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Analysis of Students' Chemical Bonding Misconception with A Four-Tier Diagnostic Test

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Abstract

Students had difficulty understanding the chemical bonding concept because of its complex and abstract nature. This difficulty could lead to chemical bonding misconceptions. This study aimed to investigate basic chemistry students' misconceptions of chemical bonding. This study used a descriptive research design with a four-tier diagnostic test. The research's subjects were basic chemistry students. Chemical Bonding Diagnostic Tool (CBDT) was used as an instrument to determine students' misconceptions. The results showed that students who had misconceptions about ionic, covalent, and coordinate covalent bonding were 48.9%, 53.0%, and 37.5%, respectively. The misconception in this course is that students need to learn about ionic bonds formed by electrostatic forces between cations and anions. As a result, students cannot determine the difference in electronegativity values in ionic and covalent bonds and the number of valence electrons of each atom in a chemical bonding. Therefore, the misconception is in the moderate category.

Keywords: chemical bonding, four-tier diagnostic test, misconception

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1. Introduction

Chemical bonding is one of the important abstract concepts in chemistry. The concept of chemical bonding was first taught to students in class X of high school, then continued in college majoring in chemistry in the subjects of Basic Chemistry, Inorganic Chemistry, Chemical Bonding, and Physical Inorganic Chemistry. The concept of chemical bonding includes bonds between atoms and/or molecules that were invisible to the eye and far from everyday life. This could cause students difficulties in understanding chemical bonding (Perez et al., 2017).

Misconceptions of chemical bonding had been previously studied. Misconceptions of chemical bonding occur at all levels. Prodjosantoso et al. (2019) used a three-tier diagnostic test to identify students' misconceptions. The results showed that the students of class X at SMAN 1 Sewon and SMAN 2 Banguntapan Yogyakarta experienced misconceptions of chemical bonding, including all metallic and non-metallic elements that bond to form ionic compounds, ionic bonds in NaCl could be seen from metal elements and non-metals, covalent bonds are formed from the interaction between non-metal elements with non-metals, non-metals could not form cations, covalent bonds were formed due to interactions between cations

and anions, HCl molecules had ionic bonds, there were coordinate covalent bonds in ammonia molecules, the compounds potassium hydroxide and sodium nitrate had only ionic bonds.

Research conducted by Fahmi and Irhasyuarna (2017) on students of class X senior high school in Banjarmasin, showed that students could not distinguish between ionic and covalent bonds, as well as molecules and atoms; students could not distinguish between covalent and molecular lattices; the general concept of ionic bonds being stronger than covalent bonds; students cannot distinguish between intramolecular forces and intermolecular forces; students did not understand that only three of the four electrons of graphite were involved in bonding, of which one electron is delocalized, which causes the graphite to have an electric charge. The students' misconceptions were collected by administrating closed-reasoned multiple-choice tests.

Research by Luxford and Bretz (2014) and Vrabec and Proksa (2016) used the Bonding Representations Inventory (BRI) to identify the misconception. The following misconceptions experienced by high school and college students are: covalent bonding had a large electronegativity difference, carbon is more electronegative than chlorine, NaCl compounds share electrons, the small electronegativity differences indicate the use of shared electrons, in carbon tetrachloride an electron transfer occurs, in phosphorus pentachloride an electron transfer occurs, electrons were transferred to neutralize the charge, electron transfer is more accurate than attraction, cations release electrons to make them more stable, bonds are formed by sharing and transferring electrons simultaneously, ions of the same type attract each other, two electrons are attracted to each other to form a bond, a bond is formed to gain eight electrons, only one Na and one Cl can bond.

Students majoring in chemistry education in the 3rd and 4th years of Universities in Nigeria still experience the misconception about chemical bonds (Fatokun, 2016). Structured essay tests were used to detect misconceptions. Misconceptions include: atoms were attracted to each other and formed ionic or covalent bonds; covalent compounds were compounds in which each atom contributes one electron to form a covalent bond; the sodium chloride molecule was represented by NaCl where the sodium atom donates one electron to the chlorine atom; Na^+Cl^- bonds do not break when dissolved in water, only the intermolecular bonds were broken. This explains why we can recover NaCl if water is removed; the formation of the bonding electrons in a covalent bond can be identified and shared equally between the two bonding atoms; HCl is an ionic compound because it can conduct electricity in water; Metallic bonds are bonds between metals. The presence of metallic bonds increases the boiling point of a compound.

