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Description of Senior High School Students' Understanding Categories about Chemical Bonds Using Two-Tier Multiple Choice Diagnostic Instrument

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Abstract - Chemical bonds are an abstract concept in chemistry which many students have difficulty understanding. Therefore, it will be great potential to form some student's understanding category which is different from textbooks and said by the teacher. The research purpose was to describe the student's understanding category about chemical bonds and to determine their misconceptions level. The research type was descriptive that used a diagnostic instrument (15 questions of two-tier multiple choices). The questionnaire was applied to 36 students from SMAN 1 Padang in West Sumatra. The results showed that some students had many misconceptions and some of them also do not understand the chemical bonds concept, especially on Lewis structure, how ionic bonds were formed, how covalent bonds were formed, and how to type a molecular shaped. So, many of them are still misunderstanding in the learning process. This research result can be used by teachers to aware of student's misunderstanding and to see the level of student's misconceptions in learning so that the teachers can solve any understanding problem of students in the chemical bonds concept.

Keywords - Diagnostic Instrument, Two-Tier Mutiple Choices, Chemical Bonds, Chemistry Learning.

I. INTRODUCTION

Chemistry is the study of the composition, composition, properties, and changes in matter and energy that accompany it (Jespersen, et al, 2012; Brady, 2009). Chemistry is an abstract and complex science subject that is difficult for students to understand (Cittleborough, 2004). One of the chemistry topics that high school students learn is chemical bonds. Chemical bonds is one of the basic concepts in chemistry which is very important to be studied and understood by students because this material is very closely related in studying other chemical materials such as chemical reactions, thermochemistry, molecular structure, chemical equilibrium, and some physical properties such as boiling points, etc. (Nahum, et al. 2010; Pabuçcu & Geban, 2012). This material is abstract because the concept is far from the daily experience of students' lives such as not being able to see atoms, the structure of atoms, and how these atoms can bond with other atoms. This makes it difficult for students to understand the concept of chemical bonds broadly from students, resulting in the formation of alternative concepts of students' understanding that varies from what is written in the textbooks or explained by the teacher (Tan & Treagust, 1999; Coll & Taylor, 2002). We know that during the learning process, students can build new knowledge from their ideas, abilities, and previous experiences. Sometimes students' ideas are not in accordance with scientific concepts so that it then gives rise to new misconceptions or alternative conceptual frameworks of students. All of these things can adversely affect learning and make it difficult for students to form new concepts that are consistent and acceptable to scientific ideas.

Basically, the ability of students to think abstractly is very limited. Though students are very dependent on learning that is based on understanding and way of thinking. This has caused some students to experience misconceptions in understanding chemical bonding material (Scepni & Cerrah, 2004; Herron, 1975; Shayer & Adey, 1993; Wu & Soloway, 2001). Misconception shows the differences in concepts that students have with scientific concepts that should be. The misconception is one of the major obstacles students have in promoting meaningful learning (Pabuçcu & Geban, 2006; Ardiansah, 2018). Students' misconceptions about the concept of chemical bonds can originate from inaccuracies in the language used by books in explaining concepts (De Posada, 1999) and can also originate from concepts explained by the teacher. Research on students' misconceptions related to chemical bonding material includes some students who have a low understanding of the topic of electrostatic properties in chemical bonds (Taber, et al, 2012), students cannot distinguish ionic bonds and covalent bonds (Coll & Treagust, 2003; Othman, et al, 2008), as well as students' misconceptions on the topic of molecular polarity and molecular geometry (Nicoll, 2001 and 2003; Uyulgan, et al, B2014). Some students experience misconceptions of covalent bonding material due to difficulties in describing Lewis's structure in accordance with octet rules (Erman, 2016). Apart from the misconception, some students did not understand the chemical bonding material. The diversity of understanding can be identified using diagnostic tests.

Diagnostic tests are tests conducted individually and are arranged to find out the weaknesses of students understanding concepts in the learning process (Hariyanto & Basuki, 2015). This diagnostic test can also diagnose students' understanding of concepts, in particular, the topic of chemical bonds. There are several types of diagnostic tests including diagnostic tests using two-tiered multiple-choice instruments. In the first level test is arranged to see the factual or conceptual knowledge of students, while the second level test is used to find out the reasons behind students' choice of answers to the first level test. The first level of questions on this test is a multiple choice question which usually has 2-3 answer choices. Whereas the second level question contains 4 possible choices of reasons for the answer to the first level question (Treagust, 1988; Treagust, 2006).

