, 2014).

A research by Vladusic et al. (2016), revealed how students had misconceptions in chemistry. Students commonly used the term "molecular" to describe ionic bonding. This finding is consistent to the research conducted by Luxford and Bretz (2014), who used bonding representation inventory (BRI) as a tool to identify the misconception. Luxford and Bretz found that students were having misconceptions over covalent and ionic bonding.

1.2 Problem statement

Chemical bonding is an important basic concept in chemistry. It is classified as sub-microscopic level in Johnstone (1997) triangle model. This concept is related to other chemistry concepts such as carbon compound in organic chemistry, polymer chemistry and constructing structural formula of an organic compound. Even though there have been many researches on the misconceptions of chemical bonding, these researches were conducted mostly overseas and were focused on how to overcome the misconceptions of chemical bonding (Al-Balushi. et al., 2012; Barke, Hazari, & Yitbarek, 2009; Chakraborty & Mondal, 2012; Ganasen & Karpudewan, 2017;

Luxford & Bretz, 2014; Melrafina et al., 2019; Papageorgiou et al., 2016; Perez et al., 2017; Prodjosantoso et al., 2019; Sen et al., 2019; Tan & Karpudewan, 2017; Tsaparlis et al., 2018; Tumay, 2016; Uce & Ceyhan, 2019; Unal, Costu, & Ayas, 2010). Among the studies, there were researchers who studied the awareness on students' misconception towards chemistry concepts. It was shown that improving the awareness of how students having misconception towards chemistry concepts does not seem to help in overcoming the misconception of chemical bonding among secondary school students (Alpaydin, 2017; Huseyin, 2017; Nakiboglu, 2003). The misconception still occurred at secondary school level where students were still confused with ionic and covalent bonding.

The types of misconceptions that happen can be categorized into preconceived notions, conceptual misunderstanding and factual misconceptions (Committee on Undergraduate Science Education, 1997). When students learn the abstract concept of chemical bonding, they find it difficult to differentiate between ionic and covalent bonding, and students are unable to identify where the problem lies. They cannot relate the concept of chemical bonding to their prior knowledge, and are unable to explain more in-depth on these two types of chemical bonding which are ionic bonding and covalent bonding (Levy Nahum et al., 2013; Levy Nahum et al., 2010; Melrafina et al., 2019; Pabuccu & Geban, 2012; Perez et al., 2017; Sen et al., 2019; Tsaparlis et al., 2018).

To remediate students' misconception, Ganasen and Karpudewan (2017) used computer-assisted instruction (CAI) to help the students in overcoming the misconceptions of chemical bonding. Recently, CAI instrument was used by one of the research on student's cognitive achievement on chemical bonding (Nomolox et al., 2019). The same instrument were used in another study conducted by Ozmen (2008).

Even with the implementation of CAI, recently, some researchers found that, misconceptions of chemical bonding still exist (Helmi, Rustaman, Tapilouw, & Hidayat, 2019; Melrafina et al., 2019; Prodjosantoso et al., 2019; Satriana, Sri Yamtinah Ashadi, & Nurma Yunita Indriyanti, 2018; Sen et al., 2019; Tsaparlis et al., 2018; Uce & Ceyhan, 2019). Hence, it is necessary to look at why misconceptions among students are still prevalent.

Communication among teachers and students is another factor that causes misconceptions of chemistry concepts during the learning process. A lack of proper communication channels such as language barrier among teachers and students (Perez et al., 2017) may cause misunderstanding among students which may eventually lead to students building their own concepts based on their prior knowledge and daily life experiences or based on common explanations used by people (Gurel & Eryilmaz, 2015; Milenkovic et al., 2016).

Prior knowledge can affect a student's learning towards a new scientific concepts (Svinicki, 1994; Thomas, 2013). Hence, if a student's basic concepts are not accurate, the student would face the problem of assimilating his or her prior knowledge with the new concepts. For instance, in Chemistry, when students are unable to differentiate ionic and covalent bonding, they will find it difficult to use the terms "sharing electrons", "losing electrons" or "gaining electrons" to describe the formation of ionic and covalent bonding. When students are unable to differentiate these three types of particles, they will find it difficult to analyze the chemical bonding (Kamariah & Daniel, 2017; Luxford & Bretz, 2014; Taber, 2011). When they progress to carbon compound, students will face the problem of relating the structural formula of a compound to the carbon compound. Hence, it is vital to find out the causes of these students' misconceptions of chemical bonding.

Moreover, the students' exposure in daily life may be one of the reasons students have misconceptions when they are learning new scientific concepts such as chemical bonding (Alpaydin, 2017; Ozmen, 2004; Taber, 2000). They are unable to visualize the types of particles in the atomic structure. Students consider types of particles as solid, liquid and gaseous. When they are confused about the types of particles, it will affect their learning of chemical bonding. This is because they are required to have prior knowledge of being able to identify particles such as atoms, molecules and ions before they proceed to chemical bonding. When students learn about chemical bonding, they are required to explain the formation of ionic and covalent bonding using terminology of ions and molecules to differentiate both ionic and covalent compounds (Ministry of Education, 2005).

Students fail in connecting their prior knowledge on concepts such as matter, particles, elements and compounds to the concept of chemical bonding because they find that the concepts they have learnt in their lower secondary contradict with the new concept. This shown that when students have conceptual misunderstandings, they will try to re-construct the chemical bonding concept based on their daily life experiences or common explanations given by the people around them without seeking further clarification (Eggen & Kauchak, 2010b; Vladusic et al., 2016; Yasri, 2014). Hence, this research would help students to identify the main causes of misconceptions in chemical bonding.

Students find it difficult to learn chemical bonding as they do not understand the concept thoroughly, thus their use of correct scientific terminology to describe and explain chemical bonding is not consistent. The reason the topic of chemical bonding is important is because this concept is related to other chemical concepts such as carbon compound in organic chemistry, polymer chemistry, and spectroscopy in analytical chemistry. Students are required to master the concept of chemical bonding, and have it as their prior knowledge when they learn about of carbon compound and hydrocarbon as they further their studies in chemistry related subjects (Ganasen & Karpudewan, 2017; Pabuccu & Geban, 2012; Perez et al., 2017).

As mentioned earlier, when students learn chemical bonding, they try to relate it to their daily experiences or their prior knowledge, which in turn is reflected upon how they interpret the concept (Milenkovic et al., 2016). It is important to identify students' misconceptions at an earlier stage. If an incorrect concept is embedded in their mind as long term memory, it would be difficult to change it (Chakraborty & Mondal, 2012). If the misconceptions of chemical bonding persist, students might face problems understanding other chemistry concepts. This is because when students misconstrue the concept of chemical bonding at the beginning of their studies, they may carry these misconceptions onto their further studies (Chin, 2000). This may lead to more misconceptions when they organic compounds that involve carbon containing compounds (Ministry of Education, 2005).

Students' pre-existing belief would indirectly cause the misconceptions to happen because students already have pre-set conceptions based on their prior knowledge or daily experiences (Kuczmann, 2017; Ohlsson, 2011). In Elliot and Pillman's (2016) study, students were guided through observation or learning experiences to answer chemistry questions throughout the learning process. However, even with the help of this guidance, misconceptions of chemical bonding remained. Hence, misconceptions of chemical bonding need to be explored to ensure students have the correct understanding of chemical bonding concept.

Apart from that, the use of wrong scientific terminology to describe ionic and covalent bonding does happen among students. Students tend to use the word "molecular" or the phrase "sharing of electrons" to describe ionic bonding (Perez et al., 2017; Prodjosantoso et al., 2019; Unal et al., 2010). Wrongly used scientific terminology can lead to misconception of the concept of chemical bonding. Students would be confused with the formation of the compound, whether the compound is formed by covalent or ionic bonding. When students have difficulty using suitable scientific terminology to describe the formation of the chemical bonding, they are unable to relate the concept of sub-microscopic to the macroscopic level as they are unable to justify the phenomenon observed with the sub-microscopic explanation. Therefore, the purpose of this study is to explore the misconception of chemical bonding and to identify how this misconception affects the students' learning of chemical bonding.

If the root causes of students' misconceptions of chemical bonding are not resolved, students will remain confused about ionic and covalent bonding. When students construct their own chemical bonding concept based on their assumption and understanding, this concept will be embedded in their minds (Elliott & Pillman, 2016; Read, 2006). Thus, it will be difficult to correct the erroneous or partially correct concept (Eggen & Kauchak, 2004). Eventually, the chemical bonding concept believed to be correct by the student will become factual to them. Hence, this leads to the factual misconception (Al-Balushi. et al., 2012; Chu & Hong, 2010; Committee on Undergraduate Science Education, 1997; Grigorovitch, 2008; Mehmet Bahar, 2003; Thompson & Logue, 2006).

In certain circumstances, if the teacher does not discover the students' misconceptions on the spot, he or she may lose the chances to test the students' understanding of chemistry concept (Fouche, 2015). Early detection of the students' misconceptions will help the teacher find alternative ways to bring students back on track on the proper concept, which will later facilitate the students in their further studies. Hence, in this study, finding out why students misconstrue chemical bonding would facilitate teachers in diagnosing the students' problems in learning chemical bonding.

According to Johnstone (1997), the learning of chemistry can be presented in a triangular model which consists of macroscopic, sub-microscopic and symbolic (Reid, 2019). Most of the time, the learning of the sub-microscopic part would prove to be an issues to students as they have to learn on atomic structure, particulate of nature and chemical bonding (Talanquer, 2011). When students cannot distinguish between ionic and covalent bonding, students would face problems in analyzing questions on chemical bonding. As a result, they may be unable to master the basic concepts in chemistry. Therefore, it is important to explore why misconceptions of chemical bonding happen.

1.3 Aim of study

The misconceptions of chemical bonding is common among Form Four pupils when they are learning about the concept of chemical bonding in class. The aim of this study is to explore the misconceptions of chemical bonding like ionic bonding and covalent bonding among Form Four pupils. This is because chemical bonding is an important fundamental concept in chemistry (Al-Balushi. et al., 2012; Holme, Luxford, & Murphy, 2015).

1.4 Research objectives

This study is to explore the misconceptions of chemical bonding among Form Four pupils. Hence, the research objectives of this study are:

1. To explore the misconceptions (if any) of the concept of chemical bonding among Form Four students
2. To describe the misconceptions on chemical bonding among Form Four students.

1.5 Research questions

Based on the research objectives mentioned above, there are research questions that need to be answered at the end of this research. The research questions are:

1. What are the misconceptions (if any) of the concept of chemical bonding among Form Four students?
2. How is the misconceptions on chemical bonding among Form Four students?

1.6 Significant of study

This study provides an idea on the misconceptions of chemical bonding, for example ionic bonding and covalent bonding among Form Four students. If conceptual misconceptions on fundamental concepts such as chemical bonding are not identified, it would have a significant impact on students in acquiring further chemistry concepts such as organic compound, polymer and others. This is because chemical bonding is pre-requisite knowledge for all these topics.

Johnstone (1997) has classified the learning of chemistry into three levels by using the triangular model which includes the macroscopic, sub-microscopic and symbolic levels. The ability to connect these three level is necessary in learning chemistry, it will help students to understand the abstracts concept in chemistry. If students has partially understand or wrong concepts on the three levels in learning chemical bonding, misconceptions on chemical bonding might happen when they failed to gain the correct concept. Hopefully the research findings will help students identify their misconceptions of fundamental concepts and rectify the misconceptions before they proceed in acquiring more in-depth chemistry concepts.

Hopefully the findings of the study would give students a clearer idea on the focus needed when learning on chemical bonding so that students are able to master the concepts of chemical bonding and reduce the chances of them having misconceptions on this basic concept. The outcome of this research hopefully will help stakeholders such as publisher, curriculum development department be aware of how students study chemistry and the problems faced by students when they take up Chemistry as a subject in school. The findings hopefully would assist educators to modify their teaching strategies to ensure students are capable of correlating all three levels, the macroscopic, sub-microscopic and symbolic levels as mentioned by Johnstone (1997).

1.7 Limitation of study

The sample of the study is very small to explore the students' misconception on chemical bonding thus it is only describing the misconceptions to understand their misconceptions only thus not for generalization. Since the in-depth exploration of the misconceptions were among low achievers only it might not represent those in the other levels of achievement.

1.8 Definition of Terms

The definition of terms used in this study are:

Misconception

When students partially understand concepts or wrongly understand concepts, they would fail to master the concepts. According to the Committee on Undergraduate Science Education (1997), there are five types of misconceptions – preconceived notions, non-scientific beliefs, conceptual misunderstanding, vernacular misconception and factual misconception.

In this study, researcher focus on conceptual misunderstanding and factual misconception. Conceptual misunderstanding is another type of misconception that happens when students fail to construct new concepts based on the fundament concepts learnt (Sen et al., 2019; Unal et al., 2010).

Lastly, factual misconception is defined as students learning wrong chemistry concepts at their earlier stage of learning, thus these erroneous concepts are carried forward into their later years (Committee on Undergraduate Science Education, 1997). As they had learnt a wrong concept at the earlier stage, it is difficult for students to adapt to the changes in a new situation (Posner, Strike, Hewson, & Gertzog, 1982). Factual misconception would probably happen when students develop a wrong concept at the beginning of acquiring chemical bonding concepts, causing the misconceptions to occur (Chi, 2013).

Ionic bonding

Ionic bonding in this study is defined as the bonding between two atoms where the electronegativity is greater than 2.0. The formation of ionic bonding involves the process of the transferring of electrons from a cation to an anion (Lee, 2004).

In an illustration of the ionic bonding structure, students need to draw a square bracket "[ ]" in the structure of ions. This is to show that the charge of the ions is evenly spread over the ions (Norris, 2015). When students failed to construct an ion with the square bracket in the ionic bonding structure, it showed that students were having wrong concepts on constructing the structure of ionic compound. This causes conceptual misunderstanding (Sen et al., 2019). According to Ministry of Education (2005), Chemistry syllabus in the secondary schools includes first 20 elements in the Periodic Table. The rules of valency electrons of an atoms are the maximum electrons that can be fit in the outermost shells. The first inner shell has maximum two valence electrons whereas the second and third shells can occupy with maximum eight valence electrons. In this study, the measure of understanding on ionic bonding is based on the worksheet answers given by students using the two-tier diagnostic instrument. Both cation and anion are held together by strong electrostatic forces of attraction (Low et al., 2005).

Covalent bonding

In this study, covalent bonding is defined as the bond formed between two nuclei, forming an area which has relatively high electron density which sharing of electrons occurs between two atoms (McNaught & Wilkinson, 1999). The formation of covalent bonding occurs between two similar atoms or two different atoms. Electronegativity between two atoms is usually smaller than 2.0 which is insufficient for it to form an ion (Lee, 2004; Ouellette & Rawn, 2018).

In the illustration of a covalent bond structure, the sharing pair of electrons has to be in the overlapping area of the two atoms (Norris, 2015). In this study, the instrument used on testing covalent bonding will be based on the worksheet answers ad given by students using the two-tier diagnostic instrument.

1.9 Summary

This chapter includes the background of the study, statement of the problem, objective of the study, research questions, significance of the study, and limitation of the study. The following chapter will include the explanation of all terminology and types of misconceptions, past research conducted, theoretical framework and conceptual framework.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

In Malaysia, the main objective of our science education is to nurture students who are equipped with intellectual skills in order for them to proceed with their studies in science related fields (Ministry of Education, 2005). Hence, every fundamental concept in science is important to students for them to face the working life in the future. In schools, the new generations is equipped with the 21st century skills. These skills include problem solving, collaborating in a team, innovative skills and creativity. Hence, the learning of science in schools provides a platform for students to gain skills before enrolling in the working force (Hilton, 2015; Raja & Kumar, 2018).

Chemistry is one of the science subjects which can equip students with the scientific and thinking skills. In Malaysia, the curriculum is designed according to theme. The themes are arranged as such: introduction to chemistry, studying matter around us, the interaction between chemicals and production, and the management of manufactured chemicals (Ministry of Education, 2005). The chemistry curriculum is designed to enable the educator to inculcate students with thinking skills and scientific skills which later may prove useful for students in their daily working lives (Lee & Osman, 2017). Hence, looking into the student's understanding of chemistry concepts is important especially looking into a fundamental concept such as chemical bonding (Levy Nahum et al., 2010).

In general, the learning of chemistry can be communicated in three different levels which are macroscopic, microscopic and symbolic level (Kamariah & Daniel, 2017; Talanquer, 2011). In this chapter, there will be further discussion on the types of misconceptions that may happen among students in their learning of chemical bonding. Apart from that, more explanations related to macroscopic, sub-microscopic and symbolic levels can reflect the students' understanding of chemical bonding. Besides that, the chemistry curriculum used by the Form Four students, obtained from the Curriculum Development Centre of the Ministry of Education Malaysia (Ministry of Education, 2005) would be discussed.

The purpose of this study is to explore the misconceptions of chemical bonding among Form Four secondary school students. Chemical bonding is part of a basic chemistry concept students need to master for them to continue their learning in chemistry. Prior knowledge of chemical bonding is a pre-requisite for students before they can proceed to Form Five the following year, as, chapter two of their Form Five syllabus involves chemical changes in organic chemistry and polymer. They would also require this basic concept when learning spectroscopy in analytical chemistry if they further their studies in chemistry at the tertiary level (Ganasen & Karpudewan, 2017; Nicoll, 2001; Pabuccu & Geban, 2012; Perez et al., 2017). However, chemical bonding is an abstract concept which students often misconstrue. Hence, students may find it difficult in relating it with prior concepts on atoms, molecules and ions (Cokelez, Dal, & Harman, 2014).

Because chemical bonding is an abstract concept which is distinct from students' life experiences, it is difficult for students to relate the concepts with their daily lives. Hence, students would find it confusing to embrace the concept of chemical bonding. In the past decade, misconceptions of chemical bonding mostly happen among students who are taking chemistry. Chemical bonding is a fundamental concept of chemistry and if not fully grasped may later lead to other misconceptions or difficulties in understanding other concepts (Levy Nahum et al., 2010; Melrafina et al., 2019; Pabuccu & Geban, 2012; Prodjosantoso et al., 2019; Taber, 2011; Vladusic et al., 2016). Therefore, if students have the misconceptions of chemical bonding, they may have difficulty in understanding organic compounds (Thomas, 2013). By the time they realize their misconceptions, it may be too late or too difficult to correct the wrong concepts. This is because once students learn a concept which they believe to be true, it is hard for them to change their belief, and this consequently may lead to more misconceptions (Chakraborty & Mondal, 2012; Eggen & Kauchak, 2010a; Svinicki, 1994). These are some of the causes of misconceptions according to past research (Hashweh, 1988).

There have been studies on students' difficulty in differentiating types of particles such as ions, molecules and atoms (Othman, Treagust, & Chandrasegaran, 2008; Talanquer, 2011). However, the researchers do not relate the fundamental concept to the concept of chemical bonding. These research also were conducted overseas. Hence, it is necessary to explore whether these misconceptions also happen in the Malaysian schools. By identifying what misconceptions exist when students learn chemical bonding, it would help stakeholders to design the curriculum for chemistry, so that students are able to see the connection between chemical bonding and types of particles. It would also help students to have a better understanding on the concept of chemical bonding.

2.1 Curriculum Content

2.1.1 Malaysian Chemistry Curriculum

In line with the 21st century, the new generation needs to acquire 21st century learning skills. Students have to be equipped with higher order thinking skills and critical thinking skills that would enable them to be holistic and all-rounded to compete globally (Ministry of Education, 2012). According to the current national syllabus of Chemistry in secondary schools, students have prior understanding of atoms, molecules and ions learnt at the lower secondary level. They have learnt the definition of atoms and how atoms look like. Students also learnt how to differentiate atoms and molecules from a chemical compound. When students proceed to upper secondary level which is Form Four, they are expected to have this fundamental knowledge as a pre-requisite for them to proceed with the topic of chemical bonding.

2.1.2 Chemistry Content

When students enter Form Four, they learn the general concept of atoms, molecules and ions in Chapter 2. The students need to know the structure of an atom before they learn how to identify electron arrangement of the elements. In Chapter 3, Chemical Formulae and Equation, students are required to relate the number of particles in a mole of chemical substances with the Avogadro constant. After mastering the basic concept, students would begin to learn on chemical bonding in Chapter 5, students study the formation of ionic bond and covalent bond, which require their prior knowledge of atoms, molecules and ions. Table 2.1 shows the curriculum content of chemical bonding and the relevant fundamental topics related to chemical bonding, obtained from the Curriculum Specification for Form Four Chemistry.

Table 2.1

Malaysian curriculum content of chemical bonding and relevant fundamental topics of chemical bonding

Level	Topic	Subtopic
Form 1	Chapter 3: Matter	3.2 Three state of matter
Form 1	Chapter 4: The variety of Resources on Earth	4.2 Elements, compounds and mixtures.[1]
Form 4	Chapter 2: The structure of the Atom	2.1 Analyze matter
Form 4	Chapter 5: Chemical bond	5.1 The formation of compounds 5.2 Synthesis idea on formation of ionic bond 5.3 Synthesis idea on formation of covalent bond 5.4 Properties of ionic and covalent compound[2]

[1] Source obtained from (Ministry of Education, 2002)
[2] Source obtained from (Ministry of Education, 2005)

2.1.3 Chemical bonding

Chemical bonding is an abstract basic concept in chemistry for students to comprehend before proceeding to other concepts such as molecular structure, organic chemistry, chemical reactions as well as physical properties like the melting and boiling point, solubility in water and electrical conductivity of ionic and covalent compound (Levy Nahum et al., 2010; Pabuccu & Geban, 2012; Prodjosantoso et al., 2019; Taber, 2011).

In the Malaysian Chemistry curriculum, students study chemical bonding which involves two types of bonding, ionic bonding and covalent bonding as their fundamental concept before proceeding to carbon compound. Students will be exposed to how a compound is formed through chemical bonding. The basic bonding concept introduced to students involves ionic and covalent bonding where students will learn how, through bonding, metal or non-metal form a compound together with another non-metal. The concept involved in chemical bonding is ionic bonding which is also known as an electrovalent bond, covalent bonding, molecules, ions are highly abstract concepts for students (Tsaparlis et al., 2018). The formation of the chemical bonds involves interaction between electrons and the forces of attraction between ions, atoms or molecules. All the forces involved could determine the properties of the compound forms (Prodjosantoso et al., 2019). It does not directly relate to a student's daily life experiences (Milenkovic et al., 2016).

As per the Chemistry curriculum, students are required to explain the formation of chemical bond based on the stability of noble gases which is known as the octet rule based on the electron arrangement (Taber, 2001). According to the Low, Lim, Eng, Lim, and Umi Kalthom (2005), students are expected to be able to differentiate ionic and covalent bonding in such a way that when an ion achieves the octet electron arrangement, the ions or molecules will either form covalent or ionic bonding. Moreover, after mastering the octet rule, students are expected to illustrate the formation of both ionic and covalent bond by drawing the electron arrangement diagram. In the process of drawing, students are expected to be able to explain in detail, the formation of both types of chemical bonding (Ministry of Education, 2005).

