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PRE-SERVICE SCIENCE TEACHER'S MISCONCEPTIONS OF THE CHEMICAL BONDS

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ABSTRACT

Science teachers in Malaysia could enter the profession via a science education degree programme, or by taking a diploma in education after completing a separate degree in pure science. Misconceptions of key concepts such as chemical bonds are a highlighted issue among pre-service science teachers. The objectives of this study were to: (i) identify the scientific and non-scientific conceptions of chemical bonds held by pre-service science teachers, (ii) identify factors that influence pre-service science teachers' conceptions, and (iii) offer strategies to overcome pre-service science teachers' misconceptions about chemical bonds. A mixed-method research methodology (qualitative and quantitative) i.e., paper-and-pencil test, and open-ended interview was adopted. Thirty respondents consisting of pre-service teachers in Science Education (majoring in Chemistry) from a Faculty of Education in a public university in Malaysia were non-randomly selected based on the purposive sampling technique. Our findings showed a high level of misconceptions that also did not alter significantly through the respondents' four years of training. The correct scientific conceptions about key concepts such as chemical bonds should be comprehensively strengthened among pre-service science teachers before they graduate to ensure that they can deliver the best quality chemistry knowledge to their future students.

1. Introduction

Science is often regarded as one of the more difficult subjects due to the need of understanding numerous concepts (Sirhan, 2007). Teaching science in school should involve a variety of ideas to present scientific concepts. It needs to be simple and understandable for the learners (Nahum, Hofstein, Mamlok & Ziva, 2004). Teachers should have a good understanding of basic scientific concepts in order to deliver a meaningful instruction. Two significant goals in teaching are to assist students' comprehension of he main concepts in a topic instead of memorizing facts (Dunlosky, Rawson, Marsh, Nathan & Willingham, 2013) and to identify any mistakes or misconceptions in learning concepts among the students (Özmen, 2004).

Learning science is a cumulative process, whereby every new information would be incorporated into the prior knowledge regarding the topics (Darling-Hammond, Flook, Cook-Harvey, Barron, & Osher, 2020). This additional new information could possibly contribute to the wrong scientific and non-scientific conceptions, fine-tuned and influenced by the previous knowledge. Griffiths and Preston (1992) stated that the new personal experiences, the media and interactions with people could be sourced from the teachers during discussions or activities in the teaching. Taber and Watts (2000) added that knowledge is personally built by the learners and they would interpret the information in order to make sense of the world. Thus, the learners could possibly construct scientific and non-scientific conceptions about certain topics based on their own interpretations. This self-constructed knowledge or information would then influence the learners' existing knowledge and social context (Gray, Wilcox & Nordstokke, 2017).

Chemistry is one of the significant subsets of science which is considered to be a strenuous and challenging subject for students (Özmen, 2004). Chemical bonds, which indicate the strength of attractions within molecules, is a central topic in the chemistry subject. Chemists are expected to understand the properties of matter and the types of bonds that hold the atoms together (Urbanger & Kometz, 2014). The topic of chemical bonds is also one of the most important topics taught in chemistry for upper secondary school students and is essential for other topics in chemistry (Tsaparlis, Pappa, & Byers, 2020). In order to have a good understanding of chemical bonds, pre-service science teachers need to know about the various models of chemical bonds (Coll, 2008).

The chemical bond models involved in this study are the intra-molecular bonds i.e., (i) ionic, and (ii) covalent bonds. These bonds are the main types of chemical bonds that are being taught in upper secondary school (Coll, 2008). A chemical bond could be defined as the "forces that hold the atoms of element together in a compound" (Sproul, 2001)and as an attractive force between atoms that is strong enough to permit the combined aggregate to function as a unit (Constable & Housecroft, 2020). The forces between particles that arise from the electrostatic force attractions between different charges are labelled as chemical bonds. Due to its difficulty, most of the pre-service science teachers and students have a variety of scientific and non-scientific conceptions regarding this topic (Kenneth, 2020). This situation could lead to the topic becoming burdensome for some teachers (De Jong & Taber, 2007).

The key aspect of learning is conceptual understanding (Khiyarusoleh, Ardiyansyah, & Wilujeng, 2018). Learning would be focused on the 'conceptual change' (Özdemir & Clark, 2007). The pre-service science teachers were introduced to the fundamentals of chemical bonds during their time in high school. Some of them might later struggle to self-construct the interpretation of detailed concepts in chemical bonds, resulting in a wrong understanding that can hinder the accurate conceptualization of scientific concepts (Canpolat, Pınarbaşı, Bayrakçeken & Geban, 2006). These incorrect ideas are known as alternative conceptions, misconceptions, non-scientific conceptions, and pre-conceptions (Goris & Dyrenfurth, 2010). However, the most accepted description is 'alternative ideas' (Mintzes & Wandersee, 2005). This is because the term better describes the experience–based explanations created by learners and also refers to the intellectual respect for the learners who hold those ideas (Burr, Haas, Ferriere & West, 2015).

Major sources of non-scientific conceptions can occur due to the teachers' methodologies and the ways of knowledge presentation in the textbooks. All of the alternative ideas that cause non-scientific conceptions are constructed based on their experiences, expectations, beliefs and emotions (Awan & Khan, 2013). Teachers with a good understanding of chemistry concepts are needed to create an education system that would benefit the students (Childs, Hayes & O'dwyer, 2015). Therefore, having chemistry teachers with a solid understanding of the key concepts of chemistry can prevent the formation of non-scientific conceptions among students (Boo, 2000). It is also important to identify the scientific and non-scientific conceptions in order to deliver the precise conceptual information to the students (Özdemir & Clark, 2007). To address this problem, pre-service science teachers should be trained to have a clear understanding of basic chemistry concepts before they start their teaching career (Sheehan, Childs & Hayes, 2011a).

In this research, we have chosen to focus on the topic of the pre-service science teachers' understanding of chemical bonds. Ideally, they should have a good understanding of this topic since it underpins many other advanced concepts in chemistry (Bergqvist, 2017). This research aims to investigate the factors that influence the pre-service science teachers' non-scientific conceptions and offer the strategies to overcome this issue.

Several studies have pointed out that undergraduate or future-teachers who were having difficulties in understanding the topic of chemical bonds would later face significant challenges when learning advanced chemistry concepts (Barker, 2000; Pabuçcu & Geban, 2012). One study found that the common non-scientific conception among pre-service science teachers was about the equal sharing of the electron pair that occurs in all covalent bonds (Coll & Taylor, 2001). Teachers were unable to define the covalent bonds accurately and were unsure about ionic, covalent, and hydrogen bonds. In another study, most of the pre-service science teachers in a university were also unsure about chemistry topics and numerous science concepts such as chemical bonds (Suat, Coştu, & Alipaşa, 2010). An earlier study by Hein, (1991) found only a small number of teachers who realized that they had been teaching several incorrect concepts to their students. Some teachers were also experiencing difficulties with creating suitable analogies to deliver concepts due to inaccurate comprehension, which could lead to non-scientific conceptions among students (Inel-Ekici & Ekici, 2021). Hence, the aims of this study are to: (i) identify the scientific and non-scientific conceptions of chemical bonds that are held by pre-service science teachers, (ii) identify factors that influence the pre-service science teachers' conceptions, and (iii) offer strategies to overcome pre-service science teachers' misconceptions about chemical bonds.