To find out the students' misconceptions about chemical bonding, a diagnostic test was used. A diagnostic test was an assessment tool used to find out the difficulties of students and the causes of these difficulties (Gurel et al, 2015). The forms of diagnostic tests that were often used are interviews (Unal et al, 2010), open-ended tests (Sampurna et al, 2020; Fatokun, 2016), multiple-choice tests (Rahayu et al, 2021; Fahmi & Irhasyuarna, 2017; Perez et al, 2017), and multiple-tier tests (Widarti et al, 2018; Suri & Azhar, 2020; Noviani & Istiyadji, 2017; Setiawan et al., 2017; Mellyzar, 2021; Sugiarti & Sanjaya, 2015). The form of diagnostic test used in this study was a four-tier multiple choice.

According to Bakti and Analita (2020), and Yan and Subramaniam (2018), the instrument in the form of a four-tier diagnostic test had several advantages, including (1) it can determine the level of confidence in each question and the reasons for the research subject; (2) more accurate in analyzing each research subject's answers and beliefs when compared to other types of diagnostic instruments; and (3) more efficient and effective in analyzing the conceptual understanding of research subjects when

compared to open-ended questions and interviews. The four-tier diagnostic test to find out the misconception of chemical bonding in Basic Chemistry students is still rarely used.

The research objectives were to determine misconceptions about chemical bonding experienced by basic chemistry students. The urgency of the research is to find out the misconceptions about chemical bonding that students had so that they could be corrected and not cause misconceptions in the next concept.

2. Research Method

The research method used was descriptive research to identify students' misconceptions by a four-tier diagnostic test. There were 20 basic chemistry students, Department of Chemistry Education, Universitas Billfath, used as research subjects.

Table 1. Combination of Four-Tier Answer

No	Answer Combination				Category
	Answer	Confidence Answer	Reason	Confidence Reason	
1.	Right	Sure	Wrong	Sure	Misconception
2.	Right	Not sure	Wrong	Sure	
3.	Wrong	Sure	Wrong	Sure	
4.	Right	Sure	Right	Not sure	Partially understand
5.	Right	Sure	Wrong	Not sure	
6.	Right	Not sure	Right	Sure	
7.	Right	Not sure	Wrong	Not sure	
8.	Right	Not sure	Wrong	Not sure	
9.	Wrong	Sure	Right	Not sure	
10.	Wrong	Sure	Wrong	Not sure	
11.	Wrong	Not sure	Right	Not sure	
12.	Wrong	Not sure	Wrong	Not sure	
13.	Wrong	Sure	Right	Sure	Not understand
14.	Wrong	Not sure	Right	Sure	
15.	Right	Sure	Right	Sure	Fully understand

Chemical Bonding Diagnostic Tool (CBDT), developed by Analita et al. (2022), was used as a research instrument. The CBDT instrument had a content validity of 94.63%, which was considered a very high criterion. CBDT reliability was 0.679, which had high criteria. The CBDT instrument was valid and reliable.

The research data analysis technique was descriptive analysis. Descriptive analysis was used to find the students' misconceptions about chemical bonding (Susanti, 2021; Fikri et al., 2022; Setiawan & Ilahi, 2022; Jusniar et al., 2020; Fauziah et al., 2021). The identification of students' misconceptions was based on Table 1. Combination of Four-Tier Test Answers adapted from Jannah and Rahmi (2020).

The analysis was carried out to determine students who had misconceptions using the percentage technique. The categories of students' level of misconceptions were presented in Table 2 adapted from Putri and Subekti (2021) and Istighfarin et al. (2015).

Table 2. Categories of Students' Misconceptions Level

Percentage of Misconceptions	Category of Misconceptions
61%-100%	High
31%-60%	Moderate
0%-30%	Low

3. Result and Discussion

A CBDT was used to find students' misconceptions. The CBDT consists of 16

questions in a four-tier test. Each question consists of a question, answer choices (1st tier), confidence answer choices (2nd tier), answer reason choices (3rd tier), and answer confidence reason choices (4th tier).

The CBDT measures students' misconceptions of chemical bonding including ionic bonding, covalent bonding, and coordinate covalent bonding. The result showed that 48.9% of students experienced ionic bonding misconceptions, 53.0% of students experienced covalent bonding misconceptions, and 37.5% of students experienced coordinate covalent bonding misconceptions. Students' misconceptions about chemical bonding are moderate category because they range from 31%-60% (Putri & Subekti, 2021; Istighfarin et al., 2015). Students' conceptual understanding is given in Table 3. Students' misconceptions about chemical bonding are shown in Table 4.