2.1.4 Ionic bonding

Ionic bonding is the chemical bonding between atoms which have a great difference in term of electronegativity, more than two (EN > 2.0) between two atoms. Electronegativity (EN) is the ability of an atom to pull an electron towards itself during bonding (Lee, 2004; McNaught & Wilkinson, 1999). Apart from that, ionic bonds also refer to the forces of attraction between two electrical charges of two ions which are cation and anion. This type of attraction is known as an electrostatic force of attraction (Ozmen, 2004; Prodjosantoso et al., 2019; Vladusic et al., 2016).

According to Vladusic et al. (2016), the explanation of the concepts should not be too complicated as students in secondary schools are still beginners in the learning of chemistry. The methods used in explaining ionic bonding should be simplified. The chemical substance consists of both positively-charged ions which are known as cations, and negatively-charged ions known as anions; both of these ions are arranged three-dimensional. The numbers used in the formula $MgCl_2$ show the composition of the elements in the compound. For instance, the number 2 in $MgCl_2$ indicates that the compound is made up of two chloride ions and one magnesium ion (Low et al., 2005).

Besides that, the composition of a chemical substance depends on the charge of the cations and the charge of the anions. So, the overall charge of the compound is zero charge. In molecule, the atoms' coordination number shows the number of atoms bonded to a given atom (Lee, 2004). Students confused about the charges of the cations and anions of an elements, they failed to identify the charges of an ions, this makes them having difficulty in interpreting the composition of a chemical substances.

In the process of learning ionic bonding in Form Four, students are required to draw the structure of the formation of the bond. Hence, while drawing the structure, students have to know the proper steps and the criteria of the electron arrangement diagram. Figure 2.1 shows the structure of the formation of magnesium fluoride, adopted from the Form Four chemistry textbook. The charge of the ions is always shown at the top right hand corner. The number of electrons released will be the same as the number located beside the charges. To show that the charge of the ions is evenly spread over the ions, students need to draw the square bracket "[ ]" for each electron arrangement or configuration diagram to shows that the structure of correct ions

(Norris, 2015). Therefore, when students failed to draw the correct structure of ions, they actually possess factual misconceptions as they failed to assimilate the correction concepts of ions in the electron arrangement diagram (Chi, 2013). The octet rules for maximum electron in the first shells is two which is commonly known as the duplet electron arrangements, whereas the second shell and third shell have maximum eight electrons, therefore it is known as the octet electron arrangement. The above mentioned rules apply when students draw any of the first twenty elements in the Periodic Table. Examples of the first twenty elements are calcium, magnesium, fluorine and, sodium among others.

Figure 2.1 Formation of Magnesium fluoride (Low et al., 2005)

However, the students' concept of ionic bonding is that the atom's electron arrangement will decide the formation of ionic bond. In addition, in the students' perception, in each transfer of electron, only one electron is involved when ionic bond is formed (Cokelez et al., 2014). This showed that students are actually confused that cation can actually release two electrons when forming of ionic bonding. Partially wrong concept on how electrons are transfer during the formation of ionic bonding implies that students are having conceptual misunderstanding (Barke et al.,2009).

2.1.5 Covalent bonding

Another type of chemical bonding in the Malaysian chemistry syllabus is covalent bond. Covalent bond is formed between two nuclei forming an area which has relatively high electron density (McNaught & Wilkinson, 1999). Hence, the sharing of one or more pairs of electrons occurs. The forming of covalent bonding can be between two identical atoms or between different atoms. The electronegativity between two atoms is smaller than 2.0 which is insufficient for it to form an ion (Lee, 2004; Ouellette & Rawn, 2018). In the formation of a covalent bond, there emerges an attractive force of attraction between the molecules which is known as intermolecular force of attraction (Tan, 2015). The term "intermolecular" describes a process that involves the interaction between two or more molecular structures (McNaught & Wilkinson, 1999). Figure 2.2 shows the dot-and-cross diagrams for the formation of covalent bond between hydrogen, adopted from (Norris, 2015).

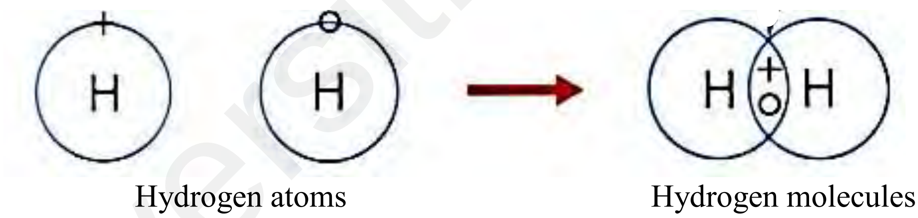


Figure 2.2 Formation of Hydrogen molecules (Norris, 2015)

When drawing the electron arrangement diagram, students have to pair up the electrons in the overlapping area. Hence, students have to remember not to draw the electrons on the orbit outside the overlapping area. Between the molecules, the molecules are intermolecular forces of attraction. Table 2 shows summary of the types of bonding and the nature of the bond according to (Lee, 2004).

Table 2.2

Summary of types of bonding and the nature of the bond

Type of bond	Nature of the bond
Ionic bond	• The difference in electronegativity is more than 2.0 • Electrons are transferred from metal atom to non-metal atom. • The forces between positive and negative ions are strong electrostatics forces.
Covalent bond	• The difference in electronegativity is very small • Two non-metal atoms share electron pairs equally.

Table adapted from (Lee, 2004)

2.2 Misconceptions

What is a misconception? A misconception happens when students partially or wrongly understand concepts because they are unable to understand the situation and fail to master the concept ("Cambridge dictionary English Dictionary ", 2020). Students to construct their own concepts their own understand or through explanations commonly used by everyone (Chakraborty & Mondal, 2012; Eggen & Kauchak, 2004, 2010a; Taber, 2011; Thompson & Logue, 2006).

Misconceptions of chemical bonding commonly happen. It is not surprising as students are merely memorizing the concept and answers given by teachers and regurgitating them during the examinations (Haidar, 1998; Levy Nahum et al., 2013; Ozmen, 2008; Tsaparlis et al., 2018). When students learn by memorizing answers, they would face problems in mastering the concept (Levy Nahum et al., 2010; Pabuccu & Geban, 2012; Perez et al., 2017; Vladusic et al., 2016). Students are unable to differentiate which terminology should be used in explaining chemical bonding. When interpreting questions given by teachers during lessons, students are unable to explain the formation of bonding using the correct terminology of ions or molecules. Most of them are actually confused when they are trying to analyse the questions given on the types of particles such as atoms, ions, molecules (Othman et al., 2008; Talanquer, 2011).

Undoubtedly, the learning of chemistry requires in-depth understanding in basic concepts such as the ability to differentiate types of particles in order to have a better understanding of chemical bonding. In learning chemical bonding, students actually have hard time giving in-depth explanations on atoms sharing, donating or receiving electrons. If this problem persists, it may lead to other problems related to the concept of chemical bonding such as the hydrocarbon concept. This is because in order to learn the concept of hydrocarbon, chemical bonding is a pre-requisite concept (Perez et al., 2017).

There are some patterns of misconceptions which can be explored among students. Misconceptions may happen if students have misunderstandings of a concept or when information given is not clear (Thompson & Logue, 2006; Treagust et al., 2003). If misunderstanding occurs, it is difficult for students to correct it as the concept they believe to be true has already been engrained in their thinking (Eggen & Kauchak, 2004). In addition, the concept, which they think is logical, will be embedded in the students' mind (Chakraborty & Mondal, 2012; Vosniadou, 2007). In past research, students tried to explain chemical bonding by saying, "When you have two electrons, they will be negatively charged ions. They will not combine together. However, when both electrons are shared, then it is known as chemical bond" (Nicoll, 2001).

According to Ganasen and Shamuganathan (2017), when students have misconceptions in learning chemistry at early stage, these misconceptions will interfere the students' understanding in learning a new concept. The misconceptions can be classified as formal and informal misconception. Students usually have problems in formal misconceptions when learning chemistry as chemistry is commonly known for its highly abstract concepts. Formal misconceptions would be reflected in the theories learnt by students who fail to merge these theories with the existing concepts in their minds. This happens because students are unable to relate the sub-microscopic concept with their daily life experiences. Therefore, misconceptions in chemistry concept would occur.

On the other hand, during the learning process in the classroom, if students do not fully grasp the fundamentals of chemistry, students will give incorrect answers when the questions asked in the examinations are slightly different. As mentioned earlier, because students merely memorize the concept of chemical bonding, they are unable to give accurate answers. According to Subari (2017), the main causes of misconceptions are due to the students' daily life experiences and beliefs which are difficult for teachers to rectify.

In this study, misconceptions do not mean that students lack knowledge in chemistry or they wrongly answer all the questions in their examinations. Misconception occur when the students fail to master the actual concept or they partially understand of the actual concept (Korur, 2015).

2.3 Types of Misconceptions

In this section, discussion will continue on the types of misconceptions that can happen in an ordinary classroom. These misconceptions are classified into five types (Committee on Undergraduate Science Education, 1997). These five types of misconceptions that happen in the classroom are preconceived notions, non-scientific beliefs, conceptual misunderstanding, vernacular misconceptions and lastly factual misconceptions as shown in Figure 2.3.

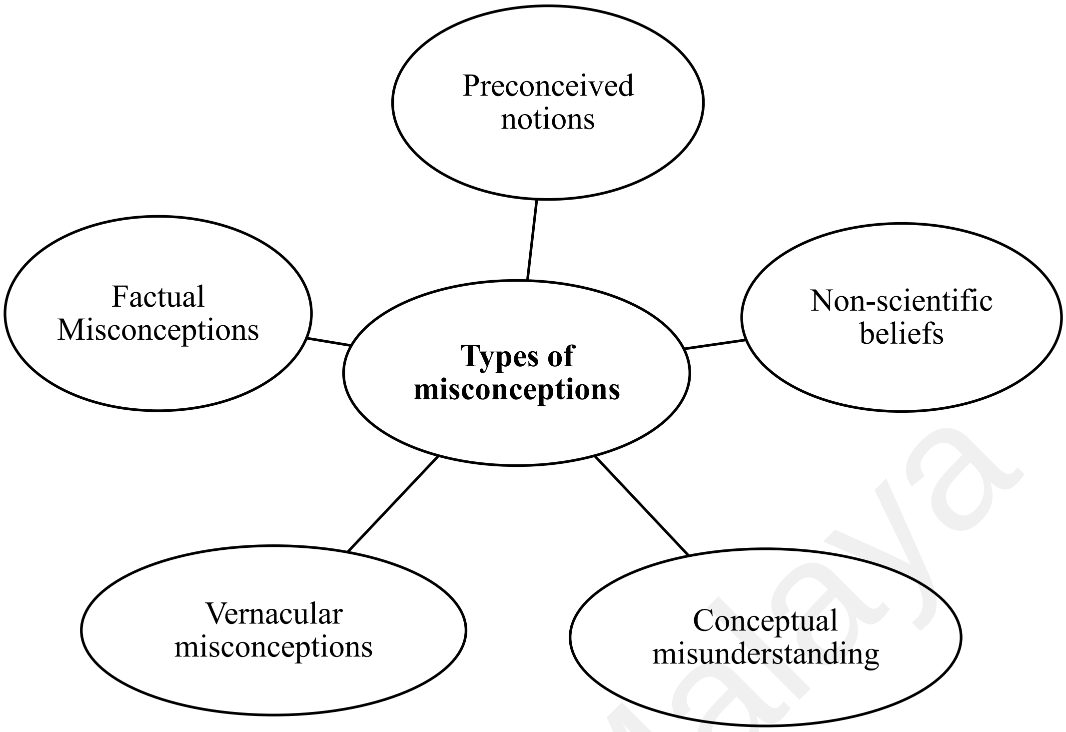


Figure 2.3 Types of misconceptions in classroom.

2.3.1 Preconceived notions

A preconceived notion is an idea generated by students at an early stage without having any other knowledge. Preconceived notions could come from daily life examples or experiences, which a student experiences since young. Eggen and Kauchak (2010a) mentioned that when students are learning a chemistry concept, daily life examples actually gives them an idea to understand the things happening in their surroundings. In chemical bonding, the contents are abstract in nature and they are not directly related to daily life experiences. Therefore, if preconceived notions happen to students in their learning process, they may cause students to partially understand the chemical concepts, thus these concepts may not be 100% accurate (Tan & Treagust, 1999; Vladusic et al., 2016; Yasri, 2014).

According to Thompson and Logue (2006), students normally develop partially correct concepts through their daily experiences. However, once they have gone through a formal learning process and told that the concept they have learnt in class is different from what they have experienced, they would be confused with the actual correct concept. Thus, misconceptions based on preconceived notions will occur. This gets more complicated when more information is added onto the current concept. With no further clarification, they will assume that the concept they initially picked up as true (Eggen & Kauchak, 2010a; Hashweh, 1988).

In 2008, a study by Grigorovitch (2008) also states that students think of chemistry concepts based on phenomena they experience or observe in their surroundings and this will have a play on how the concept is formed in their mindset. Moreover, students will also have their own perceptions according to their daily life experiences (Fouche, 2015; Milenkovic et al., 2016; Tumay, 2016). As a result, while students learn chemical bonding, a concept that is abstract, they will make assumptions of the concept in order to better understand the concept. An example quoted is this: when students think there are two electrons in the atoms, these atoms will form a negatively charged ion. The atoms do not join together. However, the atoms will combine as a chemical bond (Nicoll, 2001). However, the presumed concept is different from the actual concept (Allen, 2010). Hence, misconceptions begin at this stage.

2.3.2 Non-scientific beliefs

We are now living in an era with full technology access. This has allowed students to have the opportunity to obtain any information from various sources available. They can acquire information and facts from the internet or books, besides in the Science lesson itself. Students may also obtain knowledge from their naïve belief (McCloskey, Caramazza, & Green, 1980) or non-existent incident. Naïve beliefs mean that a person believes in things which he or she lacks of experience on (Helmi et al., 2019). For instance, a student's religion may have him believing certain things about the formation of Earth and how living things are formed. However, there are huge differences between student's beliefs based on religion and the factual reality of science (Committee on Undergraduate Science Education, 1997; Eggen & Kauchak, 2010a).

According to Ausubel (1968), the students' prior knowledge or their existing experience or belief is an important factor that may influence them in their learning process. Some non-scientific beliefs are taught by parents to the children. Thus, students are already gaining concepts at a younger age. Hence, if they discover that their personal beliefs on concepts contradict with the theory they had just learnt, it would be difficult for them to change their beliefs to fit these new discoveries (Chakraborty & Mondal, 2012; Perez & Alis, 1990).

2.3.3 Conceptual misunderstanding

Preconceived notions and non-scientific beliefs on chemical bonding brings about the problem of conceptual misunderstanding. Students will find that the concept they had learnt in their lower secondary school contradicts the concept of types of particles when they come to upper secondary school. For example, according to past research, there are existing misconceptions of learning sub-microscopic concepts such as types of particles (atoms, ions, molecules) in ionic bonding, and these misconceptions happen regardless of age, be it a 12 years old or a university students (Adbo & Taber, 2009; Cokelez et al., 2014; Griffiths & Preston, 1992; Papageorgiou et al., 2016; Unal et al., 2010).

Students may understand the definition of ions and atoms when explained through electron transfer. However, students may be confused with the term ionic bonding used in describing the formation of chemical bond of a compound. Students tend to interpret ionic bonding as equivalent to electron transfer between the atoms. Hence, when they interpret the ionic bonding structure, they tend to draw it in such a manner as shown in Figure 2.4. Students will just show how the electron transfers from one atom to another atom. The electron will move from a sodium atom to another atom. From Figure 2.4, students did not show how is the ions formed during when forming ionic bonding, it was just an illustration of the electron will be transferring to another atoms.

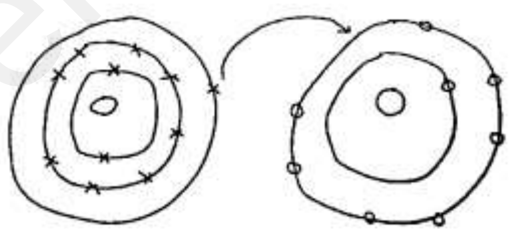


Figure 2.4 Student's drawing of ionic bonding (Barke et al., 2009; Taber, 2001)

In Figure 2.4, the student illustrates the process of forming an ionic bonding by showing how valence electrons of an atom transfers from one atom to another atom. Students do not actually show how the atoms will form an ion after donating electrons to the other atoms, whereas the other atoms will accept one electron to form an ion. From the drawing shown in Figure 2.4, students have already combined the idea of ionic bonding with the electron transferring from one atom to another. The drawing of the structure should be clearly shows with the ions charged (Tan, 2015). Hence, it is part of the misconceptions that occur.

The causes of conceptual misunderstanding may be due to a few factors. Misunderstanding may happen when teachers are teaching these scientific concepts. When students make an observation on situations, and these existing situations do not match the concept given by teachers, they may develop a misunderstanding of the concept (Elliott & Pillman, 2016; Read, 2006). This type of misconception happens with chemical bonding as students are unable to visualize how the atoms interact. They find it difficult imagine how atoms, ions or molecules look like (Rompayom, Tambunchong, Wongyounoi, & Dechsri, 2011). Conceptual misunderstanding will happen when students fail to construct the new concept based on the basic concept learnt earlier (Sen et al., 2019; Unal et al., 2010). Teachers may also have limited knowledge on certain chemistry concepts which could be one of the possible reasons misconceptions among students happen (Korur, 2015).

Huseyin (2017) suggested that chemistry teachers should gain more knowledge on their field and improve how they relate the correct concepts to their students' daily lives while they are conducting lessons. In studies on the effect of microteaching on chemistry teachers, researchers have found that teachers have misunderstanding on the naming of chemical compounds according to the International Union and Applied Chemistry (IUPAC) guidelines. Hence, these shortcomings of teachers have caused students to have conceptual misunderstandings as well. On top of that, Alpaydin (2017) indicated that teachers should have a better understanding of the concepts to conduct more meaningful lessons instead of relying on rote memorization of chemistry concepts. This way, students would be able to retain these concept longer.

Moreover, conceptual misunderstanding on types of particles in chemistry may lead to misconceptions of other concepts such as covalent and ionic bonding. Luxford and Bretz (2014) found that more than 10% of a random sampling of students showed they had significant misunderstanding on how an atom shares electrons between two atoms when they learning covalent bonding. Apart from this misconception, students are also unable to differentiate ionic and covalent bonding because they are unable comprehend gaining electrons, losing electrons in an atom and how atoms share electrons in a molecules (Levy Nahum et al., 2010; Perez et al., 2017; Taber, 2011; Vladusic et al., 2016). From here, we can infer that students are confused with the terms used in ions, molecules and atoms. Therefore, we need to further explore these issues in this study.

2.3.4 Vernacular misconceptions

Based on (“""Vernacular" " 2018), vernacular means the language used by a person to explain a scenario in an informal manner. It may be words we often use in our daily lives. Hence, vernacular language may cause confusion among students. For example, we use the word “work” in daily lives to mean “job”, as in “We are going to work”. However, in science, the word “work” is the product of an applied force with displacement. For example, if a student pushes an object with a load of 30 Newton for a horizontal distance of 5 meters, the work done by the student is 150 Joule (Tong, Wan Faizatul Shima, Yoong, Ragavan, & Roslina, 2005).

In layman language, the word “particle” is used to describe very small things (""Particle"," 2018). However, in science, we define particle as atoms, ions and molecules which are tiny and discrete in size (Low et al., 2005). Hence, if students do not have an in-depth understanding of the meaning of chemical terminology, they may misunderstand the words used (Committee on Undergraduate Science Education, 1997). Wrongly used chemical terminology can cause a misconception in the students' learning of chemistry (Smith, 2010). For instance, students use the phrase "sharing electrons" for both ionic and covalent bonding. This term is wrongly used to describe ionic bonding as in ionic bonding, the electrons are transferred from one atom to another atom.

2.3.5 Factual Misconceptions

The last type of misconception is factual misconceptions. Factual misconceptions happen when students develop wrong concept at an early age, and carry these concepts up to their adolescent stage (Committee on Undergraduate Science Education, 1997). Because the concepts they had learnt were wrong to begin with, when teachers request for them to relate the new concept they had just been taught to new situations or new scenarios, students find it difficult. The assimilation of ideas does not occur, and even if it does, the ideas assimilated are either wrong or partially correct (Posner et al., 1982). Therefore, misconceptions of the concept occur when students have wrong prior knowledge (Chi, 2013). For example, when students study covalent and ionic bonding, they find it difficult to differentiate the two types of chemical bonding because they are unable to differentiate the correct term for particles to use in the existing concept they just acquired (Cokelez et al., 2014).

In a study by Othman et al. (2008), they found that, more useful methods are needed to be implemented in the classroom for students to have a better understanding of the particulate nature of matter and chemical bonding. Therefore, students need to have a correct concept of the particulate nature of matter before they continue their learning process to more in-depth concept.

Lastly, this research will be focus on students' conceptual misunderstanding and factual misconception on chemical bonding, which only includes ionic and covalent bonding, according to the Malaysian secondary school integrated curriculum (Low, 2005). This is because other chemical bonding is not listed in the syllabus. Therefore, other types of bonding will not be discussed in this research.

2.4 Past research on Misconceptions in chemical bonding

In the past decade, according to research conducted in the fields of Biology, Physics and also Chemistry, students have misconstrued concepts in science. Research has been conducted to identify misconceptions in learning science especially in highly abstract subjects such as Chemistry (Johnstone, 2000; Vladusic et al., 2016). Due to its complexity, students think that chemistry concepts are very complex (Cardellini, 2012). In order for students to understand the concepts easily, they will simplify the concepts by themselves. From there, they create misconceptions (Alpaydin, 2017; Milenkovic et al., 2016; Nicoll, 2001; Taber, 2011).

There are many major fundamental concepts in chemistry such as atomic structure, chemical bonding, chemical equilibrium, electrochemistry, acid and bases and others. Past research have revealed misconceptions on atomic structure (Nakiboglu, 2003), chemical equilibrium (Satriana et al., 2018), acid and bases (Cetingul & Geban, 2005; Thomas, 2013) and electrochemistry (Lee & Osman, 2017; Lin, Chiu, & Chou, 2002). Another concept that should be of concern is chemical bonding as it is a fundamental concept needed for organic chemistry such as hydrocarbon compound. Research has shown that students have difficulty in understanding chemical bonding. This shows misconceptions do happen in the understanding of chemical bonding (Holme et al., 2015; Pabuccu & Geban, 2012; Sen et al., 2019; Vladusic et al., 2016). Hence, it is important for us to explore more on these misconceptions among students. This is because when students have misconceptions of the chemical bonding, it can impede their acquisition of new concept when they further their studies or they may be resist to make amendments on the wrong concept (Verkade et al., 2017).