This type of two-tiered test has two advantages compared to conventional tests. First, this test can reduce the size of the error (more accurately). Second, a two-level test can find out two aspects of information from the same phenomenon, namely the answers from the first level test and the second level test which is generally an explanation of the choice of first level test answers (Tuysuz, 2009). The method used in preparing two-level tests in this study is a method of making standard questions that identify topics, formulate standard problems, and create two-level diagnostic test questions based on predetermined standard questions. This test is very useful for testing understanding because it can determine the reliability and efficiency of assessment of multiple-choice questions, and is able to diagnose students' understanding and reasoning at a higher level (Aydeniz, et al, 2017).

Identification of students' misconceptions is the first step to prevent misunderstandings in chemistry learning, especially the topic of chemical bonds. Identification of misconceptions experienced by students must be done continuously so that the core problems in learning can be solved by the teacher (Fahmi and Irhasyuarna, 2017). Therefore, this study aims to describe the categories of students' understanding of chemical bonding material using a two-tiered multiple-choice diagnostic instrument.

II. METHODS

This research type is descriptive. Descriptive is research that describes objects/circumstances as they are the center of attention without giving special treatment to these objects (Sukardi, 2014; Trianto, 2011). The population in this study were students of class XI of SMAN 1 Padang consisting of 9 classes. Sampling was done by cluster sampling, which is taking 1 class at XI Science 6 with a total of 36 students. The instrument used in the study was a questionnaire in the form of 15 two-story multiple-choice questions as a diagnostic test to determine the category of high school students' understanding of chemical bonding material. Each student's answer was analyzed for their level of understanding. This analysis can be seen based on the scoring of two-tier multiple-choice diagnostic tests as in Table 1.

Table 1. The Scoring of Two-Tier Multiple-Choice Diagnostic Tests

Students' Answer Responses	Score	Category
The first question and the reason are true	2	Understood
The first question is true and the reason is false	1	Misconception
The first question is false and the reason is true	1	Misconception
The first question and the reason are false	0	Not Understood

The four categories of responses from a number of students from each item were analyzed and the results of the analysis were made according to the following formula.

$$\% \bar{X} = \frac{n}{N} \text{ x } 100 \, \%$$

Information:

$\bar{X}$: The average value of a two-tier multiple-choice diagnostic test

N : Number of participants who are on the diagnostic test assessment indicators

N : The total number of participants

100 : Fixed figures (Zafri, 1999)

Data on the average value of the two-tier multiple-choice diagnostic tests can be interpreted into the percentage category of students' understanding of the concept of chemical bonds which can be seen as in Table 2 (Arikunto, 2010).

Table 2. The Criteria for Students' Understanding Levels

Criteria	Percentage (%)
Very High	81 – 100
High	61 – 80
Middle	41 – 60
Low	21 – 40
Very Low	0 – 20

III. Results and Discussion

Based on the two-tier multiple-choice diagnostic test data, we obtained some information categories of students' understanding of the concept of chemical bonds. In each diagnostic test item, students are asked to choose responses from a two-tier multiple-choice consisting of parts I (conception), and Tier II (reason). After choosing their choice for Tier I, students are asked to choose one of the 4 choices in section II for reasons in section I. Table 1 illustrates the combination of answers students can choose in a diagnostic test. In category 1, students choose both correct answers to their conceptions and reasons. This shows that students understand the concept correctly in chemical bonds. In category 2, students choose the right answer at Level I but the wrong choice for Level II. This shows that students as a whole experience a misconception in a concept. In category 3, students choose the wrong answers at Level I but choose the right reasons at Level II. This shows students as a whole experience misconception about certain concepts. Likewise in category 4, students choose the wrong answers and reasons at both levels of the problem, which states that students do not understand a concept.