2. Methodology

The research is divided into sub-sections as follows:

2.1 Participants

The study was conducted among 30 respondents consisting of pre-service teachers in Science Education (majoring in Chemistry) from the Faculty of Education in a public university in Malaysia. The respondents were selected non-randomly using the purposive sampling technique.

2.2 Research Instruments

For the investigation and data collection, a mixed-method of both qualitative and quantitative research methodology was used to extensively document the real situation in the context of pre-service science teachers' knowledge and understanding of chemical bonds, and to quantify data and generalize results from the sample of population, respectively (Figure 1). Two instruments were utilized in this current work to collect the necessary information which were: (i) paper-and-pencil test on the concepts of chemical bonds, and (ii) focus group interviews. The instruments were constructed and validated based on the literature (Kemmis & Wilkinson, 1998). The adopted test questions were adapted from the literature (Chudowsky & Pellegrino, 2003; Verger, Parcerisa & Fontdevila, 2019) and consisted of 18 items (5 objective and 13 subjective questions) to examine the pre-service science teachers' understanding of the fundamental concepts of chemical bonds. The duration of the test was limited to 30 minutes. Interview sessions with open-ended questions were then carried out after the paper-and-pencil test to investigate the respondents' individual thoughts regarding scientific and non-scientific concepts, and strategies to overcome non-scientific concepts about chemical bonds among pre-service science teachers.

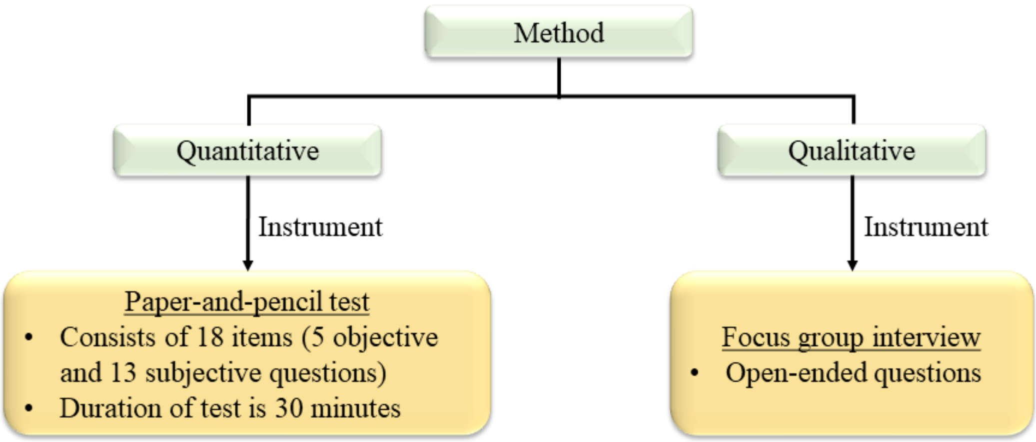


Figure 1. Summary of The Research Methodology Used

2.3 Data Analysis

The data were collected and analyzed using quantitative and qualitative analyses. The collected data from the paper-and-pencil test was analyzed using descriptive statistics. Then, the respondents who got low marks in the paper-and-pencil test were selected to be interviewed with open-ended questions. The demographic background was in section A i.e., gender. The data are presented in the form of a pie chart. For section B, the number and percentage of pre-service science teachers who responded to each question were calculated and analyzed in the chart. All responses were tabulated and categorized into their specific themes based on the number of respondents with the specific responses. The data obtained are then further discussed in the next section. Categories of diagnostic test responses were assigned based on the level of understanding of respondents. An analysis scheme was adopted from Unal et. al (2002) which consisted of 5 categories as shown in Table 1:

Table 1
Criteria of Classification Concept

Conception	***Description***
Sound understanding	Responses that include all correct and logical answers of all components.
Partial understanding	Responses that include at least one correct and logical answer without any misconception occurring.
Partial understanding with specific misunderstanding	Responses that show partial understanding and contain misconceptions.
Specific misconception, no understanding	Responses that include incorrect or illogical answers.
No understanding	Responses include irrelevant ideas and no answers.

3. Results

3.1 Pre-service Science Teachers' Understanding of the Non-scientific Concept of Chemical Bonds

This study was carried out to identify the scientific and non-scientific conceptions of chemical bonds among the pre-service science teachers. Based on the diagnostic test, most of pre-service science teachers only have a partial understanding of the chemical bond topic. It showed that pre-service science teachers had specific misconceptions about a few fundamental concepts i.e., (i) definition (items 6, 8 & 9), (ii) bonding (items 1 & 2), (iii) lattice (items 3 & 4), (iv) formation of chemical bonds (items 11, 13 & 17), and (v) types of chemical bonds (item 18).

3.2 Definition (items 6, 8 & 9)

Based on the paper-and-pencil test results, it was found that 13 of the pre-service science teachers were unable to define several scientific terms correctly. Examples of misconceptions in the definition of chemical bonds among the pre-service science teachers are shown below:

Answers from respondents	***Respondents***
Attractions between atoms that allow the formation of chemical substance that contain two or more atoms.	1
The force that hold atoms together within molecules.	2
Any rearrangement of electron in two atoms that generate force, causing the atom to bond.	5
The bonding that allow elements together to form new properties.	8
Chemical bond is the relationship with two or more atom with a chemical mean in order to form a compound.	9
(no answer).	10
Elements are sharing or transfer electron to form ionic and covalent bond.	11
Bond that used to tie or to fasten molecules together so that atom in the molecule achieves stable octet/duplet electron arrangement.	13
Chemical bond is a formation of bond when two or more atom bond together.	14
Chemical bond is a bond that hold the atom.	17
Form a achieve stable electron either sharing or transfer electron.	21
Sharing or transfer electron to achieve stable octet electron arrangement.	26
Bonding between two or more element to become stable.	27

These non-scientific ideas showed that the pre-service science teachers have difficulties in writing the accurate definition of chemical bonds. Pre-service science teachers who have a low confidence level in defining the actual understanding of the physical meaning of the terms, will encounter problems in describing the correct concept (Lloyd, Braund, Crebbin & Phipps, 2000). It appears that pre-service science teachers were experiencing confusion to differentiate between the term '*bond*' and '*bonding*' that should be used in explaining the definition of chemical bonds. This finding is supported by Boo (2000) who carried out interview sessions with trainee teachers and found that most of them have a lack of knowledge pertaining to the differences between the term '*bond*' and '*bonding*' (Boo, 2000). In the present study, 15 of the respondents were also unable to define both ionic and covalent compounds correctly in items 8 and 9. Examples of the non-scientific conceptions are shown below:

Answers from respondents	***Respondents***
Ionic compound: compound formed through the formation of ionic bond. *Covalent compound: compound form through covalent bonding*	1
Ionic compound: compound that contain only ionic bond. *Covalent compound: compound that contain only covalent bonds*	2
Ionic compound: No answer *Covalent compound: No answer*	4
Ionic compound: compound that contain both metallic and non-metallic compounds. *Covalent compound: compound that contain both non-metallic compounds*	6
Ionic compound: compound that form between metal atom and non-metal atom (transfer electron). *Covalent compound: Compound that form between metal and non-metal.*	7
Ionic compound: metal and non-metal. *Covalent compound: non-metal and non-metal*	8
Ionic compound: set of metal and non-metal that combine chemically by electrostatic force. *Covalent compound: sharing electron of non-metal with non-metal*	9
Ionic compound: transfer electron to form metal to non-metal. *Covalent compound: sharing electron of non-metal with non-metal.*	10
Ionic compound: element transfer electron to form stable molecule. *Covalent compound: element sharing electron to form stable molecule.*	11
Ionic compound: compound that contains metal atom and non-metal and contains ionic bond. *Covalent compound: compound that contain non-metal atom and metal and contain covalent bond.*	14
Ionic compound: combination of positive ion and negative ion. *Covalent compound: compound that are hot soluble in water but soluble in organic solvent.*	16
Ionic compound: combination of 2 ionic bond. *Covalent compound: combination of 2 covalent bond.*	18
Ionic compound: compound which consists of 2 ions chemically, bonded by ionic bond and by donating or receiving electron. *Covalent compound: compound that consist of two atoms that chemically bonded together by covalent bond and by share electron*	28
Ionic compound: chemical compound in which ions are held together in a structure by electrostatic force terms ionic bonds. *Covalent compound is a chemical bond that involves the sharing of electron pairs between atoms.*	29

Ionic compound: chemical compound which ion are attach together to form ionic bond. *Covalent compound: non-metal molecule that hold together to form a covalent compound.*	30

Unal, et al., (2002) suggested that a possible reason for this non-scientific conception is that students were unable to distinguish between ionic and covalent bonds with that of the ionic and covalent molecules due to a weak memorization skill (Ünal et al., 2002).

3.3 Bonding (items 1 and 2)

The pre-service science teachers had various misconceptions regarding the chemical bonding in the atom. One example of the misconceptions which has been indoctrinated among the pre-service science teachers included that sodium chloride (NaCl) exists as a molecule when the sodium atom donates its valence electron to the chlorine atom (item 1). The main factor that causes the respondents to accept the molecular framework is the way ionic bonding is presented (Vladušić, Bucat & Ožić, 2016). The 15 respondents demonstrated the topic of ionic bonding by drawing the transfer of an electron from the sodium atom to the chlorine atom, which then eventually forms positive and negative ions. They also believed that a pair of ions would be attracted by a strong electrostatic force. The drawn figure of a discrete unit of sodium chloride could lead to their future students deducing an incorrect understanding towards ionic bonding, in which they thought that both atoms formed the molecules of the ionic compound (Taber, Tsaparlis & Nakiboğlu, 2012). Moreover, 5 of the pre-service science teachers also showed non-scientific conceptions in item 2 due to a non-thorough understanding of the octet rule in ionic bonding as shown in the examples below:

Answers from respondents	***Respondents***
By sharing and transferring electron.	6
Transferring and sharing electron.	7
By the electrostatic arrangement.	10
Transferring or sharing electron. transfer: Van Der Walls forces Sharing electron: electrostatic force.	11
Based on electrostatic attraction.	14
Held by strong electrostatic force.	15
It is either to share electro or to donate electron and also to accept electron.	17
By strong electrostatic force.	22
By donating or sharing of electrons.	23
Ionic bond: strong electrostatic forces. Covalent bond: weak intermolecular forces.	20
Through the electrostatic force and Van Der wall s forces.	24
By strong electrostatic force.	26
By sharing electron or donating or receiving electron.	28
By one of these two methods which are electron transfer ad electron sharing.	29
By sharing and donate electron to achieve stability.	30

Nevertheless, 9 of the respondents managed to accurately explain that both the metal and the non-metal ions had stable octets of electrons, though they showed a lack of knowledge in the ratio of the metal and non-metal ions (Taber et al., 2012).

3.4 Lattice (items 3 & 4)

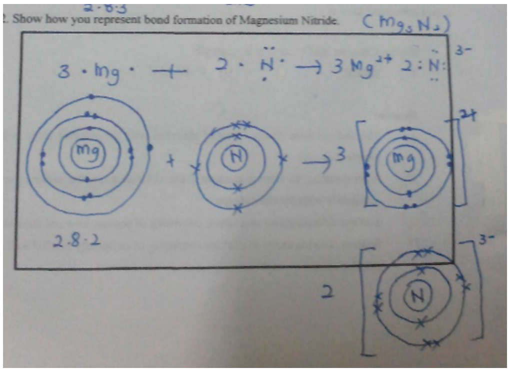
The third part of the paper-and-pencil test was related to the lattice, in which the pre-service science teachers showed various misconceptions related to lattices. It appears that 15 of the respondents were puzzled regarding the nature of the continuous covalent and molecular lattice. A similar finding was reported by Coll and Treagust (2003), who found that their respondents described the continuous covalent lattices and ionic lattices as having molecular properties. In our study, the respondents believed that the term 'simple' is equivalent to 'uncomplicated', which is an example of a non-scientific conception (Coll & Treagust, 2003). Vladušić, et al., (2016) explained that many educators tend to believe that macromolecules are big molecules, while simple molecular lattices are made up of only 2-4 atoms (Vladušić et al., 2016). Meanwhile, giant covalent lattice consists of a three-dimensional lattice of covalently bonded atoms. These atoms could be all of the same types, such as silicon atoms (silicon dioxide) and carbons (diamond and graphite) (Collins & Avouris, 2000). The non-scientific conception was indoctrinated due to the overgeneralization based on past university lessons regarding silicon, graphite and diamond that led the respondents to think that all covalently bonded atoms would form macromolecules.

3.5 Formation of Chemical Bonds (item 11)

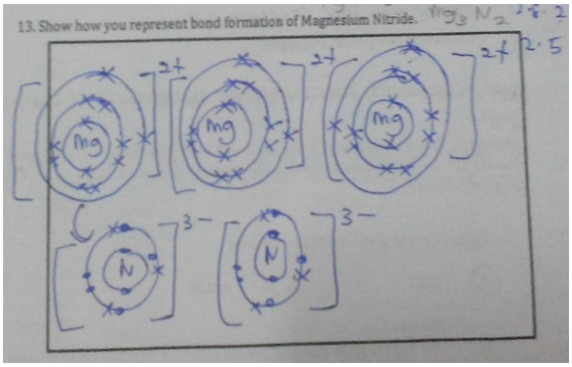
Fifteen pre-service science teachers had various non-scientific conceptions of how ionic and covalent bonds are formed. The most common non-scientific conceptions included "*by the electrostatic arrangement*" and "*by sharing and transferring electron.*" in their explanations for item 11. It is hypothesized that the pre-service science teachers were indoctrinated with the non-scientific conceptions that the ionic bond is formed by "*transferring using Van Der Walls forces or covalent bond is sharing electron using electrostatic force*". These misconceptions probably arose due to a partial understanding about the types or properties of atoms that would form covalent and ionic bonds. Another study reported a similar finding, in which students thought covalent bonding was formed through electron transfer due to the unclear explanation from the teachers (Suat et al., 2010). The non-scientific conceptions were inculcated among the pre-service science teachers due to a poor understanding pertaining to the sub-microscopic level. According to Peterson et al. (1989), students could predict correctly the characteristics of atom formation in covalent bonding and how a chemical bond was formed between atoms only if they are able to visualize the atoms (Peterson, Treagust & Garnett, 1989).