Al-Balushi. et al. (2012) conducted a research on students in Oman using a two-tier diagnostic test to study the common misconceptions of chemistry. This study was conducted to explore the seven chemistry concepts based on the Year-12 chemistry textbook in Oman. Based on the findings, researchers were able to identify seven major misconceptions of chemistry among students. Among them, were a few major misconceptions relevant to this study such as atomic structure, chemical bonding and the structure of a compound. This finding complimented with other researcher's findings (Kind, 2004; Unal, 2010; Papageorgiou, 2016; Perez, 2017; Sen, 2019). All the topics were abstract concepts which were not directly related to the students' daily experiences, making it difficult for them to imagine and correlate with their daily experiences especially concepts to do with covalent bonding and ionic bonding (Levy Nahum et al., 2010; Perez et al., 2017). Thus, it is crucial to explore the students' misconceptions of chemical bonding to identify the actual misconceptions and thereafter, correct on the concept so that students would have a better understanding of chemical bonding (D'Mello, Lehman, Pekrun, & Graesser, 2014).

Since misconceptions happen often in the classroom, researchers have tried to identify the tools used by teachers to point out the misconceptions. A two-tier diagnostic instrument was used by Tuysuz (2009) to test students on their understanding in chemistry related to the separation of matter. He found that this method was effective in recognizing students' misconceptions. Tuysuz also suggested that this two-tier method be applied to evaluate students (Ozmen, 2008; Tuysuz, 2009). Worksheets given out during lessons could be helpful for students (Taber, 2002b). If that is the case, a modification on the two-tier diagnostic instrument should be conducted and applied in the classroom to facilitate the teachers and help students to conduct a self-check on conceptual understanding.

Apart from that, Milenkovic et al. (2016) conducted a study by making use of a chemistry competition test as an instrument in identifying the misconceptions of students in differentiating elements, compounds and mixtures. Misunderstanding of these elements, compounds and mixtures could lead to a negative impact in the future learning process of the students. Most students apply their knowledge of science concepts learnt in the past to their current study and this could be one of the causes of them having misconceptions in learning chemical bonding (Milenkovic et al., 2016). However, the researcher did not relate elements, compounds and mixtures with chemical bonding. In order to facilitate the students' learning process, an immediate correction of the inaccurate concepts should be conducted to avoid further misconceptions. Elliott and Pillman (2016) also mentioned that a two-tier multiple choice can be inculcated to chemistry as in the fundamental lesson, students are learning on abstract concept in chemistry. Therefore, in this research, a two-tier question will be applied to explore the students' misconception on the fundamental concept of chemistry – chemical bonding.

In order to remediate students' misconceptions of chemical bonding, Ganasen and Karpudewan (2017) used Computer-Assisted Instruction (CAI) to help students in visualizing the abstract concept on how the structure of bonding is formed. The findings showed that students have improved understanding in chemical bonding, whereas in another study, Ozmen (2008) with the help of Computer-Assisted

Instruction (CAI), showed that students have a positive attitude towards learning Chemistry. However, with all the methods used to improve students' understanding, the answers given by students were still wrong. Hence, a modification would be made to this study to find out whether the misconceptions of chemical bonding originate from their understanding of the fundamental concepts of atoms, ions and molecules. This is because students have difficulty in differentiating atoms and molecules when they learn chemical bonding (Kumphaa, Suwannoib, & Treagust, 2014).

Today, research on chemical bonding has broaden. Taber, Tsaparlis, and Nakiboglu (2012) applied a diagnostic instrument in England in drawing out the ionic bonding concept. The study showed that students commonly use "molecular" to describe the ionic bonding which shows that students are having misconceptions of the concept. This research finding is consistent with another study conducted by Vladusic et al. (2016) in Croatia. Apart from that, Luxford and Bretz (2014) developed a bonding representation inventory (BRI) to identify the misconceptions among students on covalent bonding and ionic bonding. They found that BRI helps to identify a student's understanding of chemical bonding. This BRI is suitable for classroom use only. However, the BRI does not help to identify the main causes of misconceptions in ionic and covalent bonding. Misconceptions of chemical bonding still happen, as reported by Prodjosantoso et al. (2019). Hence, the concept of ionic and covalent bonding should be explored in Malaysia.

Unal et al. (2010) conducted a research focusing on the misconceptions of covalent bonding in Turkey among secondary school students. By giving open-ended questions and using semi-structured interviews, Unal et al. managed to identify that students had misconceptions on the properties of covalent bonding. In the research, Unal et al. found that students had problems in explaining the formation of covalent compound. The main concept of the research was on covalent bonding. In their research, they did not identify the issues of the misconceptions of ionic bonding. Hence, it is essential to look into misconceptions that happen in ionic bonding. In Malaysia, students do not only face problems in covalent bonding, they have problems in ionic bonding (Ganasen & Karpudewan, 2017). Hence, in order for students to be able to master the concepts of ionic and covalent bonding, we need to identify the root cause of their misconceptions so that appropriate methods can be used to overcome the issues of misconceptions in chemical bonding.

Sen et al. (2019) conducted a study in Turkey that related to cognitive structures and misconceptions in covalent bonding using the World Association Test (WAT). According to the findings, students were weak in using key terms to describe the bonding between chemical bonds and they had misconceptions of ionic and covalent bonding. Thus this research shows that misconceptions of chemical bonding in ionic and covalent bonding are still happening. Hence, more exploration on chemical bonding is necessary to point out the root cause of the misconceptions so that the issue of the misconceptions can be elicited.

In Malaysia, research on misconceptions of covalent and ionic bonding is rarely conducted. Research on chemistry relevant topics mostly cover topics of electrochemistry (Lee & Osman, 2017), acid and bases (Tan & Karpudewan, 2017; Thomas, 2013) and solving stoichiometric problems (Kamariah & Daniel, 2017). The study of chemical bonding by Ganasen and Karpudewan (2017) used computer-assisted instruction (CAI) to help pre-university students in understanding chemical bonding. It, was reported that, students were able to clear their misconceptions after the use of CAI. Even though the findings show that CAI could help to improve students' understanding of chemical bonding, it is believed that the students in the study have been holding onto this misconception since day one of them learning chemical bonding. This is because chemical bonding is a basic concept learnt when students are first introduced to chemistry in Form Four. Hence, exploring the root cause of the misconceptions of chemical bonding is essential. This is to ensure that students have a better understanding and are capable of differentiating ionic and covalent bonding. Knowing the root cause will help us take the necessary actions in ensuring the students' prior knowledge of chemical bonding is correct.

2.5 Theoretical Framework

This subtopic will explain on the theory used to explore the misconceptions of chemical bonding among Form Four students. The learning of chemistry involves many abstract concepts at any stage. For beginners (Form Four students) to learn numerous abstract concepts when they are first exposed to chemistry, would be tough. This is because there would be an overload of abstract information in their minds that need to be processed in trying to form a link between macroscopic concepts and sub-microscopic concepts. Chemical bonding is the foundation in learning chemistry because the concept relates to hydrocarbon compound in organic chemistry and polymer, as stated in the Malaysian Form 4 and Form 5 Chemistry Curriculum Specification (Ministry of Education, 2005).

The theory incorporated in this study would be the Information processing model – a learning model from Alex H. Johnstone, developed from Atkinson and Shiffrin's multistore model of memory which is also known as the modal model (Reid, 2019). Alex H. Johnstone's model is shown in Figure 2.5. This model consists of three sections; the first part being the perception filter. Then the model proceeds to the working space for students to interpret. The last part is the storage section to see if students are capable of understanding the concept (Johnstone, 1997).

When students learn new concepts in the classroom through ways such as hands-on activities, practice exercises, group work, teachers' presentation in the classroom or practical work in the chemistry laboratory, these activities involved in the learning are categorized as macroscopic level. The newly learnt chemical bonding concept will be passed through the perception filter. Through the perception filter, students will try to filter the sensory information and focus on what should be taken into consideration. However, there may be limitations in interpreting the information when students try to fit and link all the concepts in their brain. It is difficult for students to analyze this abstract information at one go and try to relate it to the sub-microscopic level which is the concept of atoms, molecules and ions, a concept they had learnt in their lower secondary school. When students try to bridge the concept, they may fail to link the concept of sub-microscopic level to the macroscopic level, or they make an incorrect connection between both concepts. Hence, this will lead to students being confused of the concepts or develop misconceptions.

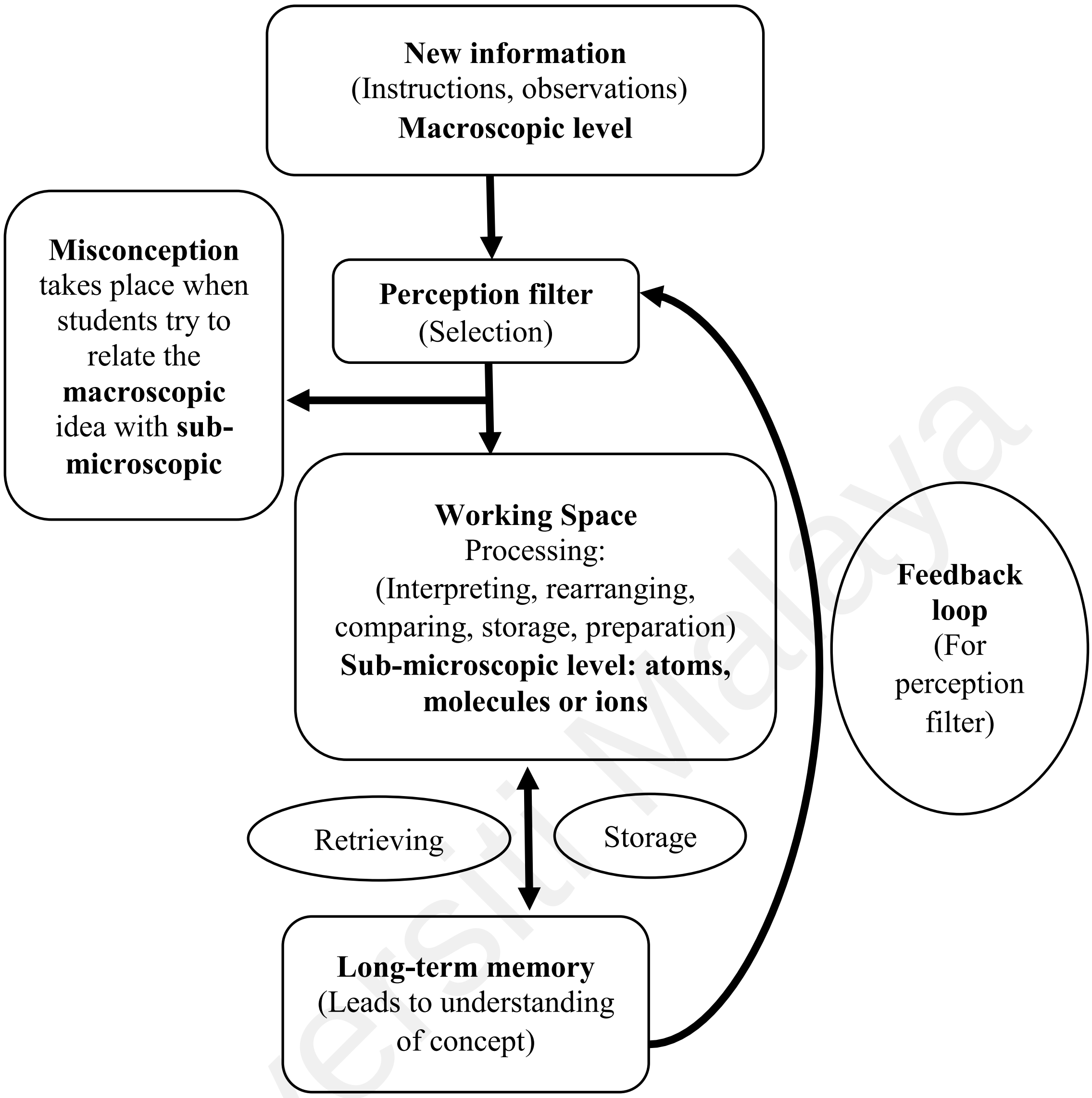


Figure 2.5 Johnstone's information processing model (Johnstone, 1997)

According to Johnstone (1997), when the chemical bonding concept passes through the perception filter, it will pass to the working space. The work space of the human brain has a limited capacity. The working memory will decide and control the understanding of concepts. While the chemical bonding concept is located in the working space, the brain will retrieve the fundamental concept such as atoms, ions and molecules from the brain to merge with this new concept that the students had just learnt. After merging the two concepts, the brain will interpret the concepts, think about them and relate them to allow student master the concepts. If the concepts are successfully merged, the information will be transformed, manipulated and prepared to be stored in the brain as long-term memory. This process leads to the understanding of concepts (Reid, 2019).

Working memory is used for our mental tasks, such as retaining early science concepts and to be applied later on, to solve questions or to do some planning when we are in the chemistry laboratory. Different students have different working memories. Hence, if students learn through rote memorisation, they will lose the information in a short period of time (Cowan, 2010).

Hence, if the two concepts cannot merge, then the students will be confused of the concept of chemical bonding they learn. When answering questions, they will fail to analyse the questions and thus provide the wrong answers (Johnstone, 1997). If the retrieved fundamental concepts such as atoms, molecules or ions from the long term memory are inaccurate or partially correct, students would develop conceptual misunderstanding as they are not able to find the link to chemical bonding (Elliott & Pillman, 2016; Read, 2006). If this happens, students would just cramp all the concepts by memorising the key terms of chemical bonding and the information will be lost after the examinations. As a result, the learning process would be shallow and students would not have a deep conceptual understanding.

However, when the new concept (chemical bonding) successfully fits into the current concept (atoms, ions, molecules), it will work well in enriching the retention of concepts, thus better understanding. Therefore, the concepts will be stored as long term memory. Students who are unable to merge the new concept (chemical bonding) to their existing concepts will have to go through a feedback loop to the perception filter. They have to identify the concept again in the perception filter to check if they have problems with their prior knowledge. Thus, it is the purpose of this study to help students in identifying their misconceptions in chemical bonding. If there are misconceptions, identification of their prior knowledge needs to be conducted during the lesson. This is because when there is incorrect understanding of prior concepts, misconceptions will occur (Chi, 2013).

2.6 Summary

This chapter began with the explanation of Malaysian Chemistry curriculum and Form Four chemistry syllabus in secondary schools. This was followed by the discussion on the scope of chemical bonding which includes ionic and covalent bonding in the syllabus. Then, the discussion proceeded with a definition of the term misconception and types of misconceptions in a chemistry class.

The discussion continued with the findings of past research on misconceptions conducted in other countries such as Turkey, Indonesia, Croatia and Australia. The theory chosen in this study is Johnstone's information processing model, together with his triangle model which describes the study of chemistry. The final part of the chapter ended with the conceptual framework of this study.

CHAPTER 3

METHODOLOGY

3.0 Introduction

This chapter will focus on the research methodology used in the study which includes the research design, methods of data collection and methods of data analysis. The purpose of conducting this research was to explore the misconceptions of chemical bonding among Form Four pupils.

In this research, a mixed method research was chosen because it fitted to the research objectives. The first part of this chapter would discuss the rationale of using a mixed method research. The method was chosen to enable the researcher to obtain more in-depth information on the misconceptions of chemical bonding. A pilot study was conducted before the actual data collection. A total of forty-five students were selected for the first phase of the two-tier diagnostic test in the pilot study. A validation of the instrument was conducted where the items in the diagnostic instrument were marked and analyzed for reliability. Items which were not relevant were removed. The second part of the research was conducted using a semi-structured interview based on the students' score in the two-tier diagnostic test. In the pilot test, two students were selected for the semi-structured interview. After a validation of the interview protocol, the actual study was conducted.

After conducting the pilot study, the researcher proceeded to the actual study. A total of thirty-six students were selected for the two-tier diagnostic test. After the questions in the diagnostic test were marked, ten students were selected for a semi-structured interview. These students were selected from the sample used in the first phase of the study. However, only seven students was able to participate in the semi-structured interview. This was because the other three students had left on their year-end holidays when the researcher started collecting data for the actual study.

3.1 Research Design

The research design provides a general platform to fulfill the objectives of the study through the methods used for data collection and the approaches for data analysis. The research design of this study was a mixed method research (MMR) design which consists of quantitative phase and qualitative phase (Creswell, 2012; Creswell & Clark, 2017). The first phase involved the collection of quantitative data, and the second phase of data collection involved qualitative data. The general pattern of the research design is shown in Figure 3.1.

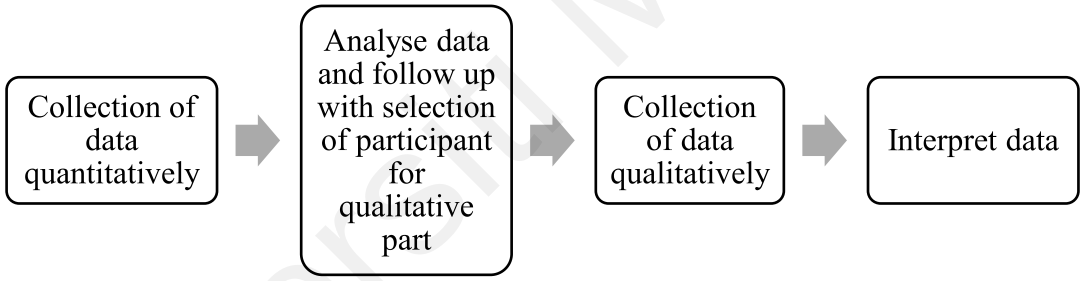


Figure 3.1 General pattern of the explanatory sequential design (Creswell, 2012)

This research study was begin with quantitative part in which the characteristics of the quantitative part of this study was to identify the misconception of chemical bonding among the Form Four students and to facilitate the selection of samples to be participants for the second part of the qualitative study and answering to the Research Question 1. The study continued with the qualitative part. This is because the characteristics of the qualitative research part focused on the exploration of the misconceptions and in this study, the researcher obtained the data based on the outcome of the semi-structured interviews and answering to Research Question 2. Qualitative data was mostly obtained from the primary source through the actual words of the participants, and through observation of what incidents happened throughout the study (Bogdan & Biklen, 2007; Johnson & Christensen, 2004). In this study, once the phase one data was analyzed, students were selected for the second phase. Students who did not attempt the questions and did not complete the two-tier diagnostic instrument were not taken into account for the data analysis. Phase one was conducted to answer Research Question 1, that is to test the students' understanding of chemical bonding and identify their misconceptions. The second phase of the study involved the qualitative collection of data with the use of a semi-structured interview. This phase tested how students drew the structure of chemical bonding and explain the formation of chemical bonding. This was to obtain more extended and in-depth information regarding the students' misconceptions of chemical bonding and describing the misconception happened among Form Four students, thus answering Research Question 2 (Creswell, 2012; Johnson & Christensen, 2004). An interview protocol was prepared for the semi-structured interview to discover how the students drew and explained the structure of chemical bonding, such as ionic and covalent bonding.

According to Dworkin (2012), qualitative research is more effective in obtaining in-depth information and focusing on the exploration of the "how" and "why" of an incident. Therefore, this study was not concerned of the generalization of the bigger population. It was only focused on exploring the misconceptions of chemical bonding (if any) and how the misconceptions affect the students' understanding of chemical bonding. The summary of the research design for this study is presented in Figure 3.2.

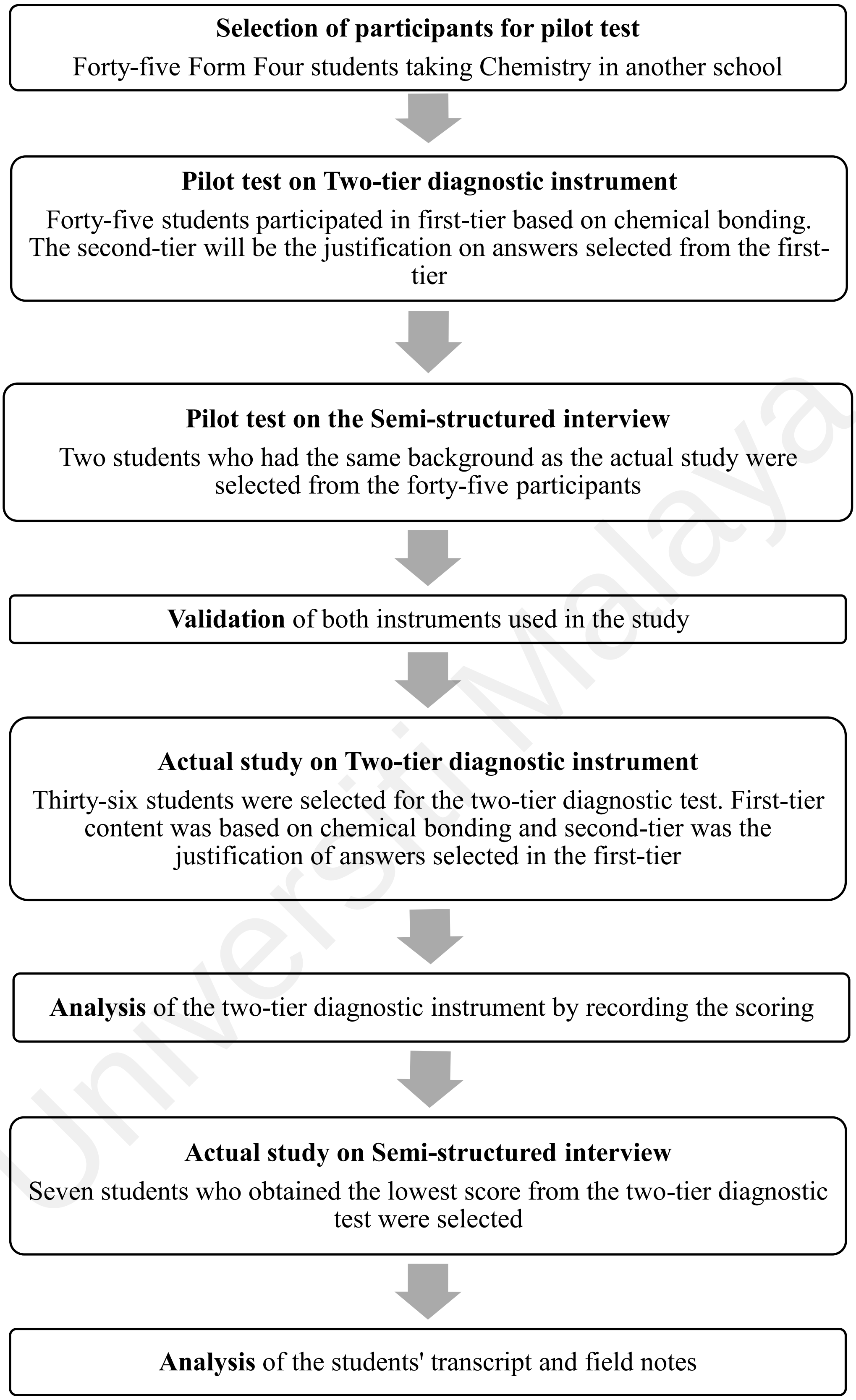


Figure 3.2 Research design of the study

The rationale of conducting a semi-structured interview was to ensure that the researcher would be able to obtain more in-depth information during the exploration of the misconceptions of chemical bonding. During the semi-structured interview, the students were requested to draw the structure of the formation of chemical bonding for both the ionic and covalent compound. While the students were drawing the structure, questions were asked based on how the structure of the formation of chemical compound was drawn by the students. At the same time, the researcher took field notes.