In short, Category I represents the correct concept. Categories II and III represent misconceptions while Category IV represents the wrong concept (Aydeniz, et al, 2017). The researcher calculates the score of students 'level of understanding based on the percentage of students' answers that answer correctly. The percentage of the results of data analysis of the students' understanding categories for each item can be seen in Table 3.

Based on Table 3 it is observed that each item available can classify several types of students' understanding, including understanding, experiencing misconceptions, and not understanding. In the first item about the Lewis structure, 47.2% of the students understood and 52.8% of the students experienced misconceptions related to the Lewis structure concept. This can show that more than a few students are on a concept that is still wrong either in the first or second level questions. However, there are no students who do not understand at all about the concept. In the second item, there were 66.7% of students who understood the concept of atomic stability and 22.2% of students who experienced misconceptions, while students who did not understand the concept of atomic stability were about 11.1%. This shows that more than a few students who already understand the concept of atomic stability even though there are still some students who experience misconceptions and some students who do not understand so that the overall concept of atomic stability can be easily understood by students.

Table 3. Percentage on Student Understanding Categories

Question item	Categories of student understanding per item (%)		
	Understand	Misconception	Not understand
1	47,2	52,8	0
2	66,7	22,2	11,1
3	0	16,7	83,3
4	2,78	75	22,2
5	83,3	16,7	0
6	13,9	86,1	0
7	41,7	58,3	0
8	0	22,2	77,8
9	0	97,2	2,78
10	86,1	11,1	2,78
11	30,6	69,4	0
12	5,56	88,9	5.56
13	0	58,3	41,7
14	0	27,8	72,2
15	100	0	0

In the third item about the concept of ionic bonding, there were 16.7% of students who experienced misconceptions and 83.3% of students who did not understand the concept. This shows that most students do not understand the concept of ion bonding correctly. In the fourth item, there were 2.78% of students understood the concept of ionic bonding, while students who experienced misconceptions were 75%, and students who did not understand the concept were 22.2%. This shows that most students experience misconceptions about the concept of ionic bonding. In the fifth item about the concept of ion compounds based on electron configurations = 83.3% of students understood and 16.7% of students were still experiencing misconceptions. This shows that in general students understand the concept of ion compounds through electron configurations.

In the eighteenth item, there were 13.9% of students who understood the concept of ionic bonds can conduct electric current, while students who were still experiencing misconceptions were 86.1%. This shows that most students still experience errors in understanding the concept. In the seventh item about the concept of covalent bonding, there were 41.7% of students who understood the concept and 58.3% of students experienced misconceptions about the concept. This shows that most students experience concept errors in answering the questions given. In the eighth item, 22.2% of students experienced misconceptions about the concept of bonding electron pairs in covalent bonds and 77.8% of students did not understand the concept. This shows that most students do not understand the concept of covalent bond appropriately. Students tend to be wrong in answering questions. This shows that the instrument diagnostic test can evaluate the level of student understanding of covalent bonding material because it can provide an effective approach in evaluating student understanding and to identify misconceptions of the material (Peterson, 1989).

In the ninth item about the molecular polarity concept, there were 97.2% of students experiencing misconceptions and 2.78% of students did not understand the concept. This shows that most students experience errors in understanding concepts. In the tenth item, as many as 86.1% of students already understood the concept of polarity, and 11.1% of students experienced misconceptions, and 2.78% of students did not understand the concept. This shows that most students have understood the concept of polarity appropriately. In the eleventh item on the concept of the polarity of molecules using symbolic representations, there were 30.6% of students who understood and 69.4% of students still experienced misconceptions about the concept. This shows that more than a few students still experience errors in understanding concepts so students tend to be wrong in answering questions.

On the twelfth item, 5.56% of students already understood the concept of metal bonding, while 88.9% of students still experienced misconceptions, and 5.56% of students did not understand at all. This shows that most students experience errors in understanding concepts. In the thirteenth item about the concept of conductivity of metal bonds, there were 58.3% of students experiencing misconceptions and 41.7% of students did not understand the concept at all. This shows that most students experience errors in understanding the concept even though there are still many students who do not understand at all about the concept. In item fourteen, 27.8% of students still experience misconceptions about the concept of molecular shapes and as much as 72.2% of students do not understand the concept at all. This shows that most students cannot understand the concept of molecular shapes precisely because students are not able to answer questions correctly. Finally, the fifteenth item about the concept of the polarity of molecules with their shapes, there are 100% of students who have understood the concepts correctly. This shows that all students have understood the concept.