3.6 Types of Chemical Bonds (items 13, 17 & 18)

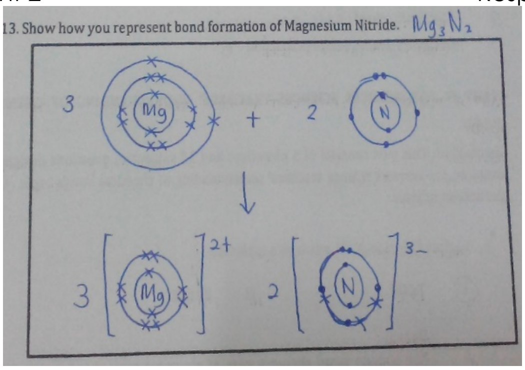
Item 13 was designed to investigate pre-service science teachers' understanding about the formation of magnesium nitride (Mg_3N_2). They should be able to deduce the chemical formula for the formation of Mg_3N_2 and the correct type of chemical bond present. An accurate answer given by 3 of the pre-service science teachers was classified as "*sound understanding*" which means they could respond correctly and logically by writing the chemical formula, determine that the Mg_3N_2 possesses ionic bonds, and draw the correct formation of Mg_3N_2. The "*sound understanding*" answers are as follows:



Respondent 2

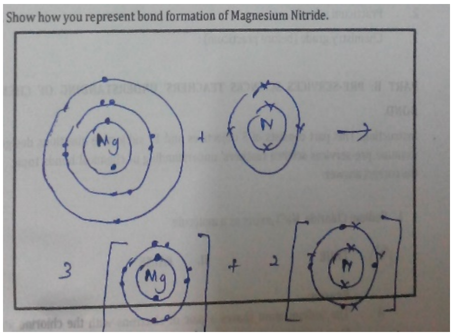


Respondent 19

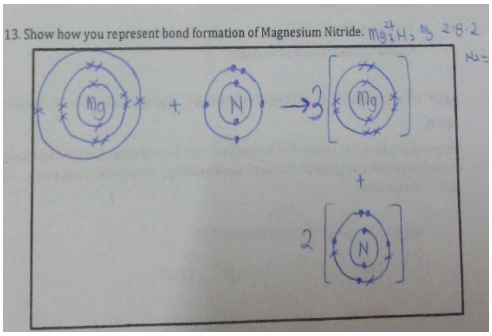


Respondent 23

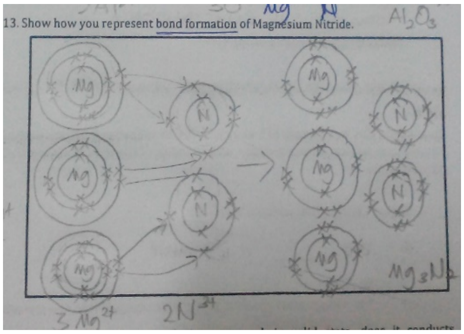
Meanwhile, a "*partial understanding*" response was classified as having correct but incomplete answers, where 3 of the respondents were able to write chemical formula and draw the formation of Mg_3N_2, though they missed some information in the drawing, such as the ionic charge in the formation of the product. Examples of answers for this category are as follows:



Respondent 1

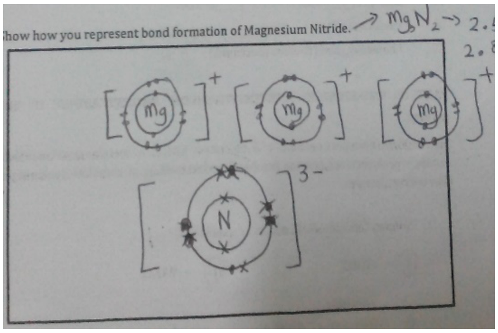


Respondent 15

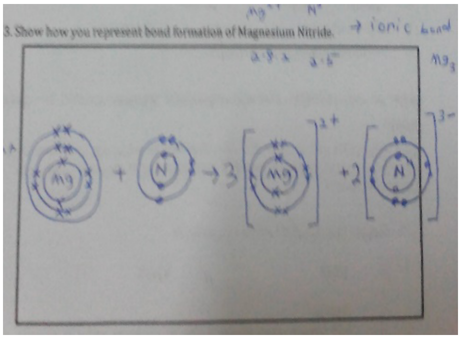


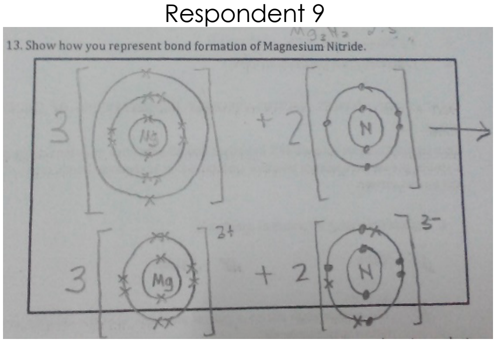
Respondent 17

Four responses classified as having "*partial understanding with specific misunderstanding*" were due to ability to determine the chemical formula, and to draw the formation of Mg_3N_2, though they provided some incorrect conception in the drawing including coefficient or ionic charge of each product formed. Examples of answers for this category are as follows:

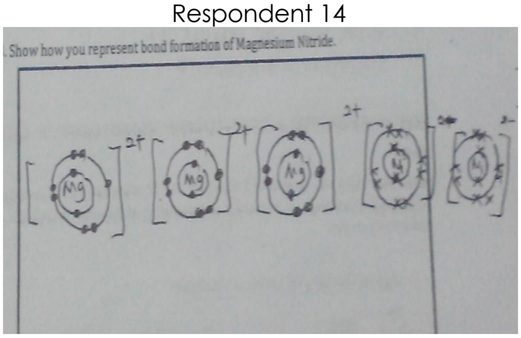


Respondent 9


Respondent 14

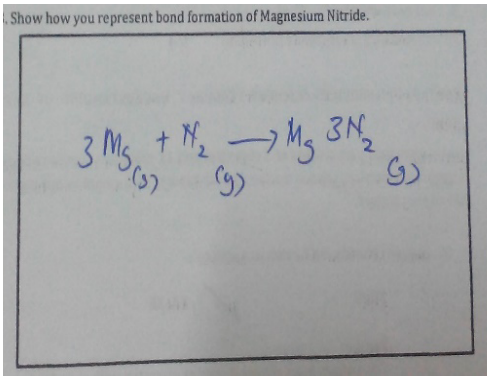


Respondent 24

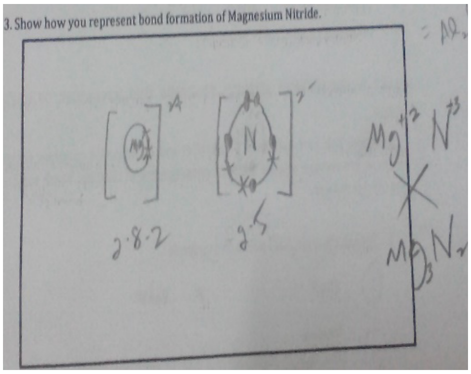


Respondent 4

Responses classified as having "*specific misconception, no understanding*" were due to poorly answered questions on the instrument and non-logical formation of Mg_3N_2. In this category, 2 of the respondents showed an incorrect chemical formula and drawing of Mg_3N_2. Examples of answers for this category are as follows:

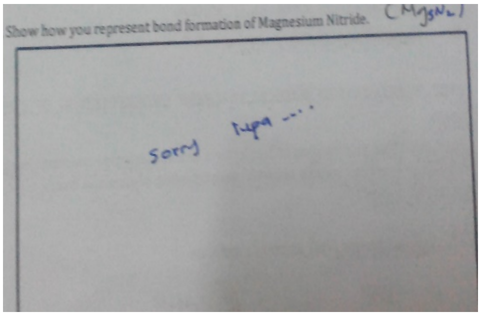


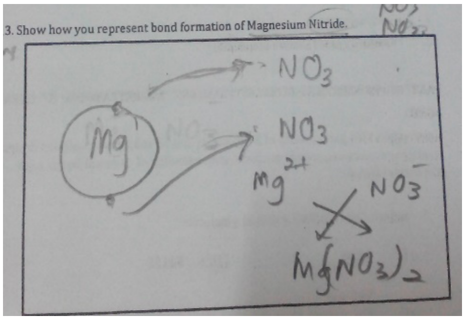
Respondent 5



Respondent 27

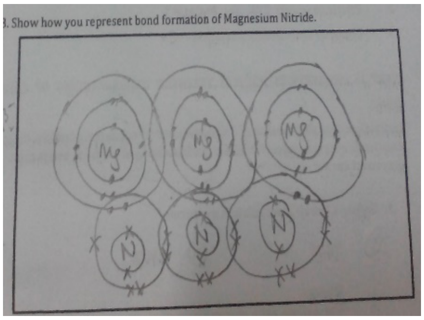
In responses classified as having "*no understanding*" the respondents were unable to draw Mg_3N_2 or the most poorly answered of all questions in the instrument. Three of the respondents were unable to state the correct chemical formula due to not knowing the type of bonds present in Mg_3N_2. Examples of answers for this category are as follows:





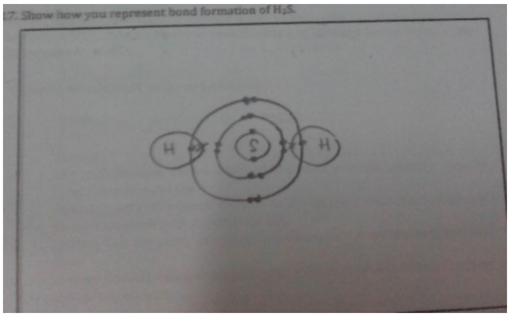
Respondent 6

Respondent 25

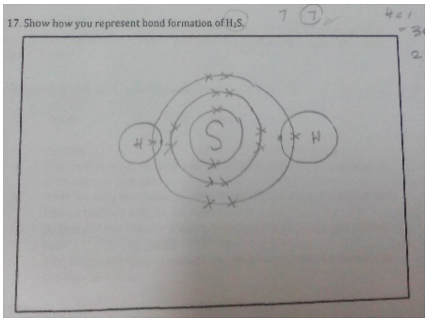


Respondent 28

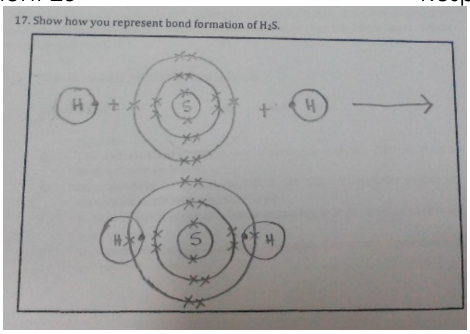
Item 17 investigates the pre-service science teachers' understanding of the formation of hydrogen sulphide (H_2S). They should be able to state the chemical formula for the formation of H_2S, and the correct type of chemical bond present. The responses could be classified as having a "*sound understanding*" if they gave accurate and logical answers by being able to write the chemical formula, determine H_2S as having covalent bonds, and draw the correct formation of H_2S. Examples of answers for this category are as follows:



Respondent 23

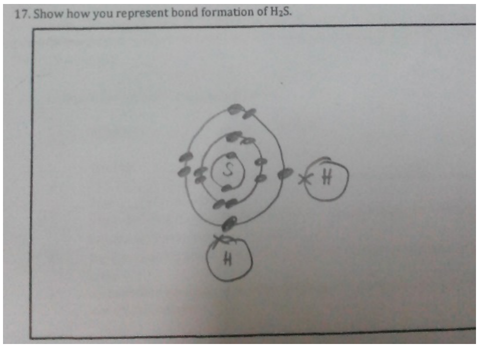


Respondent 21



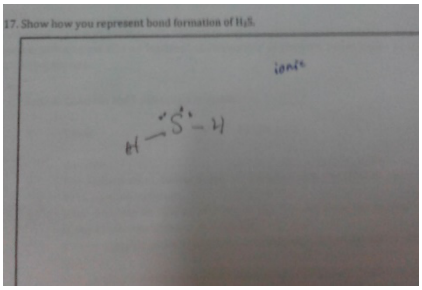
Respondent 24

Responses classified as having a "*partial understanding*" showed correct but incomplete answers. The respondents were able to draw the formation of H_2S correctly, however they missed some information in the drawing, such as an incomplete drawing of H_2S. An example response for this category is as follows:

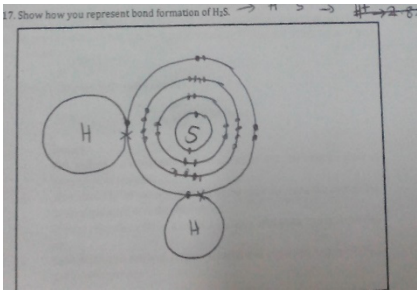


Respondent 18

Meanwhile, in responses classified as having a "*partial understanding with specific misunderstanding*", the respondents showed the ability to draw the H_2S, though they stated misconceptions due to the omission of important points, such as the correct electron configuration or they used the same symbol after the valence electron was shared. Examples of responses for this category are as follows:

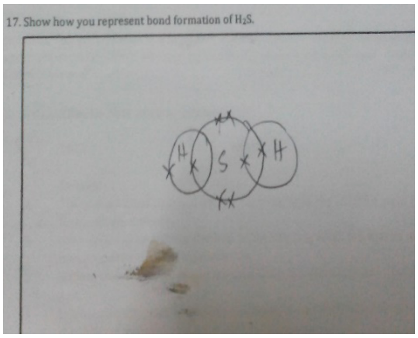


Respondent 6

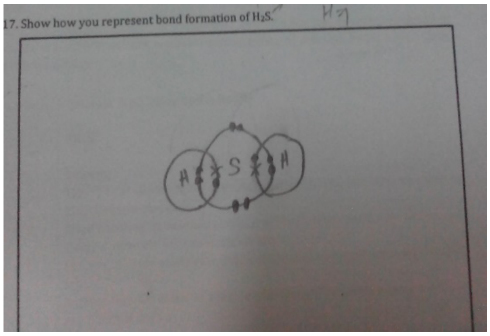


Respondent 9

Responses classified as having a "*specific misconception, no understanding*" showed the respondents were unable to provide the correct and logical formation of H_2S, such as giving the incorrect electron configuration for each atom or an incorrect drawing of H_2S. Examples of responses for this category are as follows:

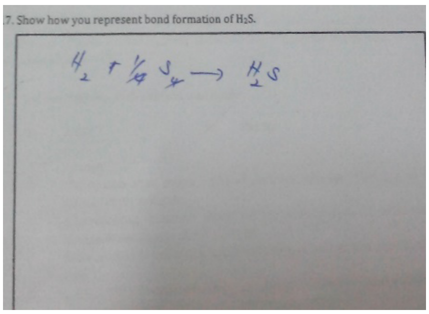


Respondent 19

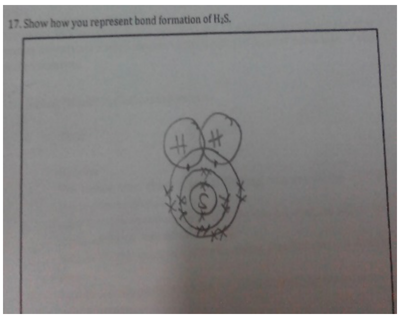


Respondent 27

Responses classified as "*no understanding*" showed the respondents' inability to draw H_2S or giving no answer at all. Some of the respondents were unable to state the correct chemical formula of H_2S due not being able to determine whether the formation of H_2S was based on the ionic or covalent bond. Examples of responses in this category are as follows:



Respondent 5



Respondent 27

Item 18 showed the pre-service science teachers' understanding about the classification of molecules according to whether they had ionic bonds or covalent bonds. It was found that half of the pre-service science teachers were unable to classify molecules according to the correct type of bonds, while others were unable to explain clearly about the concept of ionic and covalent bonds.

The respondents were classified as having a "*sound understanding*" if they were able to answer correctly or logically, and able to elaborate on why the molecule had ionic or covalent bonds. Examples of responses in this category are as follows:

Respondent 24	C_2H_2: Covalent Bond (Triple Bond) H-C ≡ C-H	Reason: electron arrangement (C=2.4, H=1) C atom will share 3 pair of the valence electron with another C atom and another 1 valence electron with H atom.
Respondent 15	C_2H_2: Covalent Bond	Reason: C= 2.4, H=1 Sharing between 2 C atom & 2 H atom. Form triple bond between C and C Form single bond between C and H.

The respondents were classified as having a "*partial understanding*" due to the ability to provide correct but incomplete answers. They were also able to elaborate about the formation of ionic or covalent bonds. Examples of responses in this category are as follows:

Respondent 17	C_2H_2: Covalent Bond	Reason: C has 4 valence electrons. It will share electron with H as H has 1 valence electron.
Respondent 25	C_2H_2: Covalent Bond	Reason: Non-metal + non-metal (carbon + hydrogen). Sharing electron.
Respondent 3	C_2H_2: Covalent Bond	Reason: Sharing electron between C and H atom

The respondents were classified as having a "*partial understanding with specific misunderstanding*" due to the ability to classify whether the element had ionic or covalent bonds, though with an incorrect reason. An inaccurate scientific term was also used in explaining the formation of ionic or covalent bonds. Examples of responses in this category are as follows:

Respondent 9	C_2H_2: Covalent Bond	Reason: Sharing pair of electrons between two C atoms and two H atoms. Double covalent bond
Respondent 11	C_2H_2: Covalent Bond	Reason: Non-metal and non-metal

		Sharing electron (two electrons). 2 valence electrons for C2 and H2 for each element
Respondent 13	C_2H_2: Covalent Bond	Reason: C has 4 valence electrons. H has 1 valence electron. 1 C share 4 valence electron with 4 H Single bond

The respondents were classified as having "*no understanding*" due to not being able to correctly classify the type of bond present in the molecules. No relevant explanation was elaborated to strengthen the answers. Examples of responses in this category are as follows:

Respondent 21	C_2H_2: ionic bond	Reason: Transferring
Respondent 19	C_2H_2: ionic bond	Reason: Transfer
Respondent 18	C_2H_2: ionic bond	Reason: C is metal and H is non-metal (transfer)
Respondent 7	C_2H_2: ionic bond	Reason: H transfer valence electron to C
Respondent 4	C_2H_2: ionic bond	Reason: Transferring

The respondents were classified as having a "*sound understanding*" due to closely correct response or logical answer provided. Nevertheless, they were able to explain the molecules were identified as having ionic or covalent bonds based on their prior knowledge. Examples of responses in this category are as follows:

Respondent 2	$MgCl_2$: Ionic Bond	Reason: Magnesium atom has 2 valence electrons. Magnesium atom donating one electron to one Cl atom and another one valence electron to another Cl atom.
Respondent 11	$MgCl_{2:}$ Ionic bond	Reason: Mg contains 2 valence electrons. 2Cl need 2 valence electrons from magnesium.
Respondent 13	$MgCl_{2;}$ Ionic bond	Reason: Mg has 2 valence electrons. Cl has 7 valence electrons. 1 Mg need to transfer 2 valence electrons with 2 Cl atom.

The respondents were classified as having a "*partial understanding*" due to only giving incomplete correct answers, but with the ability to distinguish the ionic or covalent bond. It was found out that they were able to list more than one reason regarding the ionic bond or covalent bond. Examples of responses in this category are as follows:

Respondent 27	$MgCl_2$: Ionic bond	Reason: Because they transferring electrons.
Respondent 25	$MgCl_2$: Ionic Bond	Reason: Metal + Non metal (Mg + Cl) Transferring electron.
Respondent 29	$MgCl_2$: Ionic Bond	Reason: Formed when metal react with non-metal.

The respondents were classified as having a "*partial understanding with specific misunderstanding"* due to being able to correctly classify the type of bond present in the $MgCl_2$, but using incorrect reasons to identify the ionic or covalent bond. The formation of chemical bonds was explained using incorrect scientific terms. Examples of responses in this category are as follows:

Respondent 20	$MgCl_2$: Ionic bond	Reason: Mg transfers 2 ions to Cl. Each Cl receive 1 ion Metal + non-metal
Respondent 30	$MgCl_2$: Ionic Bond	Reason: Mg ionic compound and Cl halogen

The respondents were classified as having "*no understanding*" due to the inability to correctly classify type of bond present in $MgCl_2$. Also, no relevant explanations were given. Examples of responses in this category are as follows:

Respondent 27	$MgCl_2$: covalent bond	Reason: Sharing electron
Respondent 19	$MgCl_2$: covalent bond	Reason: Sharing

Item 18(iii) investigated the pre-service science teachers' understanding of the type of chemical bond present in the N_2 molecule with a detailed explanation. Two respondents were found to have a "*sound understanding*" due to their ability to respond correct and logic in explaining whether the type of chemical bond in the molecule was ionic or a covalent bond. The stated answers are as follows:

Respondent 2	N_2: Covalent Bond :N ≡ N:	Reason: triple bond two atoms share three pairs of electrons as in nitrogen molecule
Respondent 9	N_2: Covalent Bond	Reason: sharing of electron between N atoms triple covalent bond

Respondents with a "*partial understanding*" were able to provide incomplete correct answers, classify N_2 with the correct type of bond, and list more than one explanation pertaining to the formation of the ionic or covalent bond. The responses for this category are as follows:

Respondent 3	N_2: Covalent Bond	Reason: Share three pairs of electrons

Respondent 8	N_2: Covalent Bond	Reason: Non-metal with non-metal N is non-metal Sharing electron

Respondents with a "*partial understanding with specific misunderstanding*" were able to classify N_2 into the correct type of bond, but with an incorrect reason. They pointed out the incorrect scientific terms in explaining the formation of the ionic or covalent bond. The responses are as follows:

Respondent 20	N_2: Covalent Bond	Reason: Weak Van Der Waals between N_2

Respondents with a "*specific misconception, no understanding*" were unable to provide the correct and logical definition of the type of bond present in N_2. In this study, they provided the right classification of covalent bond, though, non-scientific conceptions were given. The responses are as follows:

Respondent 11	N_2: Covalent Bond	Reason: N contain 1 valence electron Sharing electron

Respondents with "*no understanding*" were unable to classify whether N_2 had ionic or covalent bonds. No relevant explanation was included in the response. Examples of responses for this category are as follows:

Respondent 5	N_2: Covalent Bond	Reason: Not stated
Respondent 30	N_2: Covalent Bond	Reason: Not stated

Overall, it was found that the respondents showed misconceptions in drawing the formation of the ionic or covalent bonds in items 13 and 17. Thus, some of the pre-service science teachers demonstrated an inability to understand the concept of formation of chemical bonds. In contrast, drawing the diagram supposedly should be correctly performed by the respondents as educators. This is because the learning process would be highly effective by drawing the diagram based on a person's comprehension due to reduction of comprehension errors (Butcher, 2006). The visual learning would be the most effective way to support cognitive process. In this study, the respondents were asked to draw Mg_3N_2 for item 13 and H_2S for item 17. Therefore, prior knowledge on how to differentiate the type of bonds present in the molecule is needed**.** The respondents showed a weak understanding of the scientific concept of chemical bonds based on the responses for the C_2H_2 molecule in item 18(i):

"*…Sharing pair of electrons between two C atoms and two H atoms…*"

(Respondent 9)

"*…Double covalent bond…*"

(Respondent 11)

"*…C has 4 valence electron. H has 1 valence electron…*"

(Respondent 14)

"…1 C shares 4 valence electron with 4 H…"

(Respondent 21)

"…Single bond…"

(Respondent 27)

The C_2H_2 molecule contains triple bonds between two carbon atoms and all valence electrons are involved in the bonding, but some respondents were not sure of the type of covalent bond present and were ambiguous in their explanation on this matter. This indicates that they only have a partial understanding of the double and triple bonds (Treagust, 2012). The misconception of types of chemical bonds may occur due to a lack of knowledge about the concept of electronegativity and confusion of the terms "polar" and "nonpolar" among the respondents. Therefore, they were unable to relate between the terms and types of covalent bonds (Suat et al., 2010). Furthermore, they were unable to differentiate between ionic and covalent bonds in item 18(ii) based on the response:

"…$MgCl_2$ is a covalent bond and it involves sharing of electron…"

(Respondent 29)

This suggests that the respondents were unable to differentiate between ionic and covalent bonding. This was supported by Uce (2015) who reported that students were unable to differentiate between covalent and ionic bonds of a compound (Uce, 2015). The misconceptions found in the pre-service science teachers taking part in our study are likely to have persisted from their early study in secondary school if not possibly from their primary education (McCormack, 2009). Misconceptions are known to interfere with new learning (Sheehan, Childs, & Hayes, 2011b; Tarchi, Brante, Jokar, & Manzari, 2022). Therefore, the Malaysian education system is producing learners with high numbers of misconceptions and low conceptional understanding of chemical bonds in chemistry. Several possible factors of non-scientific conceptions that could induce the misconceptions about chemical bonds will be discussed in the next section.

3.7 Factors of Non-Scientific Conceptions of Chemical Bonds Among Pre-service Science Teachers

The first factor that influence the pre-service science teachers' conceptions is book and reference. The feedback obtained from respondents 9, 10, and 27 were as follows:

"…I always refer 2- or 3-times reference book per day to study chemistry. Most of the times, I will choose 2 to 3 books reference books. I believe that reference book has a lot of information compared to text book but the problems in reference book are I have difficulty in understanding certain scientific term and make me confuse about the concept. But I believe all the reference book or text book will explain right concept and give good yet simple example for me to refer during learn chemistry…"

(Respondent 9)

"…I prefer using textbook because textbook follow syllabus and give easy and simple example. For reference, I prefer local book compare to international book because easy to understand. But sometimes reference book are difficult to understand because too much long explanation. There are also contain difficult scientific term that I have never heard before. There has a reference book that I use before have different explanation with textbook and I am not sure which one should be followed…"

(Respondent 10)

"…I prefer reference book when learning chemistry. But reference book is quite complicated because of the language uses in English make me difficult to understand. A few scientific terms are difficult to understand because of the language uses. The explanation is too long and not direct. I can draw chemical bonding only if I have ever seen in the books but others than that, I can't…"

(Respondent 27)

The second factor that was obtained was the use of chemistry websites or internet. The feedbacks obtained from respondents 14, 21, and 27 are as follows:

"…Sometimes I refer to any chemistry website if I confuse the explanation from reference book and also find a various of chemical bonding example from internet because in internet contain more difficult example to be discuss…"

(Respondent 14)

"…I always refer note from internet. For me, it is more easy compare to books because I need to read one by one but when using internet, I can find simple note that summarize the whole topic…"

(Respondent 21)

"…sometimes I used internet to find simple mind map in any chemistry blog. I believe it is prepared by experience teacher so that I can use it in my learning process. I also can share it with my friends and students. Moreover, it is easy to understand because already summarize it one topic into one mind map…"

(Respondent 27)

The third factor that influence the pre-service science teachers' conceptions is teacher explanation. The feedbacks obtained from respondents 10, 14, 15, and 27 are as follows:

"…sometimes, I don't understand the explanation from the teachers because I do not know which point, she/he said is important. Moreover, my teacher only used chalk and talk method and I cannot visualize what she/he explained about the concept…"

(Respondent 10)

"…Chemistry is difficult because what had been come out in examination were not same what had been taught in class. Teacher explanation sometimes was different and too simple but in examination come out more difficult question. Teacher always used explanation inside the text book because they do not have more time to find others explanation yet the explanation from text book are simplest..."

(Respondent 14)

"…I believe explanation from my lecturer or my previous chemistry teacher is important but sometimes my lecturer and teacher tend to explain in a simple explanation but they don't explain more due to time consuming..."