3.2 Population and sampling

The selected school for this study was a private school in Selangor, Malaysia. The reason for selecting this school was that the school followed the Malaysian Education Curriculum and it was the researcher's work place making it easier to be accessed by the researcher to conduct the study and collect data. The purpose of this study was to explore whether the students had misconceptions on the concept of chemical bonding and describing the misconception on chemical bonding among Form Four student. The average number of students in each class was twenty. English language was used as a medium to conduct chemistry lessons in this school. All the selected samples in this school had taken in the Pentaksiran Tingkatan Tiga (PT3) when they were in Form Three in 2018. Figure 3.3 shows the relationship between the population and the incident.

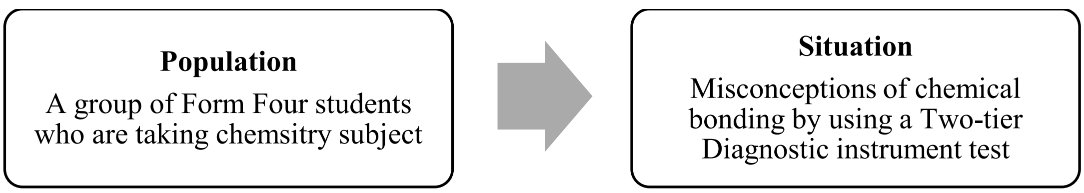


Figure 3.3 Relationship between the population of the study and the situation in the chemistry class

All the candidates selected for this research were given a consent letter. Issues on privacy and confidentiality were outlined in this letter. The letter were distributed to the parents or guardians of the participants to obtain permission for their child to take part in this research. A copy of the consent letter is attached as Appendix 1. The content of the letters included the aim of the study, the time needed for the participant to be involved in this study and the institute of higher learning that the researcher enrolled. The research was only conducted once the parents signed the consent letters even though students volunteered to be involved in this research.

In this research, two sampling methods were applied. In phase one, convenience sampling was selected for the two-tier diagnostic test because it is one of the non-probability sampling techniques that can be used in this research study. The selection of samples for this study was based on the participants' willingness to participate in the study. As long as the participants were able to contribute information to the research to help the researcher in the analyzing the data, they were welcomed (Creswell, 2012; Johnson & Christensen, 2004).

According to Patton (2002), one characteristic of convenient sampling was selecting samples who were easily assessable to the researcher. The reasons the researcher chose convenience sampling were for easier management of data collection and easier verbal permission by the school principal of the school. This school was easily accessed by the researcher and the process of collecting data was conducted during the researcher's free time in the school.

The samples selected from this school were the Form Four students in upper secondary school who took Chemistry as a subject. They were selected because they had already learnt chemical bonding and other basic chemistry concepts. In the first phase of the study, there were thirty-six students selected. The two-tier diagnostic test was given to all the Form Four students who were present that day in school.

After phase one, the researcher proceeded to the second phase of the study. Out of thirty-six samples, only seven students were selected for the semi-structured interview to obtain more in-depth information on their misconceptions. As stated by Patton (2002), no specific rules are needed in the sample size of a qualitative research as long as the process of data analysis is continued until no further information can be obtained from the samples anymore.

During the selection of the seven samples, the researcher applied purposive sampling which is also known as judgmental sampling. Purposive sampling is another non-random sampling technique where the samples selected fulfill with a few criteria (Johnson & Christensen, 2004). The criteria of selecting the samples in phase two were students who obtained a low score in their two-tier diagnostic test and were unable to give correct justifications in the second tier of the two-tier diagnostic test questions.

The number of participants involved in the semi-structured interviews was only seven participants. This was because the semi-structured interviews required more time for data collection and data analysis.

3.3 Instrument

In this research, the collection of data was conducted in two phases; the first phase was a quantitative data which contained a two-tier diagnostic test. The purpose of using a two-tier diagnostic test was to obtain a general idea of the research problem that was to explore the misconceptions of chemical bonding among Form Four students who took Chemistry as a subject. After students answered the two-tier diagnostic test, all the questions answered by the students were marked. From the marking, the researcher was able to obtain data to answer Research Question 1. Based on the results in phase one, students who were unable to answer most of the diagnostic test and scored low marks were selected for the following phase of the study which was the semi-structured interview. Hence, the data collected in phase one was only analyzed descriptively in this study.

The two-tier diagnostic instrument used in this study consisted of a total of nine items as shown in Appendix 3. The first-tier questions were related to chemical bonding content-based questions. Then, the questions were followed by a justification question based on the choices in the first-tier questions. The two-tier questions were adapted from past research (Ganasen & Karpudewan, 2017; Tan & Treagust, 1999). The selected students' background was similar; they were 16 years old and studying Form Four. All the participants had completed their Pentaksiran Tingkatan Tiga (PT3) a year before and had learnt the concept of chemical bonding in their Form Four chemistry class. Selected two-tier multiple questions would allow teachers to test for students' understanding of the concept in a shorter period of time which help to identify the students' understanding of chemical bonding (Othman et al., 2008). According to Kilic and Saglam (2009), a two-tier diagnostic test is a better tool to evaluate students during lessons because it allows teachers to identify the alternative concepts and misconceptions in a specific content scope.

After analyzing the data collected from the two-tier diagnostic test, a selection of participants for the semi-structured interview was conducted. The criteria for the selection was based on the students' two-tier diagnostic test scores. Students with the lowest scores were chosen to participate in the semi-structured interview. In this study, low score is those student who obtained less than 20 score out of total 36, the score was the passing mark for the test (Bayrak, 2013). The time frame for the semi-structured interview was about half an hours to one hour. Throughout the semi-structured interview, the responses of the participants were audiotaped or taken down as field notes depending on the participant's preference.

3.4 Pilot test

Pilot testing on the two-tier diagnostic test was essential to check the validity of the instrument used (Creswell, 2012). By using convenience sampling, the researcher distributed the two-tier diagnostic test to forty-five students to obtain general information on this study before the actual study was conducted. The samples used in the pilot study were from a different school although the students were of the same age, followed a similar syllabus, used English as a medium of instruction in the Chemistry class and had completed Pentaksiran Tingkatan Tiga (PT3) a year before. The student's ability were moderate. The school selected for the pilot test was also located in Selangor, Malaysia.

After conducting the two-tier diagnostic test, the questions were marked and two students were selected. They were the ones who obtained the lower scores in the two-tier diagnostic test and were unable to give a correct justification on the second tier of the questions. An interview protocol was prepared for this phase two semi-structured interview. These two students who participated in the phase two semi-structured interview were asked a series of questions. After conducted the semi-structured interview, the interview protocol were modified to ensure that the data collected were able to answer to research question 2. The interview protocols are shown in Appendix 5.

3.4.1 Two-tier diagnostic test

Before conducting the actual study, a pilot study for the two-tier diagnostic test was conducted on forty-five students from a school in Selangor through convenience sampling. The two-tier diagnostic questions were adapted from a previous research (Ganasen & Karpudewan, 2017; Tan & Treagust, 1999). The questions on chemical bonding were relevant and in line with the current Malaysian Chemistry syllabus. The questions in the instrument were in the form of multiple choice questions followed by the justification of the multiple choice. The pilot test was conducted to ensure that the instrument used would be consistent. According to Johnson and Christensen (2004), testing for reliability in a test is important to ensure the consistency of each test item, so that the test can be applied in other situations with participants of similar background. In addition, the purpose of conducting this pilot study was to ensure that the process of collecting actual data would be smooth and to assure that each item that used in the two-tier diagnostic test could be used to for this research to answer the research questions (Johnson & Christensen, 2004).

The question paper was distributed to the students. They were not allowed to have any discussion with other participants. The time allocation for the students to answer the questions was twenty minutes. In this research, measuring the internal consistency of the two-tier diagnostic test was conducted using Lee Cronbach's formula. The Cronbach alpha was used to estimate the reliability of the test items. The size of the coefficient alpha should be more than or equal to 0.70 for the research, so that the two-tier diagnostic test is reliable (Creswell, 2012). In the pilot test, a Cronbach alpha reliability of 0.710 was obtained which showed that this two-tier diagnostic test was reliable to be used in the phase one study to identify the students' misconceptions on the concept of chemical bonding. The analysis of the reliability test is shown in Appendix 6.

Initially, the two-tier diagnostic test was first planned with twelve items. Before removing three items in the two-tier diagnostic test, the Cronbach alpha reading was 0.611, which was less than 0.7. That meant that the items used in the two-tier diagnostic instrument were questionable. Appendix 7 shows the initial analysis of the reliability test before the three items were removed. In order to obtain a higher reliability of the instrument, these items had to be removed. The results of the pilot test of sample size (n=45) showed the students' score on the chemical bonding as (M=26.00, SD=5.641). Based on the pilot study analysis, some items which were not suitable for this research study were removed before the researcher collected the actual data for this study.

Based on the data shown in Appendix 7, item 6, item 7 and item 11 from the instrument were not relevant to the Malaysian Chemistry curriculum. The Cronbach alpha reading increased to 0.71 after these three items were removed. This meant that the remaining items were suitable for the actual study. Item 6 was related to the properties of copper metal but it was not relevant to the concept of chemical bonding. Hence, it was removed from the two-tier test. In item 7, the choices in the first tier of the question given was not clear. It would be misleading for students to answer the question. Whereas item 11 was removed because the content of the question was also related to the properties of graphite in conducting electricity, thus it was not suitable to be used to explore the misconceptions of the concept of chemical bonding in this research.

In this study, after students completed the two-tier diagnostic test, the questions in the diagnostic test (refer to Appendix 2) were marked according to the marking scheme prepared (refer to Appendix 4) and scores were given accordingly as shown in Table 3.1. A sample of the items used in the two-tier diagnostic test after modification is attached as Appendix 3.

Table 3.1

Scoring for the two-tier diagnostic instrument

Score	Description
1	Both answer and justification are wrong or no response to question
2	Answer is wrong but justification is correct
3	Answer is correct but wrong justification
4	Both answer and justification are correct

Source obtained from Bayrak (2013)

The description in Table 3.1 shows that, students will gain score of 4 if they are able to answer the two tier questions correctly with the correct justifications. When students are unable to give a correct justification for the question, the students will only gain a score of 3. If students are merely able to give a correct justification on the question, the students will score 2 points. Students would obtain a score of 1 if they are unable to give a correct response and the correct justification.

3.4.2 Preliminary study on semi-structured interview

After completing phase one, students with the lowest scores were selected to participate in the semi-structured interview. The reason for selecting students with the lowest scores was because misconceptions usually happen when students are unable to give a correct answer for both tiers of questions (Bayrak, 2013). During the semi-structured interview, students were asked to draw the structure of chemical bonding. The interview protocol was adapted from the past research of Ganasen and

Karpudewan (2017) and an expert validation was conducted. It is important to have an expert validation for the interview protocol to increase the trustworthiness of the research and ensure that the questions asked are related to the current Chemistry syllabus (Johnson & Christensen, 2004). The interview protocol was validated by an experienced Chemistry teacher before the semi-structured interviews were conducted. In the pilot test, two students who had the lowest scores which less than 20 marks out of 36 marks were chosen to participate in the semi-structured interview (Bayrak, 2013). After the interview, the interview protocol was modified to ensure that the questions asked were able to answer Research Question 2. Some unsuitable questions which did not help in answering the research question were removed.

3.5 Data Collections

The data collection involved both quantitative and qualitative data. In the first phase of the study which was quantitative in nature, the data collected was based on the scores obtained by the students in the two-tier diagnostic test. The data would be analyzed descriptively. From the two-tier diagnostic test, marking of the answers was carried out. Students who obtained a lower score were selected for the second part of the data collection. The second phase was the qualitative in nature where data was collected from the semi-structured interviews and field notes (Creswell, 2012; Creswell & Clark, 2017).

3.5.1 Two-tier diagnostic test

In the first phase of the study, a two-tier diagnostic test was used in exploring the Form Four students' misconceptions of chemical bonding (if any). In phase two, the researcher identified how misconception occurs among Form Four students in learning ionic and covalent bonding. The first part of the two-tier diagnostic test used in this study was adapted from past research to test the students' understanding of the concept of chemical bonding. Therefore, the questions posed were related to chemical bonding, in particular, ionic and covalent bonding (Ganasen & Karpudewan, 2017). The reason covalent and ionic were selected was due to chemical bonding being one of the fundamental concepts of chemistry in the current syllabus (Ministry of Education, 2005; Pabuccu & Geban, 2012; Sen et al., 2019). This instrument was originally used by Peterson, Treagust, and Garnett (1986) in their study of developing a diagnostic instrument to test students in grade-11 and grade-12 on their mastery of covalent bonding. This instrument, was modified by the researchers and applied to their study.

This instrument was modified and used by Ganasen and Karpudewan (2017) to find the effectiveness of computer-assisted instruction (CAI) in understanding chemical bonding and rectifying the students' misconceptions. It was clear that the two-tier diagnostic test could be used to identify the misconceptions of the concept of chemical bonding such as covalent bonding and the structure of chemical compound (Al-Balushi. et al., 2012; Ozmen, 2008; Treagust, 1988; Tuysuz, 2009). Questions related to the formation of ionic compound, explanations on the formation of the bond, drawing of covalent and ionic bonding and questions related to differentiating the types of particles in chemical bonding were selected for this research. The items obtained the Cronbach alpha of 0.71 in testing for reliability during the pilot test. Hence, the researcher adapted the questions from Ganasen and Karpudewan's research and selected relevant questions that could merge with the current Malaysian syllabus (Ministry of Education, 2005) to be added to the two-tier diagnostic test in this study.

Every question in the first-tier consists of two to four choices. In the second-tier, the questions tested the justification for the choices in the first tier. Both questions were in the format of multiple choice. The participant had to choose the correct answer for the first-tier questions, followed by the second-tier which was the justification of their first choice. If the participant had another answer other than the one given, they could fill in the space provided.

After selecting the suitable questions, this instrument was pilot tested on forty-five students using convenience sampling. Students were given twenty minutes to answer the questions. Discussions on the questions were not allowed. After the students completed the test, the questions were marked based on the answer scheme prepared (Appendix 2). The score of each student was recorded in a table. After that, the reliability of this instrument was tested with the Cronbach alpha to test for the consistency of items. Unsuitable items were removed from the diagnostic test. The finalized set of questions used in the two-tier diagnostic test is attached as Appendix 3.

3.5.2 Semi-structured interview

Another instrument used in this study was a semi-structured interview which was used in the phase two data collection. Semi-structured interviews would help the researcher to obtain more in-depth information about how the misconceptions of chemical bonding happened among Form Four students (Creswell, 2012; Flick, 2009; Johnson & Christensen, 2004). In a past research, Ganasen and Karpudewan (2017) used interviews to identify the students' misconceptions of the concept of chemical bonding, They tested the effectiveness of a computer-assisted instruction (CAI) in solving the misconceptions. Before applying CAI to their study, they used a similar interview protocol to identify the misconceptions of students of chemical bonding. Therefore, in this study, the researcher adapted the interview protocol and made some slight modifications in order to answer Research Question 2. The semi-structured interviews were able to provide evidence of how the misconceptions on chemical bonding happened among Form Four students. The semi-structured interviews roughly took about half an hour to one hour. All the interview sessions were audiotaped and field notes taken based on the comfortability of the participants. Expert validation was conducted on the semi-structured interview protocol. In the pilot test, two students were selected for the semi-structured interview because it was time consuming to conduct the interviews on all the students. Based on the analysis from the pilot test, modifications on the interview protocol were done. The modified interview protocol is attached as Appendix 5. Questions such as how students identify the particles from a compound given which either is formed covalently or ionic, and requesting the students to construct the chemical compound, were added to the interview protocol to help the researcher obtain more in-depth information on the misconceptions happening among Form Four students. The chemical compounds used in the interview protocol such as sodium chloride, hydrogen chloride and tetrachloromethane, are commonly used by students during Chemistry lesson.

3.6 Data Analysis

After marked the answers given by the students in the two-tier diagnostic test, students with the lowest scores were selected for the semi-structured interview. Students who scored lower than 25 marks out of 36 marks in total. From the result of 36 students, seven students were selected to participate in the semi-structured interview. The data of the first phase study was based on the answer scheme adapted from the examination scheme and validated by the experience chemistry teacher. The data for two-tier diagnostic test will be analyse descriptively using percentage. The analysis will be based on the characteristics of conceptual misunderstanding or factual misconception. For the second phase of the study, researcher analyse the qualitative part by using thematic analysis by analysing the interview transcript by identifying the common misconceptions through students' explanation on chemical bonding and eventually researcher able to identify the common type of misconception that students had in chemical bonding.

3.7 Summary

The discussion in this chapter focused on the research paradigm. In this study, a mixed method research (MMR) was conducted. In order to obtain more in-depth study on the misconceptions of the concept of chemical bonding, this study was conducted in two phases – phase one, a two-tier diagnostic test was carried out and phase two, a semi-structured interview was conducted. A pilot test was conducted before the actual study. All the instruments used were tested for reliability and validity. The reliability of the two-tier diagnostic instrument was tested with Cronbach alpha to ensure the consistency of the items used. All the data collected through the two phases were triangulated to obtain more in-depth explanation and justification to increase the trustworthiness of the study. In the next chapter, the discussion would focus on the findings of the study on the misconceptions of the concept of chemical bonding.

CHAPTER 4

FINDINGS

4.0 Introduction

This chapter will report on the main findings for this research study that is to present the results of exploring misconceptions of the concept of chemical bonding among Form Four students. The collection of data in this study was conducted in two phases in which the data collection in the first phase was based on quantitative data before the researcher looked into qualitative data. In a mixed method research study, many researchers seek for more in-depth explanation during the analysis of the qualitative phase (Creswell, 2012).

This chapter is divided into four sections. The first part gives an overview of the findings. The second part shows the analysis of the two-tier diagnostic test on how the students were selected for both phases of the study. The third part analyze the semi-structured interviews on the students' explanations and the structures drawn by the students on the formation of the chemical bond, whereas the last part would be summary of the data based on the second and third part of the analysis. An overall summary would be added before at the end of this chapter.

The first part of the analysis was based on the two-tier diagnostic instrument which was designed to answer Research Question one, that is to identify the misconceptions (if any) of chemical bonding among Form Four students. The total score for each student was counted. The two-tier diagnostic instrument was analyzed descriptively to assist the researcher to continue with the criteria of the participants needed in selecting the participants for the semi-structured interview which was conducted in the phase two of the research.

In order to answer Research Question two, which was on how the misconceptions happened among Form Four students on the concept of chemical bonding, the second part of the analysis was based on analyzing the qualitative part of the research. The findings of this study was underpinned by the transcripts of the students' semi-structured interviews. Throughout the analysis, the following abbreviations were used to indicate the source of information.

S stands for "Student"

S1 stands for "First student"

S2 stands for "Second student"

S3 stands for "Third student"

S4 stands for "Fourth student"

S5 stands for "Fifth student"

S6 stands for "Sixth student"

S7 stands for "Seventh student"

D stands for "Drawing"

T stands for transcript

L stands for line

R stands for researcher / interviewer

In the last part of this chapter, there would be a summary of the findings based on both sets of data collected, from the two-tier diagnostic instrument and the semi-structured interview. The overall findings would be presented in a table and a chart.

4.1 Overview of the findings

The first part of the findings was based on the two-tier diagnostic test which provided the characteristics of selecting participants who probably had misconceptions of chemical bonding. The scores of the students were used to show the students' understanding of chemical bonding. The first part of the scores was important as it helped the researcher identify which students to select for the semi-structured interview and the type of misconception that students possess.

The second part of the findings was based on the semi-structured interviews to obtain more in-depth information on how the misconceptions happened on the learning of chemical bonding among the students. This would help the researcher identify and fill the gap of the study. The gap of the study as mentioned earlier, is on how the students have misconceptions when learning the macroscopic concept and link them to the sub-microscopic concept. From the analysis, it was found that basic concepts such as identifying particles, applying the proton number and number of electrons of an element and application of this concept were mostly the misconceptions that happened among the students which later on caused difficulties in differentiating ionic and covalent bonding. Wrong terms were used to explain the formation of chemical bonding such as using "donating electrons" to describe covalent bonding or vice versa. On top of that, students also had difficulty in drawing the structure of ionic and covalent bonding with the proton number given as a guideline for them to answer the drawing question.

The last part of this chapter would be a discussion on the data collected based on the two-tier diagnostic instrument and the semi-structured interview. A summary of misconception would be tabulated.

4.2 Overview of misconceptions of chemical bonding

4.2.1 Two-tier diagnostic test

A two-tier diagnostic instrument with nine items, which included two-tier multiple choice questions, was distributed to thirty-six students to test their conceptual understanding and to identify their misconceptions of chemical bonding. This instrument was used to answer Research Question one. The analysis of the two-tier diagnostic instrument would generally help the researcher identify which students to select for the second instrument which was the semi-structured interview. According to Bayrak (2013), students who were unable to secure the full score meant that they had misconceptions. The scoring scale used in the two-tier diagnostic instrument is shown in Table 4.1.

Table 4.1

Scoring scale for two-tier diagnostic test

Score	Description	Classification
1	Both answer and justification wrong or no response or answer	Specific misconception
2	Answer wrong but correct justification	Partial understanding with specific misconception
3	Answer correct but wrong justification	Partial understanding with specific misconception
4	Both answer and justification correct	No misconception

Source obtained from Bayrak (2013)

After collecting the two-tier instrument and marking the answers, the score of seven students was tabulated. Table 4.2 shows the percentage of students having factual misconception and conceptual misunderstanding for each item after conducted two-tier diagnostic instrument with thirty-six students. It can be seen that for most of the items, students had misconception on the chemical bonding. In Table 4.2, the first left-hand column shows the percentage of factual misconception on chemical bonding whereas on the right-hand columns shows the percentage of conceptual misunderstanding of student on chemical bonding. The analysis of each item would be explained later on.

Table 4.2

Percentage of students having factual misconception and conceptual misunderstanding

Item	Factual misconception (%)	Conceptual misunderstanding (%)
1	36.11	-
2	-	52.78
3	-	44.44
4	-	11.11
5	25.00	-
6	-	41.67
7	61.11	-
8	-	91.67
9	13.89	-

From all the 36 students, seven students were selected because they had the lowest scores among the thirty-six participants selected in the two-tier diagnostic instrument. The lowest score meant that students were having the score below 20 mark out of 36 mark as it is lower than 60% overall. Hence, these students were chosen to participate in the phase two study which was the semi-structured interview to obtain more information about their understanding of chemical bonding.