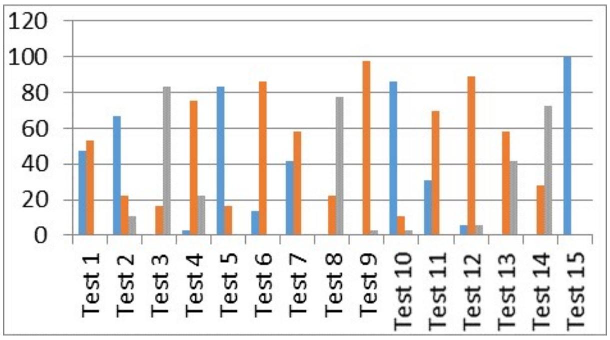

Figure 1. Graph of student understanding categories on 15 multiple-choice multiple-choice items

The graph in Figure 1 shows that overall the percentage of misconceptions is greater than the percentage of understanding and not understanding at all. To see each item experiencing a misconception can be displayed and compared from the results obtained for each question item. Each item is analyzed in depth through the percentage of students counted to find out why students experience misconceptions. This analysis is grouped into five categories or subsections: (a) Atomic stability, (b) ionic bonds, (c) covalent bonds, (d) metal bonds and (e) molecular shape and polarity.

In the first part, there are often errors in understanding the concept of atomic stability. Some students understand the formation of ions from atoms but don't understand why there are electrons being received/released so that anions/cations can form. The following is a two-tiered multiple-choice question about the formation of ionic bonds in Table 4.

Table 4.Two-tiered Multiple-Choice Question about the Formation of Ionic Bonds

Question item	**Response (Tier 1)**	**Reasons (Tier 2)**
1. Atom K has electron configuration: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1$ will form ions:	(A) K^- (B) K^{2+} (C) K^+	A. Atom K is metal so it tends to release electrons B. Atom K releases 1 valence electron to form a stable electron configuration like a noble gas C. Atom K tends to be unstable because it is not like a noble gas D. Atom K receives one more electron from another atom to form a stable noble gas

Some students can answer the first part of the question about the formation of K^+ ions, but some students cannot express the reason why ions are formed. K^+ ions can form due to the release of valence electrons on K atoms that form stable electron configurations such as noble gases. There are still students who experience misconceptions about the stability of the atom as a result of many students who are wrong in answering questions and reasons about ionic bonding. As an example of the following question in Table 5.

Table 5.Two-tiered Multiple-Choice Question about the Stability of the Atom

Question Item	**Response (Tier 1)**	**Reasons (Tier 2)**
2. The bonds formed between the $_{12}Mg$ atom and the $_{8}O$ atom are	(A) (Polar covalent bonds (B) Ion bonding (C) Nonpolar covalent bonds	A. By dividing a pair of electrons, the two electrons are obtained from the Mg atom B. B. By dividing 2 pairs of electrons,

Question Item	Response (Tier 1)	Reasons (Tier 2)
…….		where each atom contributes a pair of electrons. C. C. By giving two pairs of electrons from the Mg atom to the O atom D. D. By giving a pair of electrons from the Mg atom to the O atom

Some students understand that Mg and O atoms are ions, but students don't understand the reason why these atoms form ionic bonds. Students assume that ionic bonds are formed because of the division of electron pairs between two atoms. Although metal and non-metal atoms are bonded together, they will give up electrons to achieve stability. Metal atoms tend to release electrons while non-metal atoms tend to accept electrons. The concept of electron handover in ionic bonds is still difficult for students to understand. In addition to electron surrender, there is also the process of sharing electrons in covalent bonds as in the following items in Table 6.