(Respondent 15)

"...during my schooldays, sometimes I confuse what have been said by my teacher because explanation from my school teacher was different with my tuition teacher. They are both using

different ways in explaining the concept and I don't know which one should be follow. Teacher always used chalk and talk method so it's quiet boring in a class…"

(Respondent 27)

3.7.1 The Influence of Text Books

The analysis from the interview revealed that there were three main factors which contributed to the pre-service science teachers' non-scientific conceptions i.e., (i) text books or reference books, (ii) the internet, and (iii) educator's explanations. Most of the respondents agreed that their misconceptions were influenced by reference or text books. This was supported by Nooteboom (2006) and Segesten (2011) which stated that the source of misconceptions would be inculcated from the textbooks (Nooteboom, 2006; Segesten, 2011). This could be due to a poor "treatment of the topic" of ionic bonds, in which many textbooks only provided illustrations with a small number of atoms or molecules and with unclear explanations on the crystal lattice formation.

3.7.2 The Internet

The internet would contribute to misconceptions due to the accessibility of uploading information from the uncertified educators (Fausto et al., 2012). The use of the internet in education has become the first-choice option for students (Acar Sesen & Ince, 2010). Although surfing the internet would allow instant access to information, its reliability is questionable. Incorrect information could lead to the misconceptions related to the topic of chemical bonds or other science concepts.

3.7.3 Educator's Explanations

Educators would be the key source for pre-service science teachers to gain knowledge about chemical bonds. An incorrect concept or incomplete teaching explanation would lead to misconceptions (Chi, 2009). Students who gained prior knowledge about chemical bonds since secondary school, tend to resist modifying their pre-existing ideas in future. The new knowledge would be self-interpreted using their lack of pre-knowledge (Ionas, Cernusca, & Collier, 2012). Besides, the way educators teach their lessons about chemical bonds would contribute to an unclear understanding of scientific or non-scientific conceptions among students (Fatokun, 2016). Educators should be highly knowledgeable to promote a detailed discussion about abstract concepts in class and provide opportunities for students to ask questions and share their opinions. This practice would increase students' chances to promote their own ideas and remediate their existing misconceptions (Halim, Finkenstaedt-Quinn, Olsen, Gere, & Shultz, 2018).

3.8 Strategies to Overcome Non-Scientific Conceptions of Chemical Bonds Among Pre-Service Science Teachers

The first strategy to overcome non-scientific conceptions of chemical bonds among pre-service science teachers is make mind-map or own notes. The feedbacks obtained from respondents 9, 14, and 27 are as follows:

"…*In order to overcome my non-scientific conception, I think I should do my own map or note so that I can understand well. In order to do that, I think I have to read more than 4 books so that I can compare contain inside the books…"*

(Respondent 9)

"…if I have misunderstanding in chemical bonding, I always refer more books than usual. Then, I'll make my own note follow my own understanding. I also will refer science dictionary to find meaning for scientific term…"

(Respondent 14)

"…i will use simple word to make me understand the explanation from books. I will use more than 2 books because I believe to have better understanding, I should create my own words to understand the difficult concept. Then, I will make exercise or past year questions to test my understanding…"

(Respondent 27)

The second strategy to overcome non-scientific conceptions of chemical bonds among pre-service science teachers is using an interactive web-based program to learn chemistry. The feedbacks obtained from respondents 14, 21, and 27 as follows:

"…I think there are so many interactive chemistries online website that helps in learning chemistry. I rarely look into it but I know some of the interesting chemistry website such as ChemBalancer and ChemCollective that I have always used during my teaching practicum. It just not helps me to understand the lesson but also help my students …"

(Respondent 14)

"…I think using interactive chemistry website can help gain more understanding because it is more interesting and we can visualize it…"

(Respondent 27)

"…I have tried one interactive website for chemistry. Inside it contain explanation, games and experiment. I can try it and can see the colour changes in experiment. Its help me but I cannot use it every day because of time constrain…"

(Respondent 21)

Third strategy to overcome non-scientific conceptions of chemical bonds among pre-service science teachers is by using teaching aid or model. The feedbacks obtained from respondents 9, 10, 14, and 27 are as follows:

"…I think used model can also help me in understanding chemical bonding because people can see clearly by using model…"

(Respondent 9)

"… Teaching aid helps me to visualize more and I can identify which part that make me confuse by using the model…"

(Respondent 10)

"…Teaching aid can help to overcome misconception in this topic because chemical bonding involving electron sharing and transfer. So, it's good if we can see the electron transfer and sharing rather than imagine it…"

(Respondent 14)

"…other than that, by using teaching aid such as model of chemical bonding. I prefer teaching aid more than books because I can see more clearly…"

(Respondent 27)

3.8.1 Use of Mind Mapping and Exercises

The analysis from the interview revealed three key strategies to overcome pre-service science teachers' non-scientific conceptions i.e., (i) mind mapping and exercises, (ii) web-based learning, and (iii) using models. The use of mind-mapping could promote critical thinking skills and help to construct new ideas related to the topic of chemical bonds. Mind mapping could also be used to assess the students' understanding (Yunus & Chien, 2016). The practice and training of using mind mapping could assist the respondents to memorize the facts and relate the new knowledge with that of the previous knowledge of chemistry concepts (Liu, Zhao, Ma, & Bo, 2014).

3.8.2 Web-based Learning

Interactive web-based learning has already been implemented in chemistry, such as the *ChemCollective* and *ChemBalancer* online games to improve learners' understanding. These web-based learning tools provide explanations, exercises, games, formula and assessment. According to Frailich et al., (2009), web-based learning activities could integrate the visualization tools with the active cooperative learning style. Therefore, web-based learning could assist pre-service science teachers to construct their knowledge of chemical bonds and obtain a better understanding of this topic. In an earlier paper, Frailich et al. (2007) also stated that effective web-based learning could also enhance students' comprehension of the concept of chemical bonding. Meanwhile, Dori et al. (2013) also supported the use of computer-based learning to enhance students' understanding of chemistry and improve the understanding of the chemical concepts, theories and molecular structures among educators (Dori, Rodrigues, & Schanze, 2013).

3.8.3 Using Models

Hybrid models have already been used as curricular models in learning about chemical bonds (Bergqvist, Drechsler, De Jong, & Rundgren, 2013). Molecular models, simulations, and animations could contribute to the effective learning of chemistry for a better understanding of chemical bonds among the pre-service science teachers (Galvez, 2018; Listyarini, 2021).

4. Conclusion

In conclusion, the pre-service science teachers were shown to have non-scientific conceptions in five areas related to chemical bonds, i.e., definition of terms, bonding, lattice, formation of chemical bonds, and type of chemical bonds. The three key factors that contribute to the misconceptions are text books, the internet, and poor explanations from educators. Several learning and teaching strategies were suggested to overcome these non-scientific conceptions i.e., mind mapping, web-based learning, and the use of models. These strategies could remediate the misconceptions related to chemical bonds among pre-service science teachers. The implications in this research i.e., most of the pre-service science teachers still have a partial of misconceptions; understanding of the chemical bonding topic. If the issue is pro-longed, it would hinder the process of delivering the right concepts in a classroom. Recommendations suggested for future research are (i) a large research sample (more than 30 respondents) should be used to obtain a highly reliable finding, and (ii) Faculties of Education in all universiites in Malaysia should be included in the research.

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Conflict of Interest
There is no conflict of interest associated with this publication.

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