From Table 4.2, it can be seen that students were having factual misconception on item 1, 5, 7 and 9. On the other hand, students were having conceptual misunderstanding on the item 2, 3, 4, 6 and 8. The highest percentage of conceptual misunderstanding were on the item 8 which is 91.67%. Item 8 tested on the physical properties of chemical bonding. The actual concept of silicon carbide consists of strong covalent bonding and it exists as a macromolecule. The compound given to students was silicon carbide with a high melting point and boiling point. Most of the students were competent to state that the chemical bonding between silicon carbide is strong. However, students failed to explain in-depth that the strong bond in silicon carbide consists of many atoms that are covalently bonded which form a macromolecule. The student explained that a lot of energy is needed to break the forces between the molecules instead of explaining the structure. This is one of the misconceptions as students understand that bonding in silicon carbide is strong covalent bonding and energy is used to break the intermolecular forces.

Based on the result of students from the two-tier diagnostic test, it can be seen that the selected seven student obtained a low score on Item 1. They gave the wrong answer for both the first tier and justification on the correct type of particles in sodium oxide. Five students selected the answer “molecules” to describe the particles of sodium oxide. Two students gave partially correct justification by choosing the answer “oxygen” accepting one electron. Student number 22, justified that the sodium oxide formation through sharing electrons among the sodium atoms and oxygen atom. The student had misconceptions in identifying the type of particles in the sodium chloride compound. In the actual concept, sodium chloride exists as ions. Students were confused between the term “molecules” and “ions” in describing ionic bonding.

For Item 2, student number 7 and 19 failed to identify the correct type of particles either ions or atoms even though the electron arrangement of the ions was given in the question. Student number 1 failed to explain how the fluorine atom forms ions with the electron arrangement given in terms of sharing or transferring of electrons among the atoms. In the actual concept, fluorine atom gains electrons to form fluoride ions with an electron arrangement of 2.8. Therefore, the researcher found that students were unable to identify how fluorine forms ions, either through releasing, accepting or sharing electrons.

Item 3 tested the actual concept of sodium chloride compound which consists of sodium ions and chloride ions and held in a giant lattice structure. The majority of the students were unable to provide both correct answer and explanation on the formation of sodium chloride. Student number 7, 17 and 22 gave the wrong answer by stating that sodium chloride is a molecule. Student number 1 and 22 explained that sodium chloride formation is the sodium atom and chlorine atom sharing electrons among each other. This showed that the students did not fully understand the concept of chemical bonding. On top of that, their understanding of prior knowledge could have caused misconceptions to occur as students were unable to explain on particles. This would be further discussed in the semi-structured interview. In general, items 1, 2 and 3 clearly showed that students were unable to determine what type of particles can be found in chemical bonding. On top of that, students were confused in using the term "sharing" or "transferring" of electrons to describe the electron arrangement of the atoms.

Item 4 tested, the actual concept of ionic bonding due to the transfer of ions between an elements A to an element B. Student number 1, 7 and 19 were unable to give an accurate answer in explaining the formation of chemical bonding between the elements given in the question. Student number 19 was unable to give a correct answer on how the elements form in the second-tier of the answer. Student number 19 only knew about the transfer of electron between the elements. However, student number 19 failed to identify that the compound formed was actually an ionic compound. Student number 1 and 7 stated the reason of the element given was as sharing electron between the elements. Hence, the misconception occur when students think that atom A will share one pair of electrons with each atom B to form a covalent molecule, AB_2.

The analysis continued with Item 5. This item tested, the actual concept of bonding between hydrogen and chlorine as covalent bonding and this is due to the sharing of electrons between hydrogen and chlorine atoms to form hydrogen chloride. The majority of the students were unable to identify the correct type of chemical bonding between hydrogen and chlorine atoms. Student number 7, 19 and 20 chose the answer ionic bonding. The reason for choosing ionic bonding was that electrons were shared between the hydrogen atoms and chlorine atoms. Student number 17 stated the justification as both hydrogen atoms and chlorine atom having different charges. Student number 1 was able to give the answer of covalent bonding forming between hydrogen and chlorine but the justification given by student 1 was partially correct. The student gave the answer that both are non-metals in the space provided. Based on the data obtained, it showed that students were unable to differentiate how covalent and ionic bond are formed.

The concept of chemical bonding involves the drawing of the structure of chemical bonding. The actual concept between element A and element B is the formation of ionic compound and the correct structure is shown in Figure 4.1. Therefore, Item 6 tested students on the structure of the compound.

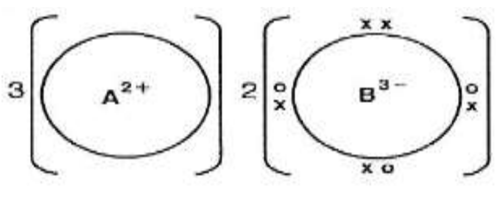


Figure 4.1 Structure of chemical bonding for element A and B

It was found that the 41.67% of the students were unable to choose the correct drawing. Students failed to analyze the question correctly. Students chose the answer covalent bonding instead of ionic bonding when they answered Item 6. Student number 1 and 22 failed to choose the answer of covalent bonding and their justification using drawing was wrongly selected. Both the students chose the answer as shown in Figure 4.2 below. This is one of the misconceptions of chemical bonding. Constructing the structure is a fundamental concept for students to be able to explain more on chemical bonding.

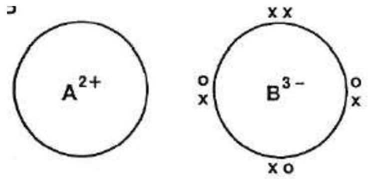


Figure 4.2 Structure of chemical bonding for element A and B selected by student number 1 and 22

In addition, S7 and S19 selected the answer as shown in Figure 4.3. They were unable to choose the correct structure of drawing where the ionic bonding structure should contain the square bracket in the drawing.

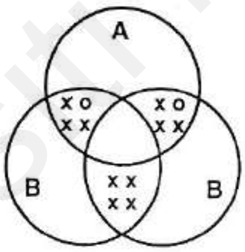


Figure 4.3 Structure of chemical bonding for element A and B selected by student number 7 and 19

Another student, number 25, selected the answer of the drawing of ionic bonding without square bracket as shown in Figure 4.4 below. Students thought that the structure should be overlapping continuously as shown in Figure 4.4. With the reference of these three answers chosen by the students, the researcher was able to identify that students actually had wrong concept in terms of the chemical bond and students were unable to choose the answer for ions with bracket.

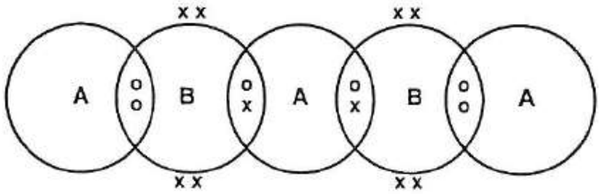


Figure 4.4 Structure of chemical bonding for element A and B selected by student number 7 and 19

Items 4, 5 and 6 show that students had misconceptions in differentiating ionic and covalent bonding. In addition, students also had difficulty in selecting the correct answer on the structure given. After analysing the structure of the drawing, the researcher moved on to analyse item 7, differentiating molecular compound and macromolecule of a sulphur atom. Sulphur is formed by a simple molecular compound where the molecules are held together by weak intermolecular forces between the molecules. However, student number 17, 19, 22 and 25 gave the answer macromolecules with the justification that all the atoms are covalently bonded. Student number 1 was able to state that the sulphur atom is a simple molecular compound but student number 1 gave a partially correct justification by saying that the molecules are made up of four atoms. Therefore, the researcher can conclude that students were confused on identifying how the covalent compound structure looks like.

In the last item which was item 9, the physical properties of ionic bonding were again tested. The actual concept is that the strong ionic forces between magnesium and oxide ions in the lattice allow magnesium and oxygen to be used as heat resistant material. In this item, student number 1, 19, 20 and 25 failed to state the properties of ionic bonding correctly and they were unable to justify that the structure of ionic bonding is held together by strong ionic forces. Hence, based on items 8 and 9, the researcher found that students failed to relate chemical bonding with its physical properties such as the melting and boiling point and the forces of attraction between chemical bonding. Table 4.3 shows the summary of misconceptions among the Form Four students.

Table 4.3

Misconceptions of chemical bonding among Form Four students

No.	Misconceptions of chemical bonding
1.	Sodium chloride is a molecule / atom / solid
2.	Fluorine atoms share electrons to form fluoride ions
3.	Fluorine atom has an electron arrangement of 2.8
4.	Fluorine atoms lose electrons to form fluoride ions
5.	Sodium chloride, NaCl exists as a molecule because sodium donates electrons to chlorine atom, the sodium ion forms a molecule with the chloride ion
6.	Sodium chloride, NaCl exists as a molecule because the sodium atom shares a pair of electrons with the chlorine atom to form a simple molecule
7.	Sodium chloride, NaCl exists as a molecule because sodium chloride exists as a lattice structure consisting of covalently bonded sodium and chloride atoms
8.	Element A (electron arrangement of 2.8.8.2) reacts with element B (electron arrangement of 2.8.7) to form an ionic compound of AB_2 because atom A will share one pair of electrons with each atom B to form a covalent molecule, AB_2
9.	The bond between hydrogen and chlorine is an ionic bonding because electrons are transferred from chlorine to hydrogen
10.	Sulphur atoms form rings consisting of eight atoms (S_8) covalently bonded together. Sulphur is a macromolecule because macromolecules contain molecules which are covalently bonded together.
11.	Sulphur atoms form rings consisting of eight atoms (S_8) covalently bonded together. Sulphur is a macromolecule because when the atoms of an element are covalently bonded, they will form macromolecules.
12.	Silicon carbide has a high melting point and high boiling point because silicon carbide bonds are strong. A large amount of energy is required to break the intermolecular forces in silicon carbide.
13.	The intermolecular forces between the magnesium oxide molecules are weak.

Hence, misconceptions of chemical bonding do happen as shown in Table 4.3. After the analysis of the two-tier diagnostic instrument, students had factual misconception and conceptual misunderstanding on the chemical bonding as shown in Table 4.2 and Table 4.3. The selection of participants for the semi-structured interview was based on the total score obtained by students (shown in Table 4.4). Table 4.4 is the final list with the students' total score using the abbreviation used in the semi-structured interview.

Table 4.4

Students with lower score selected for the semi-structured interview

Students	Total score	Abbreviation used in interview
1	19	S1
7	17	S2
17	23	S3
19	15	S4
20	25	S5
22	22	S6
25	24	S7

4.3 Misconceptions of chemical bonding

From the two-tier diagnostic instrument of thirty-six students' results, the researcher initially planned to call ten students for the semi-structured interview. However, the researcher only managed to call seven students to participate in this semi-structured interview as three students went off for their school holidays. The semi-structured interview protocol used was based on the pilot test's interview protocol in order to identify the misconceptions of chemical bonding that affect students' understanding. From the analysis of the worksheet and interviews five types of misconceptions emerged which were 1) unable to differentiate ionic and covalent bonding, 2) Unable to apply proton number and valency of electron of an elements in chemical bonding, 3) Unable to construct correct structure for ionic and covalent bonding, 4) Unable to identify the types of particles in ionic and covalent bonding and 5) Wrongly used terminology in describing chemical bonding.

4.3.1 Unable to differentiate ionic and covalent bonding

Before the interview on the actual concept of chemical bonding, the session started with some questions like how the students revise chemistry and the difficulty they faced while revising chemistry. Students claimed it was difficult for them to understand covalent bonding. Students had problems learning chemical bonding as they were confused with the terminology. The summary of the students' conversation regarding the difficulties they had in learning chemical bonding is shown in Table 4.5.

Table 4.5

Summary of students' difficulty in learning chemical bonding

Student	**Difficulty in learning chemical bonding**	
S6	R :	What are the problems you face?
	S6 :	Is like the covalent things…ionic bond…
	R :	What about ionic / covalent bond?
	S6 :	I don't understand like how they donate or accept.
	R :	What do you mean by how they donate or accept?
	S6 :	Like covalent and ionic bond….what words I can use or how to explain the drawing…
	R :	Drawing do you have a problem?
	S6 :	Drawing I don't think so…not really.
		(S6, T6, L11-16)

Based on the conversation shown in Table 4.5, student 6 faced the problem in understanding the concept of chemical bonding. S6 was not sure of the situation of ionic and covalent in terms of sharing or donating, S6 was unable to differentiate both bond. These were shown when S6 answered the question in the two-tier diagnostic instrument. S6 was unable to justify correctly the types of bonding formed between sodium ion and chloride ion. S6 chose the answer of sharing electrons among atoms. During the interview, S6 was not sure about how the formation of ionic and covalent bonding occurred, S6 usually guessed and memorized the answers given by the teacher. From the answers given by students, it shows that students had misconceptions on the type of chemical bond a compound contains.

4.3.2 Unable to apply proton number and valency of electron of an elements in chemical bonding

After identifying that the students were having learning difficulties in chemical bonding, the conversation continued further to explore about their understanding of the concept. In all the interviews, the researcher began by requesting students to construct the formation of sodium chloride. When students were asked to draw the structure, they were unable to remember the proton number of the atoms sodium and chlorine. When the researcher saw this situation, she provided the students with the proton number. However, even after the researcher gave them the proton number, the students still had difficulty in applying the concept of valency of electrons to begin their construction of the structure of sodium chloride. The evidence is shown in Table 4.6.

Table 4.6

Summary of students unable to state the proton number of atoms

Student		Unable to state the proton number of atoms
S2	*S2* :	Can I know what the proton number for sodium and chlorine is?
	R :	Proton number for sodium is 11 and chlorine is 17.
		(S2, T2, L46-47)
S5	R :	Can you please try to draw the formation of sodium chloride?
	S5 :	(Student showing that he cannot draw)
	R :	Maybe you can try to begin by recalling the proton number
	S5 :	(Student showing that he cannot remember)
	R :	Try to recall, the proton number of sodium is located after neon.
	S5 :	(Student showing that he cannot remember)
	R :	How about chlorine?
	S5 :	(Student showing that he cannot draw)
	R :	Okay, sodium is 11 and chlorine is 17.
	S5 :	Okay, I'll try.
		(S5, T6, L22-31)

Table 4.6 (continued)

Student	Unable to state the proton number of atoms
S6	*S6* : Sodium got how many electrons ar? R : Sodium has 11 electrons. *S6* : Symbol of Sodium is "No" ar? R : Why do you say "No"? *S6* : I think "No" is same like nitrate. I am actually not sure…. (S6, T6, L32-35)

Based on Table 4.6, students 2, 5 and 6 were unable to recall the number of proton of chlorine and sodium if there was no information provided for them. Without any information or hints given to them, it was difficult for the students to draw the structure of chemical bonding. To begin with, they did not have prior knowledge of learning chemical bonding thus they were unable to explain the proton number of an atoms as stated earlier in Table 2.1. Understanding the elements such as the symbol of each element is the pre-requisite for students to learn chemical bonding (Ministry of Education, 2005). The evidence of students having problems can be shown by one of the participants in this study. Student S6, mentioned that the sodium symbol is "No" which is a wrong concept. This showed that factual misconceptions happens in the classroom, as students unable to assimilate the prior knowledge when answering the chemical bonding concepts. From the above data, the students' prior knowledge on symbol of elements was a wrong concept or partially correct concept (Chi, 2013). This factual misconception causes them to face problems in their learning process of chemical bonding. This phenomenon is shown by student S5. After being provided with the proton number, student S5 still drew the wrong structure of ionic bonding for sodium chloride as shown in Figure 4.5.

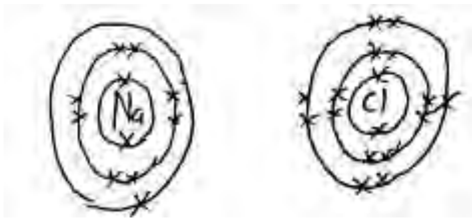


Figure 4.5 Structure of sodium chloride by Student S5

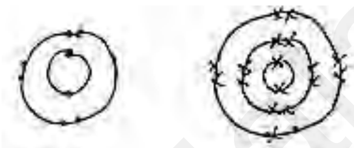
Student S5 was unable to show the correct structure of both sodium ions and chloride ions. S5 failed to show how the transfer of electrons occurs even with the proton number of both sodium and chlorine atoms provided by the researcher. If students do not have any misunderstanding on their prior knowledge of proton number, they should know that one single valence electron should be transferred to the chlorine atom and form ions. Unfortunately, students could not form the bridge between the concept of proton number and the symbol of atoms. According to S5's explanation, S5 was trying to relate the construction of sodium chloride with the table salt according to S5 experiences in daily life. However, S5 failed to see the connection between the salt and sodium chloride and S5 unable to provide a clearer explanation on how to construct the sodium chloride bonding. It clearly shows that students have misconceptions in relating the macroscopic level learning with sub-microscopic level in chemistry. This would lead to further conceptual misunderstandings in learning chemistry.

4.3.3 Unable to construct correct structure for ionic and covalent bonding

After realising that students were having conceptual misunderstanding in applying the proton number when learning chemical bonding, further exploration on the structure of chemical bonding was conducted, based on the answer of sodium chloride structure given by the students. After receiving the structures drawn by the students, the researcher noticed the students did not show the correct electron arrangement diagram between the two atoms. In their explanation, students were able to indicate that the compound of sodium chloride formed is an ionic bonding. However, by viewing their ionic bond structure, the compound drawn was a wrong structure. Moreover, most of them were unable to give a correct justification of the bonding. Table 4.7 shows the results given by S1.

Table 4.7

Structure and explanation of sodium chloride by S1

Student	S1
Drawing	
Student's justification	R : Yes. How's sodium chloride formed? *S1* : Sodium chloride is ionic compound right? R : Yes, you may write down your answer. *S1* : Okay. R : Why do you say it is an ionic compound? *S1* : Because sodium ions will donate the electron to chloride. R : Explain more about it. *S1* : Then, chloride will accept one electron from sodium. R : What happens after accepting electron? *S1* : Stable lo… R : The name of the bonding is? *S1* : Ionic bond. (S1, T1, L28-39)

Based on Table 4.7, S1's drawing was not a complete diagram. In S1's diagram, there was no symbol of element indicated and the correct ionic bonding of the structure was not shown. Initially S1 asked the researcher to confirm the answer given before beginning the drawing. The explanation on how the ionic bonding formed given by S1 was not complete. It showed that S1 was not sure of the answer. When the researcher further asked for explanation on the structure, S1 failed to explain why the structure was as such. Apart from that, in the two-tier diagnostic instrument, S1 chose the answer of sodium chloride existing as a molecule with the explanation that sodium chloride contains sodium ions and chloride ions.

The above data shows that students actually have the wrong concept in understanding chemical bonding. Student S1 failed to explain further when he was asked the reason of showing the structure. This shows that they failed to form a bridge from their prior knowledge of particles to chemical bonding. On top of that, S1 mentioned that the chlorine received electron to form stable. Before ending the interview, the researcher requested S1 to explain further on the definition of "stable". This is shown in the dialogue below.

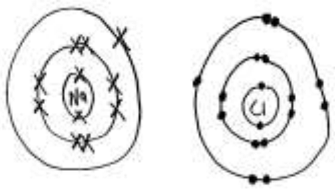
R : Earlier on in sodium chloride, you mentioned about "stable". How do you define the meaning of "stable"?
(Student took time to think of the answer, she was unsure about her answer)
S1 : They will not break easily.
R : What do you mean by "they do not break easily"?
S1 : …… (No answer from her, so I guided her on her structure)
R : Based on your structure, what do you mean by "they will not break easily"
S1 : Because they are stable so they won't break easily.
R : Meaning of break is? The molecules just break?
S1 : The melting and boiling…
R : Why you says is melting and boiling?
S1 : I am not sure.

(S1, T1, L96-109)

Unfortunately, S1 failed to explain the term "stable". S1's explanation was the structure does not easily break and S1 was unable to further elaborate. The explanation given by S1 was wrong. S1 defined "stable" as "not easily break". It can be seen that students had difficulty in relating the concept of stability on inert gases learnt before they learnt chemical bonding. Conceptual misunderstanding in their prior knowledge of stability in inert gases happened which led to difficulty in understanding chemical bonding. Let us look at another student's answer in Table 4.8.

Table 4.8

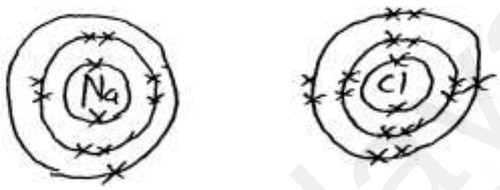
Structure and explanation of sodium chloride by S3

Student	S3
Drawing	
Student's justification	R : Can you please draw the structure of sodium chloride and tell me about the formation? *S3* : Okay… (Student began to draw the structure). R : Done ya? So this is your structure? *S3* : Yes. Sodium has the electron arrangement of 2.8.1, it belongs in Group 1, so it's a metal atom whereas chlorine it has electron arrangement of 2.8.7, it's belong in Group 17, therefore, and it's a non-metal. Therefore, both sodium atom and chlorine atom forms an ionic bond. R : Why do you say ionic bond? *S3* : Because sodium is a metal, chlorine is a non-metal. Sodium needs to donate one electron to obtain its stable octet electron arrangement. Therefore, it forms a positive ions, whereas chlorine needs one electron to achieve stable octet electron arrangement, therefore it formed chloride ion, negative ion. (S3, T3, L24-39)

Based on Table 4.8, S3 managed to explain the formation of sodium chloride. However, the drawing of the structure was incomplete and S3 was not able to show the bond between sodium and chlorine. S3 actually drew the structure of sodium and chlorine's individual atom instead of showing the sodium ion and chloride ion correctly. S3 was unable to answer how the structure of sodium atoms transfers electrons to chlorine atoms. In the two-tier diagnostic instrument, S3 chose the answer that sodium chloride is made up of molecules and S3's justification of the answer was sodium is sharing electrons with chlorine. It shows that S3 had the wrong concept in identifying the ionic and covalent bonding. The students had conceptual misunderstandings in terms of the types of particles such as atoms, ions and molecules. They had the wrong concept earlier on which led to the difficulty in understanding chemical bonding. Further exploration on how to differentiate ionic and covalent bond would be conducted in the next section. Table 4.9 shows another student's answer, student S5 regarding the formation of sodium chloride.

Table 4.9

Structure and explanation of sodium chloride by S5

Student	**S5**
Drawing	
Student's justification	R : Can you please try to draw the formation of sodium chloride? *S5* : (Student showing that he cannot draw) R : Maybe you can try to begin by recalling the proton number? *S5* : (Student showing that he cannot remember) R : Try to recall, the proton number of sodium is located after neon. *S5* : (Student showing that he cannot remember) R : How about chlorine? *S5* : (Student showing that he cannot draw) R : Okay, sodium is 11 and chlorine is 17. *S5* : Okay, I try. R : What is the type of bonding? *S5* : For sodium chloride? R : Ya. *S5* : Ionic bond. R : Why do you say it is ionic? *S5* : I do not know how to answer the question. (Student tried to think of the answer) R : Why do you think it is ionic? *S5* : Do not know why. Just remember teacher said is ionic. (S5, T5, L23-45)

According to Table 4.9, S5 gave the similar structure of chemical bonding as S3. S5 drew the structure of individual atoms of sodium and chlorine. On top of that, S5 was not sure about the symbol of sodium which was taught as a fundamental concept at the beginning of the Chemistry lesson. S5 was only able to give an ionic bond as an answer but when the researcher asked for more in-depth explanation, S5 was unable to explain further on why the structure formed was ionic. With reference to the two-tier diagnostic test, S5 also chose the answer that sodium chloride is a molecule but the justification of the answer was that the molecules are formed between sodium ions and chloride ions. From the justification given by S5, it can be seen that student S5 had conceptual misunderstanding of the basic concept of the types of particles. S5 was unable to relate the molecules in the learning of chemical bonding. By looking back at the earlier conversation, S5 did mention that in order to answer the question in an examination, S5 would just memorize all the notes given by the teacher.