Table 6.Two-tiered Multiple-Choice Question about the Covalent Bonds

Question Item	Response (Tier 1)	Reasons (Tier 2)
3. Which is the correct position of the bonding electron pair in the HF molecule below?	(A) H :F (B) H : F	A. Non-binding electrons affect the position of bonding electron pairs B. The hydrogen and fluorine atoms that form a covalent bond must position the bonding electron pair in the middle C. The fluorine atom has a strong interaction with the bonding electron pair D. The Flor atom is greater than 2 atoms so that it has a greater role in pulling the bonding electron pair toward it

Students often make mistakes in understanding the concept of the distribution of electron pairs bound to covalent bonds. Students understand that covalent bonds are bonds that are formed due to the use of shared electrons from both non-metallic atoms. However, students do not associate the electronegativity relationship with the distribution of electron pairs when both atoms are bound. This causes students to experience misconceptions about the topic of covalent bonding. Next is the matter of metal bonding in Table 7.

Table 7.Two-tiered Multiple-Choice Question about the Metallic Bonds

Question Item	Response (Tier 1)	Reasons (Tier 2)
4. Fe (iron) atoms can bind together in metal bonds. Is the statement true / false?	(A) True (B) False	A. Metal lattice contains neutral atoms B. Metal or ionic lattices are molecular C. Electrostatic bonds between metals and non-metals in alloys D. Metals are electropositive atoms that are bound to their valence electrons

Likewise, with the concept of metal bonding, most students have understood the concept that Fe atoms can bind with other Fe atoms. But students misinterpret the reasons why metal bonds can form. They assumed that metal bonds formed between the electrostatic forces of metal atoms and nonmetals. Whereas bonding occurs because interactions between atoms are more electropositive and their valence electrons. Then the concept of molecular shape in the following problem in Table 8.

Table 8.Two-tiered Multiple-Choice Question about Molecular Shaped

Question Item	Response (Tier 1)	Reasons (Tier 2)
5. Nitrogen atoms (class VA) join with bromine atoms (group 7A) to form molecules. This molecule has a shape which is described as:	(A) Tri gonal planar (B) Tri gonal pyramid (C) Tetr ahedral	A. The central atom of Nitrogen has 3 binding electron pairs and 1 silent electron pair to form a trigonal pyramid B. The arrangement of the bonding electron pair and the lonely electron pair that surrounds the nitrogen atom will form a tetrahedral C. The polarity of the nitrogen-bromine bond determines the shape of the molecule D. The difference in electronegativity value between the bromine and nitrogen atoms can determine the shape of the molecule

Most students already understand the concepts of molecular shape and molecular polarity. Even so, students still have difficulty understanding the relationship of electronegativity with molecular polarity and molecular shape. The overall level of students' understanding of chemical bonds can be shown in Table 9.

Table 9. Category of Students' Understanding Level

Question Items	Percentage of Students' Score (%)	Students' Understanding Level
1	75	High
2	77,3	High
3	8,33	Very Low
4	40,3	Low
5	91,7	Very High
6	56,9	Middle
7	70,8	High
8	11,1	Very Low
9	48,6	Middle
10	91,7	Very High
11	65,3	High
12	50	Middle
13	27,8	Low
14	15,3	Very Low
15	98,6	Very High

Based on Table 9, it can be seen that there are still many students who have a relatively low understanding of some chemical bond concepts. This shows that the concept of chemical bonds is a relatively difficult concept understood by students. The difficulties students face in understanding the concept of chemical bonds have been the subject of much research. Based on the literature, abstract concepts of chemical bonds are considered by teachers, students, and chemistry educators as concepts that are very difficult and complicated to learn (Frailich, 2009).

IV. Conclusions and Implication

This study revealed were still various students' understanding of chemical bonds, among them were some students who had understood the concept, there were some students who still have misconceptions, and there were even some other students who did not understand the concept of chemical bonds. This diversity of understanding can be characterized by the number of questions students cannot answer correctly. In addition, most students experience misconceptions about the concept of ionic bonding. Students cannot distinguish the bonds formed in compounds or molecules. Some students assume that molecules are formed by ionic bonds, whereas molecules are formed by covalent bonds between two nonmetal atoms.

Some students experience misunderstandings need teacher's efforts to minimize these obstacles. The teacher needs to identify problems in students' understanding of the learning process that have an impact on the integrity of concepts so that misunderstandings occur. This research can be used as a reference by teachers in conducting assessments to identify the extent to which students understand the concept of chemical bonds and what concepts often occur in students' misconceptions in understanding concepts.

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