The exploration is continued by looking at the structure that students drew. In drawing ionic bond structure, a square bracket "[ ]" is needed to show that the charge of the ions is spread evenly throughout the ions (Norris, 2015). Hence, a conclusion was made on how the students' understanding of the square bracket is needed to be used in the construction of the structure of ionic bonding. Students who had misconceptions on the use of the bracket were unable to give a clear explanation on why the bracket is necessary when drawing the structure of ionic bonding. The findings on the summary of the students' concept are shown in Table 4.10.

Table 4.10

Summary of ideas on the use of square bracket in ionic bond structure

Student	Idea on square bracket in ionic bond structure	
S2	R :	What is the purpose of drawing the bracket?
	S2 :	Bracket is to show that it is a cation or anion.
		(S2, T2, L54-55)
S4	R :	What is the meaning of the bracket here? (I pointed at the bracket on the structure she drew).
	S4 :	The bracket is to state whether it is a stable octet or duplet of electron arrangement.
		(S4, T4, L43-46)
S6	R :	Can I know why you must have the bracket? (I pointed to the structure which had the bracket)
	S6 :	Because after it donate electron, it will become positively charged.
	R :	What is the meaning of this bracket?
	S6 :	After donate electrons, so you need to draw the bracket.
	R :	Any other?
	S6 :	Ya. Chlorine accept electron and then electrons is negatively-charged.
	R :	After chlorine accepts the electron, what does it form?
	S6 :	Not sure…
		(S6, T6, L69-77)
S7	R :	Regarding the structure, what is the meaning of the bracket?
	S7 :	I am not sure. I know you are supposed to draw it in the diagram.
		(S7, T7, L64-65)

Based on Table 4.10, students did not really know that the reason of adding a square bracket "[ ]" in drawing the ionic bonding structure. S7 said he was not sure he only knew that he was supposed to draw the square bracket. S2 and S6 only managed to give some ideas on the square bracket. S4 said the bracket was to show the stability of the electron arrangement. From all their response, students showed conceptual misconceptions on the concept of chemical bonding as they did not know that the square bracket means that the charge is actually spread evenly throughout the whole ion. Hence, the misconception in chemical bonding is due to conceptual misunderstanding of fundamental concept.

4.3.4 Unable to identify the types of particles in ionic and covalent bonding

The exploration is continued on the structure of sodium chloride where students were asked to identify the types of particles. This is also a fundamental concept for chemical bonding. Table 4.11 shows the summary of how participants answered the question related to the types of particles of chemical bonding.

Table 4.11

Summary of the problems on types of particles

Student	Problem with types of particles
S1	R : What are the types of particles in sodium chloride? *S1* : Not sure. (Student took time to think of this answer) R : Any possible answer you can give? *S1* : (Student shook her head). Erm…… R : Okay, I give you some choices. Which of the following is the answer? (Researcher wrote out three choices for the student: molecules, ions or atoms) *S1* : Molecules…. (Answer given in an unsure manner) R : Why do you say it is a molecules? *S1* : Because they are compound… (Student took some time to think of the reason, she was unsure of it) (S2, T2, L38-51)
S3	R : Based on the structure, what are the types of particles in sodium chloride? *S3* : I think molecules. R : Why do you say is molecules? *S3* : They shared electrons together. R : Meaning they are ionic and sharing electrons? *S3* : Ya. (S3, T3, L40-46)
S4	R : What are the types of particles in sodium chloride? *S4* : (Student smiled and shook her head, she did not know the answer) (S4, T4, L49-51)
S5	R : What are the types of particles for sodium chloride? *S5* : Liquid. R : Why do you say liquid? *S5* : In daily life, chlorine is like liquid for me. I think chlorine is always liquid. For sodium, we usually use this to do solution for experiment. So, I will say is liquid. (S5, T5, L48-53)

Table 4.11 (continued)

Student	Problem with types of particles
S6	R : What are the types of particles in sodium chloride?
	S6 : I don't know. (Student unable to answer the question)
	R : You need help?
	S6 : Yes.
	R : I give you some choices ya.
	S6 : (Nodded his head)
	R : Solid, liquid, gas, atoms, molecules, ions.
	S6 : Molecules.
	R : Why you say it is molecules?
	S6 : Because it is different elements.
	R : That's all?
	S6 : Yes.
	(S6, T6, L77-89)
S7	R : What are the types of particles in sodium chloride?
	S7 : Argh…type of particle.
	R : Are you having a problem with that?
	S7 : Yes. Is it like free moving ions?
	(S7, T7, L70-73)

Based on Table 4.11, S1, S2 and S6 gave the same answer which was molecules whereas S5 gave the answer as liquid. S4 and S7 were not sure of the answer. This clearly showed that students were unable to identify types of particles which is a fundamental concept. S6 stated that molecules were due to sodium chloride being formed by two different elements. This answer seemed logical to them but it was a partially wrong concept in chemical bonding.

In addition, S1 and S6 initially were unable to provide the answer, so the researcher gave them choices. However, their final answer based on the choices given was wrong too. Hence, these findings showed that their fundamental understanding on the types of particles is a conceptual misunderstanding. Moreover, the drawing made by S1 in constructing the structure of sodium chloride was also wrongly drawn (Appendix16A).

Through the analysis of students' two-tier diagnostic instrument, it was discovered that the students were confused with ions, atoms or molecules. They had a conceptual misunderstanding on these three terms which led them to have difficulties in differentiating them in the compound formed by ionic and covalent bond. The phenomenon can be seen in the two-tier diagnostic instrument. The students described sodium oxide and sodium chloride consisting of molecules instead of ions. When the researcher asked for more explanation on why they thought the answer was molecules, the students were unable to justify the answer.

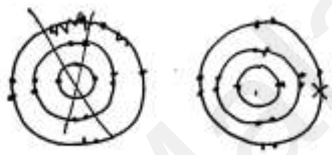
4.3.5 Wrongly used terminology in describing chemical bonding

Apart from giving the students an ionic compound structure, another question was given to the students in which the question was related to covalent compound structure which is hydrogen chloride. The results showed that the students were unable to differentiate whether hydrogen chloride is an ionic or covalent bond compound. Students misused the word "donating", "accepting" and "sharing electrons" in the formation of chemical bonding. In the two-tier diagnostic instrument, the students used the term "sharing electrons" in describing ionic bonding. Students S3, S5 and S6 used the term "sharing electrons" to describe the formation of ionic sodium chloride compound. When the students were asked to justify their answer, most of them faced problems. They were uncertain of how ionic and covalent are formed.

The actual concept of drawing covalent bonding is that the sharing of electrons is between the overlapping regions of atoms. There is one part in this study where students did not indicate correctly when sharing electrons. They, drew the sharing electron on the orbit of the individual shells when they were supposed to draw it on the overlapping region (Norris, 2015). The diagrams drawn by students S4 and S7 (as shown in Table 4.12) showed the shared electron on the atom's respective orbit. This phenomenon showed that the students were confused on how to differentiate the ionic and covalent bonding in the compound provided. Table 4.12 shows the summary of all the students' explanations regarding the formation of hydrogen chloride and the structure of drawing of hydrogen chloride.

Table 4.12

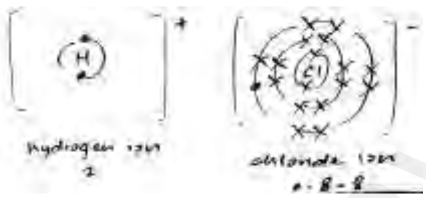
Summary of S1's explanation on the formation of hydrogen chloride

Student	Explanation on the formation of hydrogen chloride
S1	 Appendix 18 A (D12)
Student's justification	R : This is the structure of hydrogen chloride. Why does your structure look like this? Can you please explain more? *S1*: Because chloride will donate one electron to… oh no… it is hydrogen will donate one electron to chloride. R : Any further explanation? *S1*: So, they become stable. (S1, T1, L63-68)

Based on Table 4.12, S1 and S2 used the term "donate" while explaining the formation of hydrogen chloride. With reference to the structure drawn by S1 (Appendix 18A), S1 did not show the element in the structure and no bond was clearly shown in the formation of covalent bond between hydrogen and chlorine. Merging the explanation with the diagram, it clearly showed that S1 has partial conceptual misunderstanding of ionic and covalent bonding. S1 was not sure how to draw the hydrogen chloride diagram even though he was given the proton number by the researcher. The student failed to apply the concept on the drawing. S1 was unable to justify why he could not draw the structure and was only able to explain that "they become stable”. An analysis on with S2’s diagram and explanations are as shown in Table 4.13.

Table 4.13

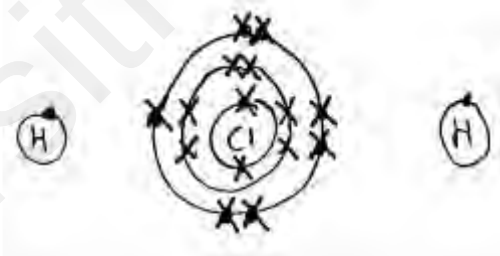
Summary of S2’s explanation on the formation of hydrogen chloride

Student	**Explanation on the formation of hydrogen chloride**
S2	 Appendix 18 B (D13)
Student’s justification	R : Can you explain to me why your structure looks like this? *S2*: Because the electron arrangement of hydrogen is 2.1 which has one valence electron, therefore, it donate one valence electron to achieve hydrogen ion, which is the most stable duplet electron arrangement. And chloride ion with the electron arrangement of 2.8.7 has seven valence electron and it accept one valence electrons to achieve sodium ion. R : Sodium ion or … *S2:* Oh …. chloride ion…which is the most stable octet electron arrangement. R : That’s all? *S2* : Yup. (S2, T2, L78-89)

The structure drawn by S2 was wrong because S2 drew hydrogen chloride existing as an ionic compound (Appendix 18B). In S2’s explanation, the student mentioned that hydrogen has an electron arrangement of 2.1, which was wrong. In the actual concept, the electron arrangement for hydrogen is 1. From here, we can clearly see that S2 was unable to apply the correct electron arrangement in covalent bonding even though S2 knew the proton number. It again showed that students had the wrong basic concept which led to the difficulty in drawing the correct structure of hydrogen chloride. Apart from that, S2 said that during the formation of hydrogen bonding, the electron was actually donated by hydrogen and accepted by chlorine atoms. This showed that S2 had conceptual misunderstanding on the formation of covalent bonding. In the actual concept, hydrogen and chlorine are formed by covalent bonding because the electrons are shared between the hydrogen and chlorine atoms. Based on the answers given by S2, the researcher can say that students had conceptual misunderstanding on the concept learnt in atomic structure which is related to the electron arrangement of an atom and how the element achieves stability. Another analysis on S3 was conducted to obtain more information on how misconceptions affect the students' understanding in chemical bonding. Table 4.14 shows the summary of explanation given by S3.

Table 4.14

Summary of S3's explanation on the formation of hydrogen chloride

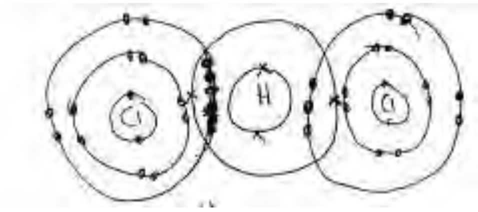
Student	**Explanation on the formation of hydrogen chloride**
S3	 Appendix 18C (D14)
Student's justification	R : Done. So this the structure for hydrogen chloride? *S3* : Yup. R : Can you explain a bit about your structure? Why does it look like this? *S3*: Two hydrogen atoms need to share with chlorine to achieve stable duplet electron arrangement whereas chlorine needs one electron to achieve stable octet electron arrangement. R : Anything else you can add on? What is the type of bonding? *S3* : I think is covalent bonding. Because both are non-metal. (S3, T3, L55-63)

S3 claimed that two hydrogen atoms are needed to be shared with the chlorine atoms. This explanation showed that S3 partially understood the meaning of sharing electrons in covalent bonding. This was because in the structure drawn (Appendix 18C), the structure was constructed in such as a way that no overlapping in the valence shells was shown and no illustration of sharing of electrons occurred between the hydrogen and chlorine atoms.

Apart from that, only one hydrogen was needed by S3 said that two hydrogen atoms were needed for the structure to achieve stable duplet electron arrangement. The students was not sure how many hydrogen atoms were needed in the formation of covalent bonding in order for the compound to achieve stability. S3 gave the wrong answer even though the drawing of each individual elements was correct. This showed that conceptual misunderstanding of the compound achieving stability occurred which led to the misconception of the formation of covalent bonding between hydrogen and chlorine atoms. The researcher continued with more analysis on S4, as shown in Table 4.15 to allow the researcher to obtain more information on how students have conceptual misunderstandings of the drawing of hydrogen chloride.

Table 4.15

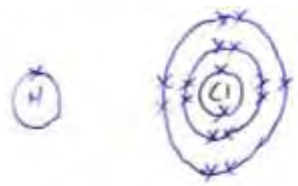
Summary of S4's explanation on the formation of hydrogen chloride

Student			Explanation on the formation of hydrogen chloride
S4			 Appendix 18 D (D15)
Student's justification	R	:	Can you please draw the structure of hydrogen chloride?
	S4	:	(Student began to write out the electron arrangement of hydrogen and chlorine) So, the bonding between hydrogen chloride is covalent bond. Because hydrogen is a ….. Student was not sure about her answer, after thinking for a short while) Nope. It is an ionic bond.
	R	:	So, would you like to further explain your answer?
	S4	:	Just give me a second. (Student took a long time to think about the answer) It is a covalent bond. Because hydrogen is from Group 12 and Chlorine is from Group 17. So, two hydrogen atoms will donate… (After thinking for a short while, she changed her answer). So, one hydrogen atom will share two of its valence electrons with two chlorine atoms.
	R	:	Why do you says that hydrogen is Group12?
	S4	:	I am not sure.
	R	:	So, now can you draw the structure for me to see?
	S4	:	(She nodded, then she began to draw) (Student took some time to draw the structure, she was a bit confused with her own drawing)
	R	:	Is that your structure?
	S4	:	Yes (Nodding her head)
	R	:	Can you explain to me?
	S4	:	So, basically, hydrogen has two valence electrons, so, it will shared two valence electrons with two chlorine atoms because chlorine has seven valence electrons and it need one more to achieve the most stable electron arrangement. Therefore, they shared, they don't donate.
	R	:	Anything else to add to your explanation?
	S4	:	Nope. (S4, T4, L61-90)

In S4's interpretation, the diagram drawn (Appendix 18D) showed an overlapping region in the compound but the sharing of electrons was not clear. In the actual concept, the shared electrons are supposed to be drawn on the overlapping region. In addition, S4 interpreted that hydrogen was from Group 12 but she failed to explain why it was in Group 12. Hence, when S4 drew the structure, she interpreted that the valence electron of hydrogen was two. This statement clearly showed that it was a conceptual misunderstanding. This was the reason S4 was unable to construct a correct electron arrangement diagram and gave an answer of ionic bond. It showed that S4 was also unable to differentiate ionic and covalent bond formed in a compound even though S4 changed her answer later on. It showed that students actually are not sure about the concept, they are guessing the answer in order to explain the formation of both chemical bonds. Another analysis is carried out to show how students S5 and S6 interpret hydrogen chloride compound, as shown in Table 4.16.

Table 4.16

Summary of S5 and S6's explanation on the formation of hydrogen chloride

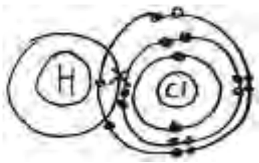
Student	Explanation on formation of hydrogen chloride
S5	 Appendix 18E (D16)
Student's justification	R : That is your hydrogen chloride structure? *S5* : Ya. R : Why does your structure look like this? Can you try to explain to me? *S5*: Because hydrogen I know, it is always one, so I just draw one atom here. And then chlorine is the same as just now. R : Basically, this one is considered what type of bonding? *S5* : I would say it is the same it is ionic bonding. R : Why is it ionic bond? *S5*: (Student struggled to answer. After asking a few times, he tried to give an answer.) Because it is not a solid. (S4, T4, L59-70)
S6	 Appendix 18F (D17)
Student's justification	R : Can you please draw another structure of hydrogen chloride? *S6* : Hydrogen… (Student began to draw the structure) R : Okay, that is your structure of hydrogen chloride? *S6* : Ya. (Unsure) R : This is your final answer? *S6* : Ya. R : Why does your structure look like this? *S6* : Because hydrogen got one electron, chlorine got 17. R : What is the type of bonding for this? *S6* : Covalent. R : Why do you say it is covalent? *S6*: If ionic you need to donate ma…. If the hydrogen donate one electron, then it became nothing. R : "Nothing" meaning… *S6* : No electron and stable (S6, T6, L90-105)

Viewing both of S5 and S6's constructed electron arrangement diagram, it was clear they only managed to show the original atoms for hydrogen atom and chlorine atom without any significance of overlapping shells or sharing of electrons occurring among the elements. S6 tried to explain covalent but her explanation was incomplete, whereas S5 mentioned that hydrogen chloride was an ionic compound. The reason given by S5 was that it was not a solid.

From S5 and S6's answers, it seemed they misunderstood the terms "sharing" and "donating" electron. They failed to apply the concept of how the elements achieved stability in forming the ionic or covalent bonding. S6 thought that covalent bonding was due to the transferring of electron from hydrogen to chlorine atom, thus the hydrogen atom will have no more electron in the shell and become stable. S6's justification on stability was it was not reactive. Hence, an analysis of the answers provided by both the students showed conceptual misunderstanding on stability occurring and failure to apply the idea of how electrons are shared or transferred among the elements. The last analysis is on student 7, as shown in Table 4.17.

Table 4.17

Summary of S7's explanation on the formation of hydrogen chloride

Student	**Explanation on the formation of hydrogen chloride**
S7	 Appendix 18G (D18)
Student's justification	R : So, hydrogen is 2 electrons? *S7* : So after hydrogen ions sharing. R : (Referring to the diagram in hydrogen chloride) This one dot is for…? *S7* : That is the seven electrons for the outer shell. R : (Pointed to the dot- electrons in the diagram) Here there are two of them. One is sharing, the other one is not sharing? *S7* : Ya, they only shared one. (S7, T7, L95-101)

The electron arrangement diagram constructed by S7 seemed correct but it actually had one extra electron in the valency shells. When the researcher asked for further clarification, S7 was unable to explain and merely said that chlorine was sharing one electron with hydrogen. Student S7 failed to justify how the element achieved stability with how many maximum number of electrons in the valence shell.

All the interpretation from the students showed that students were not mastering the concept well. There were conceptual misunderstandings occurring such as wrongly used terminology like "donate", inability to explain the stability of an element after forming a chemical bond and failure to construct a correct electron arrangement diagram to show the chemical bonding occurring in either an ionic or covalent compound. These were the misconceptions found in covalent bonding.

The last interview question on chemical bonding tested the students' construction and explanation of another compound which was Tetrachloromethane, CCl_4. The findings were similar to the question on hydrogen chloride; students had the same difficulty in applying the proton number of carbon. Even though the researcher gave them the proton number, they still struggled in drawing the structure. Table 4.18 shows the students' explanation on the formation of Tetrachloromethane.

Table 4.18

Summary of S1's explanation on the formation of Tetrachloromethane

Student	Drawing	Explanation on formation of Tetrachloromethane
S1	Appendix 19 A (D21)	R: Why does your structure look like this? Can you please explain more on it? *S1*: Because they will share electrons. R : What do you mean by "they"? *S1*: CCl_4 R : How do hey share electrons? *S1*: By contribute one electron. R : Who contributes one electron? (Student showed that she was not really sure about the answer by shaking her head, she took some time to think about the answer) *S1*: Cl will contribute. R : And then, any more explanation regarding your structure? *S1*: Argh… (S1, T1, L79-92)

According the diagram drawn by S1 (Appendix 20A), S1 did not show the element in the drawing and she did not show how the electron was sharing at the overlapping area. According to S1, it was not clearly stated how covalent bonding was formed. It seemed that S1 was not sure of her answer in how the electrons share in the bonding. The similar difficulty existed in the question on hydrogen chloride. S1 was provided with the proton number but she could not apply the concept in constructing the structure correctly.

Table 4.19

Summary of S5's explanation on the formation of Tetrachloromethane

Student	Drawing	Explanation on formation of Tetrachloromethane
S5	Appendix 20 E (D25)	R : Why does your structure look like this? What type of bonding is this? *S5*: I would said this is covalent bonding. R : Why does your structure look like this? *S5*: Because Cl there is an extra one proton number, so CCl_4 need to make it balance. So, they shared what the proton number is to make it balance. So, now Cl is 18… all Cl is balanced. R : So what is the meaning of balance to you? *S5*: From what my teacher said, it is like Cl does have extra one. Is like alone, so the carbon need to donate one of the electron to Cl, so to make balanced. Something like that…. (S5, T5, L80-90)
S7	Appendix 20 G (D27)	R : Can you please draw the structure of Tetrachloromethane, CCl_4 molecules? *S7*: Erm…(While student is drawing) Do I have to explain? R : Ya, can you please explain. *S7*: Carbon is 2.6, the electron arrangement, chlorine is 2.8.7. Carbon needs two electrons to achieve stable octet electron arrangement. Chlorine needs one electron and because carbon and chlorine both are non-metals, so they will form covalent bond. R : Carbon is 2.6? *S7*: Ya.. Oh no, that is oxygen. R : So, carbon should be…? *S7*: Is it 2.4? R : Ya. *S7*: They will share one electron each, there will be four chlorine atom and one carbon atom. (Student continued her drawing. She took some time to draw the structure) Chlorine ions electron arrangement will be 2.8 and one carbon will also be 2.8. (S7, T7, L102-122)

The structure drawn by S2, S3, S4, S5, S6 and S7 showed the same structure as shown in Appendix 20 (B – G). All of them did not show exactly where the sharing of electrons occurred and did not fill in the electron in the overlapping region. S5 mentioned that the electrons were shared so that it could be balanced. S5 further explained that Cl did have one extra electron, so carbon needed to be donated to Cl. This sentence it is showed that S5 was actually having conceptual misunderstanding that carbon donated electrons to chlorine.

> R: So what is the meaning of balance to you?
> *S5*: From what my teacher said, it is like Cl does have extra one. Is like alone, so the carbon need to donate one of the electron to Cl, so to make balanced. Something like that….
>
> (S5, T5, L88-90)

As mentioned earlier, students had problems in explaining the formation of chemical bonding, for example they needed to clarify the proton number of the atoms. Then when the students explained and drew the structure of arrangement, this was a new misconception which the researcher found from this study. These problems have to be looked into as knowing the proton number and number of electrons are fundamental concepts for students in learning chemical bonding. This is because, only when they know the number of electrons, then only can they identify the valency of electrons in the valence electrons. Then from there, they can determine the types of bonds formed (Ministry of Education, 2005).

4.4 Summary

In this chapter, the researcher has described the findings of the study. The purpose of this study was to explore the misconceptions of chemical bonding among Form Four students by using a mixed method research and an explanatory sequential design. This study was to explore the misconceptions of ionic and covalent bonding and to obtain more in-depth information on how students understand ionic and covalent bonding.

From the overall findings, students were unable to differentiate ionic and covalent bonding. Through their explanations, the findings showed that students used wrong terminology to describe ionic and covalent bonding. Apart from that, they had difficulties in identifying the types of particles in ionic and covalent bonding.

In addition, from the data collected, it showed that students were unable to construct correct structures for ionic and covalent bonding and they could not relate the physical properties of the chemical compound to chemical bonding. The researcher found that the misconceptions on chemical bonding occurs because students were unable to apply the proton number of the element and valency of electron of an elements. They failed to explain the stability of a compound based on the stability of inert gases. The discussion in the next chapter will focus on the conclusion of the findings and suggestions for future studies.

CHAPTER 5

DISCUSSION, CONCLUSION, IMPLICATIONS AND SUNGGESTIONS OF THE STUDY

5.1 Introduction

In this chapter, the researcher focused on the discussion and conclusion of the findings of the study, implications as well as suggestions of the study. This chapter began with the overview of the study which included the research questions, problem statement, methodology used for data analysis and research findings. This discussion followed by the conclusion of this study. The discussion will then highlight implications of this study to teachers, students and stakeholders. Lastly, the discussion focused on the suggestions for future studies.

5.2 Overview of the study

The learning of chemistry can be divided into three levels, the macroscopic level, sub-microscopic level (Gabel, 1999; Treagust et al., 2003; Tumay, 2016) and symbolic level (Johnstone, 1982, 1991, 1997, 2000; Reid, 2019). Therefore, learning the concepts of chemistry may seem complex and complicated to students as they, must correlate all three levels in their learning process (Reid, 2019) in order to master the concepts. The understanding of fundamental concepts such as matter, compound stability based on inert gases and chemical bonding is important for students to proceed with their studies in Chemistry. When students have partial understanding of a fundamental concept such as the type of particles and matter, they will have the misconceptions at the advance level of their studies when learning organic chemistry, such as hydrocarbon compound and polymer chemistry (Levy Nahum et al., 2010; Pabuccu & Geban, 2012; Pardhan & Bano, 2001).

Misconceptions will occurs when students gain partial understanding of concepts or learn wrong concepts as they are unable to comprehend the situation or fail to master the concepts ("Cambridge dictionary English Dictionary ", 2020). The aim of this study was to explore the misconceptions of chemical bonding such as ionic and covalent bonding among Form Four students. Chemical bonding was chosen because this topic is an important basic concept in Chemistry (Al-Balushi. et al., 2012; Holme et al., 2015). The research questions of this study are:

1. What are the misconceptions (if any) of the concept of chemical bonding among Form Four students?
2. How is the misconceptions on chemical bonding among Form Four students?

The first research question was to identify the misconceptions (if any) of the concept of chemical bonding among Form Four students. The findings showed that misconceptions of chemical bonding do happen among Form Four students. In the phase one analysis, a quantitative analysis was conducted descriptively for the researcher to continue phase two of the research study. From the findings, students had conceptual misunderstanding and factual misconception in chemical bonding. In the two-tier diagnostic test, students who scored low and were unable to give correct justifications for the first tier answers were selected as a participants for the phase two semi-structured interview. From the analysis, every item in the two-tier diagnostic instrument had students who were unable to provide the correct answer and justification. Hence, the research question has been answered as shown in Table 4.3.

In the phase two study, seven students were selected for the semi-structured interview. The interview sessions were conducted one-to-one. The second research question was to explore how these misconceptions on chemical bonding happened. The gap of the study was to identify misconception on chemical bonding among the Form Four students. From the findings, the researcher managed to abstract six main concept on chemical bonding which conceptual misunderstandings and factual misconception possessed by the students which caused them to misunderstand the concept of chemical bonding. The six main conceptual misunderstandings are:

1. Unable to differentiate ionic and covalent bonding
2. Wrong terminology used to describe ionic and covalent bonding
3. Unable to identify the type of particles in ionic and covalent bonding
4. Unable to construct correct structure for ionic and covalent bonding
5. Unable to apply proton number and valency of electron of an elements
6. Unable to explain the stability of a compound based on the stability of inert gases

In this study, the purpose of the research was to explore the misconceptions of the students' ability to relate the macroscopic level and to the sub-microscopic level so that students are capable explaining how chemical bonding is formed based on the phenomena or diagrams given. The misconceptions of students' failure to apply proton number and valency of electrons of an element has to be looked into to avoid any further misconceptions occurring in the learning of other concepts related to chemical bonding.

5.3 Discussion and Conclusion

In this chapter, the discussion continues with how the findings and conclusion can be abstracted from this study. This is to answer the research questions on the misconceptions possessed by the Form Four students in their learning of chemical bonding. Through the two-tier diagnostic instrument, the researcher managed to identify and abstract from the students' answers, the misconceptions they had.

In a research that uses more than one method of data collection, which was two-tier diagnostic test and semi-structured interview. The researcher will try to look for converging data and corroboration of the results obtained from the data collected. In this research the purpose of using mixed methods is to have development. The term development means the researcher will use the data obtained from the two-tier diagnostic instrument to elicit which students to call for the semi-structured interview in phase two and identify the type of misconception student had.

According to both sets of data collected, the misconceptions that happen among the students will be discovered. The answers to Research Question one is students possess conceptual misunderstanding and factual misconception on chemical bonding. The misconception on chemical bonding was summarised in Table 5.1 showing that misconceptions of chemical bonding do happen among Form Four students.

Table 5.1

Summary of misconceptions of chemical bonding

No	Misconceptions of chemical bonding
1	Students are unable to differentiate between ionic and covalent bonding
2	Students use the wrong terminology (sharing, losing or gaining electrons) in describing ionic and covalent bonding
3	Students are unable to state the type of particles (molecules / ions / atoms) in the ionic or covalent compound
4	Students are unable to state the definition and function of the square bracket in ionic compound.
5	Students are unable to construct the structure of ionic bonding correctly – drawing without charges and square bracket.
6	Students are unable to construct the structure of covalent bonding correctly – did not draw the sharing electrons in the overlapping region.
7	Students could not relate chemical bonding to the physical properties of chemical bonding such as melting and boiling point and physical state.
8	Students failed to explain the stability of a compound based on the stability of inert gases

In this study, students were unable to differentiate ionic and covalent bonding. This finding in line with the findings of other researchers in other countries (Levy Nahum et al., 2010; Perez et al., 2017; Taber, 2011; Vladusic et al., 2016). Apart from that, students used a wrong terminology to describe the formation of ionic and covalent bonding. Students used the terms "molecules" and "liquids" to describe ionic bonding such as sodium chloride. In this finding, S3 and S6 used the term "molecules" to describe sodium chloride during the semi-structured interview. S2, S3, S6 answered that sodium chloride was a molecule in their two-tier diagnostic instrument. In addition, S3 used the term "sharing electrons" to describe the formation of ionic bonding and S1, S2 and S6 used the term "donating electron" to describe covalent bonding. The same misconception was found when S5 and S7 answered the two-tier diagnostic instrument. This finding clearly shows that students have misconceptions of the terminology used in describing chemical bonding. This finding is in line with research in other countries (Taber et al., 2012). Hence, students' misconception in applying the wrong terminology to describe chemical bonding has to be taken into consideration as they were unable to imagine and explain how sodium chloride is formed.

Other than that, students had misconception in identifying the type of particles during the formation of chemical bonding. During the semi-structured interview, S1, S3, S4, S5, S6 and S7 had difficulties in identifying the type of particles in chemical bonding. S1, S3 and S5 gave the wrong answer, S4 was unable to provide the answer and S6 initially could not answer, even after the researcher gave some clues. In addition, in the two-tier diagnostic instrument, S1, S2, S4, S5 and S6 chose, "molecules" as the answer for the type of particles for sodium oxide. This phenomenon proves that misconception of identifying the type of particles by analyzing the chemical compound in chemical bonding happens among Form Four students. Students had conceptually misunderstood on the type of particles, hence, this issue should be taken into consideration to rectify the misconception.

Other than that, students also had misconception in constructing the structure of chemical bonding. In the findings, S1, S3, S5 were unable to draw the structure of sodium chloride correctly. In their drawings, they were unable to draw cation and anion with the square bracket. When the researcher asked why the square bracket is needed in the drawing, all the seven participants were unable to give the correct answer.

Besides constructing the sodium chloride structure, the researcher requested the students to draw another structure which was hydrogen chloride. Students had hard time drawing this structure. S1, S3, S5 and S6 only managed to draw the individual atoms of hydrogen and chlorine, S2 drew hydrogen chloride as ionic bonding structure and S4 gave the wrong structure. S7's answer was partially correct but S7 did not allocate the shared pair of electron in the overlapping region.

The last structure the researcher requested the students to construct was Tetrachloromethane, CCl_4. All of them managed to draw the shape but were unable to give a complete answer by allocating the shared pair of electrons in the overlapping region. In the semi-structured interview, the findings showed that the students were unable to select the correct structure of chemical bonding. Thus, both methods of data collection clearly show that students had misconception in drawing the structure, which is an important fundamental concept that students need to know before they further their studies in organic chemistry (Levy Nahum et al., 2010; Pabuccu & Geban, 2012; Perez et al., 2017; Vladusic et al., 2016).

During the interview, the researcher also found that students were having difficulties in applying the proton number of the elements and used the concept to explain the chemical bonding. If the researcher did not provide the proton number of the elements, they would not be able to draw and explain. However, even after the researcher provided them with the proton number, the students still gave the wrong structure of sodium chloride, hydrogen chloride and Tetrachloromethane. In their answers, they failed to explain the compound formed based on the stability of inert gases which made it difficult for them to relate with the sharing or transferring process that occurs in chemical bonding.

According to Johnstone's information processing model, when students have difficulty in analyzing the information, they are unable to visualize the formation of chemical bonding. Hence, this will lead to students being confused of the concepts or have misconceptions. Students would not be able to retrieve their fundamental concepts as the misconceptions are there (Johnstone, 1991). The finding shows that the mastery of basic concepts in learning chemical bonding is important. This is because any conceptual misunderstanding in the fundamental concepts may lead to students having difficulty in understanding chemical bonding.

The purpose of this research study and the gap was to explore the misconceptions of chemical bonding so that students can relate the macroscopic concepts with the sub-microscopic concepts. From the overall findings of the study, the gap shows that students are unable to explain correctly and in-depth how chemical bonding is formed, and what ionic and covalent bonding are. The main finding in this study which has not been identified by other researchers, was that students are unable to apply the proton number and valency of electron of an element on chemical bonding. Because of this, they are unable to continue with their explanation of chemical bonding. As mentioned earlier, this misconception has to be looked into seriously as these factual misconceptions and conceptual misunderstandings can lead to students having difficulties to further their studies in chemical bonding. Students will carry these misconceptions and more confusion might occur in other concepts related to chemical bonding. There are six concepts which the students had misconceptions of while learning chemical bonding:

1. Unable to differentiate ionic and covalent bonding
2. Wrong terminology used to describe ionic and covalent bonding
3. Unable to identify the type of particles in ionic and covalent bonding
4. Unable to construct correct structure for ionic and covalent bonding
5. Unable to apply proton number and valency of electron of an element
6. Unable to explain the stability of a compound based on the stability of inert gases

This finding was consistent with the results of past research conducted by other researchers in other countries. From this study, we can conclude that these students were having the same problem which was the inability to differentiate ionic and covalent bonding because they were unable to relate it to the phenomena they observed in their daily lives or relate it to their prior knowledge (Perez et al., 2017). In this study, students tried to relate the concept of chemical bonding to their daily experiences. For example, students tried to relate sodium chloride to salt used for cooking. When the students were unable to see the relation, they were confused. According to Johnstone, when students are unable to see the link as they try to filter new concepts, they are unable to correlate with the existing knowledge or fundamental concept. In this study, the researcher found a new misconception possessed by the students, that was, students had difficulty in applying the concept of the proton number and valency of electron of an element when explaining chemical bonding. This in turn, will affect their understanding of this concept. The rest of the findings was also in line with the study of Fouche (2015) where the students tried to relate their daily experiences with the learning of chemistry bonding. When the students saw the phenomena or daily experiences (macroscopic level) and they could not relate them to the existing concept they had learnt (sub-microscopic level), misconceptions happened which caused the students to interpret the chemical bonding questions wrongly.

Wrong terminology was used by the students which contributed to the students' difficulty in understanding the concept of chemical bonding. In this study, the findings showed that students used the word "molecular" to explain the formation of ionic bonding and the words "donate" and "accept" to explain the formation of covalent bonding. The finding was consistent with past research conducted overseas (Taber, 2011; Vladusic et al., 2016). The finding of this study is comparative to what others found, that misconceptions of chemical bonding exist among the students. The researcher also found that the students commonly used the word “molecular” to describe the ionic bonding of a compound. This finding was also comparable to previous research from other countries (Taber, Tsaparlis and Nakiboglu, 2012) where the students had similar misconceptions in the concept of ionic bonding. Furthermore, Vladusic et al. (2016) conducted a related study which obtained a similar outcome as Taber and the team. Therefore, it is crucial for the stakeholders to look into the matter seriously so that the issue of conceptual misunderstanding of chemical bonding among Form Four students can be resolved.

The third misconceptions in this study was the students were unable to identify the types of particles in the compound formed by ionic and covalent bonding. From the findings, the students had difficulty in relating the sub-microscopic level concepts such as atoms, ions and molecules to the concept of ionic and covalent bonding. This phenomenon affected their understanding of the concept of chemical bonding. This result was in line with past research where students showed difficulty in learning particles (Adbo & Taber, 2009; Cokelez et al., 2014; Griffiths & Preston, 1992; Papageorgiou et al., 2016; Unal et al., 2010). However, the past research did not study the concept of chemical bonding.

The fourth misconception in this study showed that the students were unable to construct the correct structure of the compound formed by ionic and covalent bonding. In the semi-structured interview, the students could only explain that the compound was molecule or the compound was ion, they are unable to explain further. When the students said that the compound formed was molecules, it showed that students possessed wrong concepts of ionic bonding. This showed that the students had misconception in analyzing the structure of the compound formed by chemical bonding. Apart from that, the students were unable to show the exact location a shared pair of the electrons should be placed in the compound formed by covalent bonding (Ouellette & Rawn, 2018). All the structural drawings of chemical boding are important because this is a basic concept required by the students in order for them to pursue organic chemistry as they further their studies (Pabuccu & Geban, 2012; Perez et al., 2017). The finding only focused on how the misconceptions on chemical bonding among Form Four students.

Another misconception possessed by students was they were unable to relate the physical properties (macroscopic level concept) of the chemical compound to the concept of chemical bonding. In the two-tier diagnostic instrument, the students were unable to relate the compound given to the physical properties of the melting point of the compound. Findings from previous studies showed students having difficulty in explaining the concepts of covalent bonding and ionic bonding (Cokelez et al., 2014; Luxford & Bretz, 2014; Prodjosantoso et al., 2019; Rompayom et al., 2011; Unal et al., 2010).

Lastly, another misconception identified in this study was that students were unable to apply the concept of the proton number and valency of electrons of an element to the concept of chemical bonding. The concept of the proton number and valency of electrons is a fundamental concept in learning chemistry. Students need to master this concept for their further study of chemical bonding. However, from the findings, the students were found to have failed to apply the concept of valency of electrons even though the proton number of the elements was given to them when the researcher found that they were unable to give the proton number of the elements. The study discovered, when students failed to apply the concept of the proton number and the valency of electrons, this would lead to another misconception that is, students failed to explain the stability of the chemical compound formed based on the concept of inert gases (the octet rules).

According to Johnstone's model, when the students are unable to filter the newly learn concept (chemical bonding) with their existing concept (proton number and valency of electrons), this would affect their understanding of the newly learnt concept. In this study, the inability of the students to merge the newly learnt concept of chemistry bonding to their prior knowledge of applying the proton number and valency of electrons in the questions given, means the students failed to master the concepts of chemical bonding. Due to the misconceptions of the fundamental concepts, the students to had difficulty in analyzing the question on chemical bonding and failed to master the concept of chemical bonding. Thus, students possess factual misconception.

By referring to Johnstone's information processing model, when the concept of chemical bonding (new concept) passes through the perception filter, this concept will transfer to the students' working space. The working space of the human brain has limited capacity. The students' working memory will decide and control all the understanding of the concepts. When the chemical bonding concept is transferred to the students' working space, their brain will retrieve the fundamental concepts they had learnt before, such as the concept of atoms, ions and molecules, the concept of proton number and the valency of electrons in the elements, from their brain to merge with the newly learnt concept which is the concept of ionic and covalent bond. After merging the two concepts, the students' brain will interpret both concepts, think about them and relate them.

When the newly learnt concept of chemical bonding cannot merge with the fundamental concepts mentioned early, the students will be confused about the concept of chemical bonding. From the findings, the results show that the students were having factual misconceptions on fundamental concepts such as the inability to identify the types of particles and to retrieve the number of electrons of an element. Therefore, when the students tried to answer the questions, they failed to analyse the questions and gave the wrong answers (Johnstone, 1997). If the retrieval of a fundamental concept, such as atoms, molecules or ions and the concepts of proton number and the valency of electrons of an element, comes from a wrongly inculcated concept in the students' long term memory, the students will develop conceptual misunderstanding on the concept because they cannot find the link between the macroscopic level and the sub-microscopic level (Elliott & Pillman, 2016; Read, 2006).

Research on misconceptions of chemical bonding have been conducted in other countries. The students, without fully understanding the concept of chemical bonding, would just memorize the answers for the purpose of answering examination questions. This shows the students were having problems in mastering the concept of chemical bonding (Levy Nahum et al., 2013; Levy Nahum et al., 2010).

In conclusion, the results have shown that the students were not able to apply the concept of the proton number and the valency of electrons of an element to the concept of chemical bonding when the students answered questions even though the researcher provided them with the proton number of the elements. This caused them to have problems in analyzing the valency of the electrons of an element. In addition, the researcher also found that the students were unable to explain the stability of a compound based on the stability of inert gases. This was because when the students failed to identify the valency of electrons, they were caused unable to identify how many valence electrons the element was supposed to have to achieve stability. When students failed to relate the valency of the electrons of an element, they would face problems in differentiating between ionic and covalent bonding.

5.4 Implications of the study

The findings of this research provide some implications to stakeholders, policy makers and the Chemistry teachers. The results showed that considerations have to be taken when teachers conduct chemistry lessons on the concept of chemical bonding and how students handle the concepts when learning chemical bonding. The Curriculum Development Centre has to look into the matter and have proper plans to revise the curriculum.

5.4.1 Implications to the teachers when conducting chemical bonding lessons

From the research findings, the outcome shows that the students in schools have misconceptions of the concept of chemical bonding. The results are similar to the findings of other research in other countries (Barke et al., 2009; Ganasen & Karpudewan, 2017; Levy Nahum et al., 2013; Melrafina et al., 2019; Jazilah Othman, 2008; Ozmen, 2004; Perez et al., 2017; Tsaparlis et al., 2018). These findings show that students have conceptual misconceptions in the basic concepts which affect their understanding of chemical bonding. Therefore, the Chemistry teacher should look into the students' fundamental concepts, such as the learning of matter, atom, ions and molecules, as well as the concept of proton number and the valency of electrons of an element. The teachers should spend some time to help students recall their fundamental concepts before moving on to more in-depth concepts of chemical bonding, especially in areas related to the misconceptions found in this study. The students' misconceptions related to chemical bonding were presented in Table 4.3 earlier.

During a lesson, the teacher may not have enough time to revise all the basic concepts of chemistry. Hence, the list provided in Table 4.3 gives teachers an idea on what to look into when teaching the concept of chemical bonding. This will help the teachers save time for the revision of fundamental concepts. As the learning of chemistry is a continuous process, the chemical concepts learnt by students will get progressively more difficult. Therefore, it is important for the teachers to identify the misconceptions possessed by the students.

Apart from that, the research findings give an idea to Chemistry teachers on the scope of misconceptions of chemistry concepts possessed by students when they are learning chemical bonding. The teachers may modify their teaching strategies during Chemistry lessons so that it is easier for students to digest the content. The current teaching strategies used by teachers may not be suitable for students in learning chemical bonding, therefore, changing the teaching strategies may help reduce the students' misconceptions of chemical bonding.

5.4.2 Implication to the students when learning chemical bonding

Throughout the study, the researcher realized that the students should approach the teachers for help when they do not understand the concepts of chemistry. Apart from that, the students should put in more effort in learning Chemistry. More revision is needed for a better retention of the concepts and to enable the students to recall and master the basic concepts. Based on the findings of this study, the students should be aware of the concepts that they may encounter possible difficulties with. Hence, more effort should be put into those topics especially on basic concepts such as the proton number and the valency of electrons of an element. In addition, the research findings also guide the students on how the misconceptions happens, and which area of study that may be confusing so that, students may rectify the problems directly. For instance, the findings show that students have problems in recalling the concepts of the proton number and applying the valency of electrons of an element. Therefore, students may try to solve the misconceptions by approaching teachers or peers. If the misconceptions can be rectified, students will not carry the misconceptions which may lead to further misconceptions in learning chemical bonding related concepts and this ultimately will help them have a smoother learning process.

5.4.3 Implication to the policymakers

In this study, the researcher has discussed students' misconceptions of the concept of chemical bonding and abstracted the concepts that student have partially understood. This research gives impact to the policymakers to be aware of the students' misconceptions of fundamental concepts in learning chemistry such as chemical bonding.

The Curriculum Development Centre plays an important role in helping to reduce the misconceptions of chemical bonding. When the Curriculum Development Centre plans Chemistry syllabus in the future, they should be aware of the research findings. A more simplified format should be given to students to help them understanding the highly abstract concept in Chemistry.

Apart from the Curriculum Development Centre, the policymakers could collaborate with the private sectors to help reduce the misconceptions in learning chemistry such as in the concept of chemical bonding or other fundamental concepts. An intensive program could be conducted to help students in their learning of chemistry. Teachers maybe can apply various teaching strategies to invoke the cognitive conflict that happened. This is because the students must be able to relate the triangular model proposed by Johnstone which is to link the macroscopic, sub-microscopic and the symbolic levels, so that students are able to bridge the gap in learning chemistry.

5.5 Suggestions for future research

The main purpose of this study was to explore the misconceptions of the concept of chemical bonding among Form Four students. The findings showed that the misconceptions happened in six main aspects. Hence, here are some suggestions for the future studies related to this concept.

a. This study only focused on one school. The study would be more encompassing if the same exploration can be conducted to larger populations of students with similar background.

b. A larger sample of quantitative measures could be applied to explore the misconceptions in a larger population. This would establish the validity of the findings.

c. Due to the limitation of this study, the researcher only conducted the exploration on the misconceptions of chemical bonding. The researcher would recommend follow up studies on the suitable methods to rectify the misconceptions of chemical bonding.

d. Apart from the misconceptions of chemical bonding, the researcher would recommend future studies on other fundamental concepts in chemistry such as the concept of electrochemistry as the learning of electrochemistry is also an important fundamental concept in chemistry.

e. The methods used to solve the problems of the students' inability to recall the proton number and to apply the concept of valency of electrons would be recommended for future studies.

5.6 Conclusion

In this last chapter, the researcher has made known the findings that six misconceptions of chemical bonding among Form Four students were discovered. The type of misconception possess by Form four students are conceptual misunderstanding and factual misconception. Firstly, the students were unable to differentiate ionic and covalent bonding while explaining and answering the relevant questions. Secondly, the students used wrong terminology to describe the compound formed by ionic and covalent bonding. Third, the students were unable to identify the types of particles in the compound formed by ionic and covalent bonding. Fourth, the students had difficulty in constructing the correct structure for the compound of ionic and covalent bonding and the students had a difficult time explaining the structure drawn. Fifth, the students were unable to relate the physical properties of chemical compound in relevance to chemical bonding. Sixth, the students were unable to apply the concept of the proton number and the valency of electrons of an element to chemical bonding. Lastly, implications of the study and suggestions of the study on the rectification of the misconceptions of fundamental concepts that need to be considered were presented.

BIBLIOGRAPHY

Adbo, K., & Taber, K. S. (2009). Learners' Mental Models of the Particle Nature of Matter: A study of 16 - year - old Swedish science students. *Internation Journal of Science Education, 31*(6), 757-786.

Al-Balushi., S. M., Abdullah, K. A., Ali, H. A.-S., & Taylor, N. (2012). Omani Twelfth grade students' most common misconceptions in chemistry. *Science Education International, 23*(3), 221-240.

Allen, M. (2010). *Misconceptions in primary science*. Berkshire: Open University Press.

Alpaydin, S. (2017). Determining the level of understanding and misconceptions of science teacher candidates about the concepts related to material and its properties. *Journal of Education and Practice, 8*(30), 25-31.

Ausubel, D. P. (1968). *Educational Psychology: A cognitive view*. New York: Holt, Rinehart and Winston.

Barke, H. S., Hazari, A., & Yitbarek, S. (2009). *Misconceptions in chemistry: Addressing perceptions in chemical educationMental models on ionic bonding*. doi:10.1007/978-3-540-70989-3

Bayrak, B. K. (2013). Using two-tier test to identify primary students' conceptual understanding and alternative conceptions in acid base. *Mevlana International Journal of Education (MIJE), 3*(2), 19-26.

Bogdan, R. C., & Biklen, S. K. (2007). *Qualitative research for education: An introduction to theory and methods*. Boston: MA: Allyn & Bacon.

Cambridge dictionary English Dictionary (2020). Retrieved from https://dictionary.cambridge.org/dictionary/english/misconception

Cardellini, L. (2012). Chemistry: Why the subject is difficult? *Educacion Quimica, 23*, 305-310. doi:10.1016/S0187-893X(17)30158-1

Cetingul, P., & Geban, O. (2005). Understanding of acid-base concept by using concceptual change approach. *Hacettepe University Journal of Education, 29*, 69-74.

Chakraborty, A., & Mondal, B. C. (2012). Misconceptions in chemistry at Ixth grade and their remedial measures. *Indian Streams Research Journal, 2*(7), 1-9.

Chi, M. T. H. (2013). Two kinds and four sub-types of misconceived knowledge, ways to change it, and the learning outcomes. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (2nd ed., pp. 49-70). New York: Routledge Press.

Chin, C. T. (2000). Relationships between student scientific epistemological beliefs and perceptions of constructivist learning environments. *Educational Research, 42*(2), 193-205.

Chu, C. K., & Hong, K. Y. (2010). *Misconceptions in the teaching of chemistry in secondary schools in Singpore and Malaysia*. Paper presented at the Proceedings of the Sunway Academic Conference, Sunway College Johor Bahru.

Cokelez, A., Dal, B., & Harman, G. (2014). Turkish middle school students' conceptions and modelling of chemical bonds. *Journal of Baltic Science Education, 13*(4), 483- 496.

Committee on Undergraduate Science Education. (1997). *Science teaching reconsidered: A handbook* Washington DC, United States of America: National Academy Press.

Cowan, N. (2010). The magical mystery four: How is working memory capacity Limited, and why? *Current Direction Psychological Science, 19*(1), 51-57. doi:10.1177/0963721409359277

Creswell, J. W. (2012). *Educational research planning, conducting and evaluating quantitative and qualitative research*. United State of America: Pearson.

Creswell, J. W., & Clark, V. L. P. (2017). *Designing and conducting mixed method research* (3rd ed.). Thousand Oaks, California: Sage.

D'Mello, S., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction, 29*, 153-170. doi:10.1016/j.learninstruc.2012.05.003

Dworkin, S. L. (2012). Sample size policy for qualitative studies using In-depth Interviews. *Archives of Sexual Behaviour, 41*(6), 1319-1320.

Eggen, P., & Kauchak, D. (2004). *Educational Psychology: Windows on Classrooms*. Upper Saddle River: Pearson Prentice Hall.

Eggen, P., & Kauchak, D. (2010a). *Educational psychology windows on classroom* (8 ed.). United State of America: Pearson Education.

Eggen, P., & Kauchak, D. (2010b). *Educational Psychology: Windows on classroom*. Upper Saddle River: Pearson Prentice Hall.

Elliott, K., & Pillman, A. (2016). Making science misconceptions work for us. *Teaching science, 62*.

Flick, U. (2009). *An introduction to qualitative research* (4 ed.). London: SAGA Publications.

Fouche, J. (2015). Predicting Student Misconceptions in Science. *Educational Leadership*.

Gabel, D. (1999). Improving teaching and learning through Chemistry education research: A lool to the future. *Journal of Chemical Education, 76*(4), 548-554.

Ganasen, S., & Shamuganathan, S. (2017). The effectiveness of Physics education technology (PhET) interactive simulations in enhancing matriculation students' understanding of chemical equilibrium and remediating their misconceptions. In *Overcoming students' misconception in Science* (pp. 157-180). Malaysia: Springer Nature Singapore.

Ganasen. S, & Karpudewan. M. (2017). *Overcoming students' misconceptions in science*. Malaysia: Springer Natura Singapore.

Gilbert, J. K., & Boulter, C. J. (2000). *Developing models in science education*. Dordrecht, the Netherlands: Kluwer Academic.

Gilbert, J. K., & Treagust, D. F. (2009). Introduction: Macro, submicro and symbolic representation and the relationship between them: Key models in chemical education. In J. K. Gilbert & Tre (Eds.), *Multiple representations in chemical education*. the Netherlands: Springer.

Gkitzia, V., Salta, K., & Tzougraki, C. (2019). Students' competence in translating between different types of chemical representations. *Chemistry Education: Research and Practice*(4), 1-37. doi:10.1039/C8RP00301G

Griffiths, A. K., & Preston, K. R. (1992). Grade‐12 students' misconceptions relating to fundamental characteristics of atoms and molecules. *Journal of Research in Science Teaching, 29*(6), 611-628.

Grigorovitch, A. (2008). Children's misconceptions and conceptual change in Physics education: the concept of light. *Journal of Ascances in Natural Sciences, 1*(1), 34-39.

Gurel, D. K., & Eryilmaz, A. (2015). A review and comparison of diagnostic instruments to identify students' misconceptions in science. *Eurasia Journal of Mathematics, Science & Technology Education, 11*(5), 989-1008.

Haidar, A. H. (1998). Prosepctive chemistry teacher's conceptions of the conservation of matter and related concepts. *Journal of Research in Science Teaching, 34*(2), 181-197.

Hashweh, M. (1988). Descriptive studies of students' conceptions in science. *Journal of Research in Science Teaching, 25*(2), 121-134.

Helmi, Rustaman, N. Y., Tapilouw, F. S., & Hidayat, T. (2019). *Misconception types analysis on mechanism of evolution*. Paper presented at the Journal of physics: Conference series.

Hilton, M. (2015). Preparing students for life and work. *Issues in Science and Technology, 31*(4).

Holme, T., Luxford, C., & Murphy, K. (2015). Updating the general chemistry anchoring concepts content map. *Journal of Chemical Education, 92*(6), 1115-1116.

Huseyin, A. (2017). The effect of microteaching on Pre-service Chemistry teacher's teaching experiences. *Cukurova University Faculty of Education Journal, 46*(1), 202-230.

Johnson, B., & Christensen, L. (2004). *Educational Research Quantitative, Qualitative and Mixed Approaches* (Second ed.). New York: Pearson.

Johnstone, A. H. (1982). Macro- and micro-chemsitry. *School Science Review, 64*, 377-379.

Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning, 7*(2), 75-83.

Johnstone, A. H. (1997). Chemistry teaching - science or alchemy? *Journal of Chemical Education, 74*(3), 262-268.

Johnstone, A. H. (2000). Chemical education: Where from here? *University Chemistry Education, 4*(1), 34-38.

Kamariah, S., & Daniel, E. G. S. (2017). Understanding of Macroscopic, Microscopic and Symbolic representation among form four students in solving stiochiometric problems. *Malaysin Online Journal of Educational Science, 5*(3), 83-96.

Kilic, D., & Saglam, N. (2009). *Development of a two-tier diagnostic test concerning genetics concepts: The study of validity and reliability*. Paper presented at the World Conference on Educational Science 2009, Turkey.

Korur, F. (2015). Exploring seventh-grade students' and pre-service science teachers' misconceptions in astronomical concepts. *Journal of Mathematics, Science and Technology Education, 11*(5), 1041-1060.

Kuczmann, I. (2017). The structure of knowledge and students' misconceptions in physics. In *AIP Conference Proceedings 1916*.

Kumphaa, P., Suwannoib, P., & Treagust, D. (2014). Thai Grade 10 students conceptual understanding of chemical bonding *Procedia - Social and Behavioral Sciences, 143*, 657 - 662. doi:doi: 10.1016/j.sbspro.2014.07.458

Lee, C. N. (2004). *Kursus lengkap sarjana STPM Physical Chemistry*. Selangor: Pustaka Sarjana Sdn. Bhd.

Lee, T. T., & Osman, K. (2017). Misconceptions in Electrochemistry: How do pedagogical agents help? In *Overcoming Students' Misconceptions in Science: Strategies and Perspectives from Malaysia* (pp. 91-110): Springer.

Levy Nahum, T., Mamlok-Naaman, R., & Hofsein, A. (2013). Teaching and learning of the chemical bonding concept: Problems and some pedagogical issues and recommendations. In G. Tsaparlis & H. Sevian (Eds.), *Concepts of matter in science education* (pp. 373-390). Dordrecht, the Netherlands: Springer.

Levy Nahum, T. L., Mamlok-Naaman, R., Avi Hofstein, A., & Taber, K. S. (2010). Teaching and learning the concept of chemical bonding. *Studies in Science Education, 46*(2), 179-207.

Lin, H. S., Chiu, H. L., & Chou, C. Y. (2002). Students' difficulties in learning electrochemsitry. *Procedia National Science Council, 12*(3), 100-105.

Low, S. N., Lim, Y. C., Eng, N. H., Lim, E. W., & Umi Kalthom. (2005). *Integrated Curriculum for Secondary Schools - Chemistry Form 4*. Kuala Lumpur: Abadi Ilmu Sdn. Bhd.

Luxford, C. J., & Bretz, S. L. (2014). Development of bonding representations inventory to identify student misconceptions about covalent and ionic bonding representations. *Journal of Chemistry Education, 91*(3), 312-320.

McCloskey, M., Caramazza, A., & Green, B. (1980). Curvilinear motion in the absence of external forces: naive beliefs about the motion of objects. *Science education, 210*(4474), 1139-1141.

McNaught, A. D., & Wilkinson, A. (1999). *IUPAC. Compendium of chemical terminology*. In S. J. Chalk (Ed.), (2nd edition ed.). doi:https://doi.org/10.1351/goldbook.

Mehmet Bahar. (2003). Misconceptions in Biology Education and Conceptual Change Strategies. *Educational Science: Theory and Practice, 3*(1), 55-64.

Melrafina, M., Wiji, W., & Mulyani, S. (2019). *Misconceptions and threshold concepts in chemical bonding*. Paper presented at the International Conference on Mathematics and Science Education.

Milenkovic, D. D., Hrin, T. N., Segedinac, M. D., & Horvat, S. (2016). Identification of Misconceptions through Multiple Choice Tasks at Municipal Chemistry Competition Test. *Journal of Subject Didactics, 1*(1), 3-12.

Ministry of Education. (2002). *Integrated Curriculum for secondary school: Curriculum specification Science Form 1*. Kuala Lumpur, Malaysia: Ministry of Education Malaysia

Ministry of Education. (2005). *Integrated curriculum for secondary school: Curriculum specifications Chemistry Form 4*. Putrajaya, Malaysia: Ministry of Education Malaysia Retrieved from http://www.stsimon.edu.my/mn/wp-content/uploads/2015/05/hsp_chemistry_f4.pdf

Ministry of Education. (2012). *Pelan pembangunan pendidikan negara Malaysia 2013-2015: Malaysia education development plan.* Kuala Lumpur, Malaysia

Nakiboglu, C. (2003). Instructional misconceptions of Turkish prospective chemistry teachers about atomic orbitals and hydridizationn. *Chemistry Education: Research and Practice, 4*(2), 171-188.

Nicoll, G. (2001). A report of undergraduates' bonding misconceptions. *International Journal of Science Education, 23*(7), 707-730.

Norris, R. (2015). *Essential chemistry for cambridge IGCSE* (2nd edition ed.). United Kingdom: Oxford University Press.

Novick, S., & Nussbaum, J. (1981). Pupils' understanding of the particulate nature of matter: A cross - age study. *Science education, 65*(2), 187-196.

Ohlsson, S. (2011). *Deep learning: how the mind overrides experience*. Cambridge, England: Cambridge University Press.

Othman, J. (2008). An investigation into the relationship between students' misconceptions of the particulate nature of matter and their understanding of chemical bonding. *Intternatinal Journal of Science Education, 30*(11), 1531-1550.

Othman, J., Treagust, D., & Chandrasegaran, L. (2008). An investigation into the Relationship between students' conceptions of the particulate nature of matter and their understanding of chemical bonding. *International Journal of Science Education, 30*(11), 1531-1550.

Ouellette, R. J., & Rawn, J. D. (2018). *Organic chemistry structure, mechanism, synthesis* (2nd edition ed.). United Kingdom: Academic Press.

Ozmen, H. (2004). Some student misconceptions in Chemistry: A literature Review of Chemical Bonding. *Journal of Science Education and Technology, 13*(2), 147-159.

Ozmen, H. (2008). The influence of computer-assisted instruction onstudents' conceptual understanding of chemical bondingand attitude toward chemistry: A case for Turkey. *Computer and Education, 51*(1), 423-438.

Pabuccu, A., & Geban, O. (2012). Students' conceptual level of understanding on chemical bonding. *Internation Journal of Science Education, 4*(3), 563-580.

Papageorgiou, G., Markos, A., & Zarkadis, N. (2016). Understanding the atom and relevant misconceptions: Students' profiles in relation to three cognitive variables. *Science Educational Internationa;, 27*(4), 464-488.

Pardhan, H., & Bano, Y. (2001). Science teachers' alternate conceptions about direct-currents. *International Journal of Science Education, 23*(3), 301-318.

"Particle". (2018). Cambridge University Press

Patton, M. Q. (2002). *Qualitative Evaluation and Research Methods* (3rd ed.). London: SAGE.

Perez, B., Perez, M. E. B., Calatayud, Garcia-Lopera, R., Montesinoes, J. V. S., & Gil, E. T. (2017). Student's misconceptions on chemical bonding: A comparative study between high school and first year university students. *Asian Journal of Education and e-Learning, 5*(1), 1-15.

Perez, D. G., & Alis, J. C. (1990). What to do about science "misconceptions". *Science education, 74*(5), 531 - 540.

Peterson, R. F., Treagust, D. F., & Garnett, P. (1986). Development and application of a diagnostic instrument to evaluate grade -11 and -12 students' concepts of covalent bonding and structure following a course of instruction. *Journal of Research in Science Teaching, 26*(4), 301-314.

Philip, B., Rose, R., & Pikington, A. (2017). Mixed method - theory and practice, sequantial, explanatory approach *International Journal of Quantitative and Qualitative Research Methods, 5*(2), 10-27.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accomodation of a scientific conception: Toward a theory of conceptual change. *Science education, 66*(2), 211-227.

Prodjosantoso, K., Hertina, M., & Irwanto. (2019). The misconception diagnosis on ionic and covalent bond concepts with three tier diagnostic test. *International Journal of Instruction, 12*(1), 1477-1488.

Raja, V., & Kumar, P. (2018). *21st century learning skills*. Paper presented at the Conference Monograph

Read, J. R. (2006). *Children's misconceptions and conceptual change in science education*. School of Chemistry. The University of Sydney.

Reid, N. (2019). *A tribute to Professor Alex H. Johnstone.* Paper presented at the Chemistry Teacher International.

Rompayom, P., Tambunchong, C., Wongyounoi, S., & Dechsri, P. (2011). Using open ended question to diagnose student's understanding of inter-and intramolecular forces. *US-China Education Review B, 1*, 12-23.

Satriana, T., Sri Yamtinah Ashadi, & Nurma Yunita Indriyanti. (2018). *Student's profile of misconception in chemical equilibrium*. Paper presented at the Journal of Physics Conference Series

Sen, S., Varoglu, L., & Yilmaz, A. (2019). Cognitive structures and misconceptions with thematic framework: The case of chemical bonding. *Journal of Education and Future*(16), 65-78.

Smith, M. (2010). Current status of research in teaching and learning evolution: II. Pedagogical issues. *Science & Education, 19*, 539-571.

Subari, K. (2017). Improving understanding and reducing Matriculation students' misconception in Immunity using the flipped classroom approach. In *Overcoming students' misconception in Science* (pp. 265-282). Malaysia: Springer Nature Singapore.

Svinicki, M. (1994). What they don't know can hurt them: The role of prior knowledge in learning. . *The Professional & Organisational Development Network in Higher Education, 5*(4).

Taber, K. S. (2000). Chemistry lessons for universities? A review of constructivist ideas. *University Chemistry Education, 4*, 63-72.

Taber, K. S. (2001). Building the structural concepts of chemistry: Some considerations from educational research. *Chemistry Education: Research and Practice in Europe, 2*(2), 123-158. doi:10.1039/B1RP90014E

Taber, K. S. (2002a). *Chemical misconceptions - Prevention, diagnosis and cure : Volume I: Theoretical background*. London: Royal Society of Chemistry.

Taber, K. S. (2002b). *Chemical misconceptions - Prevention, diagnosis and cure : Volume II: Classroom resources*. London: Royal Society of Chemistry.

Taber, K. S. (2011). Models, molecules and misconceptions: A commentary on secondary school students misconceptions of covalent bonding. *Journal of Turkish Science Education, 8*(1), 3-18.

Taber, K. S., Tsaparlis, G., & Nakiboglu, C. (2012). Student conceptions of ionic bonding: Patterns of thinking across three European contexts. *International Journal of Science Education, 34*(18), 2843-2873.

Talanquer, V. (2011). Macro, Submicro, and Symbolic: The many faces of the chemistry "triplet". *International Journal of Science Education, 33*(2), 179-195.

TalanquerM, V. (2006). Commonsense chemistry: A model for understanding students' alternative conceptions. *Journal of Chemical Education, 83*(5), 811-816. doi:10.1021/ed083p811

Tan, D. K. C., & Treagust, D. F. (1999). Evaluating students' understanding of chemcial bonding. *School Science Review, 81*(294), 75-84.

Tan, H. H., & Karpudewan, M. (2017). Green chemistry-based dual-situated learning model: An approach that reduces students' misconceptions on acids and bases. In A. L. Chandrasegaran (Ed.), *Overcoming students' misconception in Science* (pp. 133-155). Malaysia: Springer Nature Singapore.

Tan, Y. T., Loh, W. L., & Tan, O. T. (2015). Success Chemistry. Selangor, Malaysia: Oxford Fajar Sdn. Bhd.

Thomas, D. T. S. (2013). Prior Knowledge in chemistry instruction: Some insights from students' learning of ACIDS / BASES. *International Journal of Psycho-Educational Sciences, 2*(1), 34-53.

Thompson, F., & Logue, S. (2006). An exploration of common student misconceptions in science. *International Education Journal, 7*(4), 553-559.

Tong, Y. C., Wan Faizatul Shima, Yoong, K. S., Ragavan, R., & Roslina. (2005). *Intergrated Curriculum For Secondary Schools - Physics Form 4*. Selangor: Danalis Distributiors Sdn. Bhd.

Treagust, D., Chittleborough, G., & Mamiala, T. (2003). The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education, 25*(11), 1353-1368.

Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal of Science Education, 10*(2), 159-169.

Tsaparlis, G., Pappa, E. T., & Byers, B. (2018). Teaching and learning chemical bonding: Research-based evidence for misconception and conceptual difficulties experienced by students in upper secondary schools and the effect of an enriched text. *Chemistry Education: Research and Practice, 19*(4), 1253-1269. doi:10.1039/C8RP00035B

Tumay, H. (2016). Reconsidering learning difficulties and misconceptions in chemistry: Emergence in chemistry and its implications for chemical education. *Chemistry Education: Research and Practice, 17*(2), 229-245.

Tuysuz, C. (2009). Developing of two-tier diagnostic instrument and assess students' understanding in chemistry. *Scientific Research and Essay, 4*(6), 626-631.

Uce, M., & Ceyhan, I. (2019). Misconception in Chemistry education and practices to eliminate them: Literature analaysis. *Journal of education and training studies, 7*(3), 202-208. doi:10.11114/jets.v7i3.3990

Unal, S., Costu, B., & Ayas, A. (2010). Secondary school students' misconceptions of covalent bonding. *Turkish Science Education, 7*(2), 3-29.

Verkade, H., Mulhern, T. D., Lodge, J. M., Elliott, K., Cropper, S., Rubinstein, B., . . . Livett, M. (2017). *Misconceptions as a trigger for enhancing student learning in higher education: A handbook for educators*(pp. 3-10).

"Vernacular" (2018). Cambridge University Press.

Vladusic, R., Bucat, R. B., & Ozic, M. (2016). Understanding ionic bonding-a scan across the Croatian education system. *Chemistry Education: Research and Practice, 17*(4), 685-699.

Vosniadou, S. (2007). The cognitive-situative divide and the problem of conceptual change. *Educational Psychologist, 42*(1), 55-66.

Yasri, P. (2014). A systematic classification of student misconceptions in biological evolution. *International Journal of Biology Education, 3*(2), 31-41.