Table 3. Students' Conceptual Understanding of Chemical Bonding

No	Sub-Concept	M (%)	PU (%)	NU (%)	FU (%)
1	Ionic bonding	48.9	21.1	10.0	20.0
2	Covalent bonding	53.0	13.0	12.0	22.0
3	Coordinate Covalent Bonding	37.5	25.0	12.5	25.0
	Average	**46.5**	**19.7**	**11.5**	**22.3**

Description:
M : Misconception
PU : Partially Understand
NU : Not Understand
FU : Fully Understand

The students' misconception of ionic bonding was measured by questions 1, 2, 3, 4, 11, 12, 13, 14, and 16. The most misconception about the ionic bonding concept is experienced by students in question No. 1, as given in Figure 1. Based on Figure 1, it is known that 70% of students answered wrong in the answer choices, and 80% responded wrong about the reason in question No. 1. Therefore 100% of students are sure about their answer choices and the reason. Based on Table 1, it's known that students who choose the right or wrong answer and the wrong reason and they are sure about their answer then it categorized as having a misconception. So, in question No. 1, 80% of students had a misconception.

Question

Nutrient availability in wetlands is affected by colloidal ion uptake in peat soils. The nutrient bromide ion (Br^-) is one of the anions readily absorbed by colloidal peat soils. So that the soil becomes productive for plants. Some of the following compounds are examples of compounds containing bromide nutrients.

I. $CaBr_2$
II. $AlBr_3$
III. NH_4Br
IV. HBr

The above compounds contained in compound ions are...

(A) i and ii (35%)
(B) i and iii (30%)
(C) i, ii, iii (10%)
(D) i, ii, iii and iv (25%)

Level of confidence in the answer choices

(A) Sure (100%)
(B) Not Sure (0%)

Reason

(1) NH_4Br and HBr are covalent compounds because they consist of nonmetals and nonmetals (10%)
(2) $CaBr_2$ and $AlBr_3$ are ionic compounds because they consist of metals and nonmetals (50%)
(3) $CaBr_2$ and NH_4 Br are ionic compounds because they consist of cations and anions and have ionic bonds (20%)
(4) All compounds are ionic compounds because they consist of cations and anions (20%)

Level of confidence in the choice of reasons

(A) Sure (100%)
(B) Not Sure (0%)

Note: The bold is the right answer

Figure 1. Question Number 1 with Percentage of Students Answer

There were 80% of students assumed that ionic compounds are composed of metals and non-metals. It's because the common example of an ionic compound is NaCl which is composed of metals and non-metals. Students do not understand that ionic bonding can also consist of non-metals and non-metals, for example, NH_4Cl. This result was consistent with the studies of Widarti et al. (2018) and Suri and Azhar (2020).

Based on question No. 4, it is known that 75% of students consider the formation of ionic compounds to involve the transfer of electrons between atoms, this is also seen in question No. 16. As many as 70% of students think that calcium atoms donate their valence electrons

to oxygen atoms, then bond. In general, students do not understand the formation of ionic bonds. This follows previous studies (Pikoli, 2018; Widarti et al., 2018; Vladusic et al., 2016; Suri & Azhar, 2020; Taber, 2002; Nahum et al., 2010). Students understand that ionic bonds are composed of cations and anions, but students assume that cations always come from metals, and electron transfer occurs between atoms. Students do not understand that ionic bonds are formed from electrostatic forces between cations and anions. Cations can come from metals such as K^+, Na^+, Mg^{2+}, and non-metals such as NH_4^+ (Effendy, 2008; Robinson et al., 2020; Chang, 2010; Silberberg & Amateis, 2018). This is similar to the research of Yastophi and Ritonga (2019) which states that students do not understand the effect of electrostatic forces on bond formation.

Table 4. Students' Misconceptions about Chemical Bonding

Sub-Concept	Question No.	Misconceptions	Percentage (%)	Category
Ionic Bonding	1	Ionic compounds are composed of metals and non-metals	80	High
	2	Ionic compounds are always solid	15	Low
	3	In ionic compounds, there is a balanced distribution of electrons, so that the electrons are distributed symmetrically on the atoms	20	Low
	4	The formation of ionic compounds involves the transfer of electrons between atoms	75	High
	11	The sodium atom has high ionization energy while the chlorine atom has a small electron affinity	40	Moderate
	12	The potassium atom has high ionization energy while the bromine atom has a high electron affinity	35	Moderate
	13	Students have difficulty describing the bonds that occur in ionic compounds	40	Moderate
	14	Students have difficulty describing the bonds that occur in ionic compounds	65	High
	16	The calcium atom donates its valence electrons to the oxygen atom, then bonds	70	High
Covalent Bonding	5	Covalent bonds are formed when non-metallic element bonds with a non-metallic element	35	Moderate
	6	Ionic bonds are formed when a metal element bonds with a non-metallic element	40	Moderate
	7	HI compounds tend to be ionic rather than covalent	55	Moderate
	8	$AlCl_3$ compounds are derived from cations and anions	65	High
	15	NaCl compound consists of molecules because the sodium atom donates its valence electron to the chlorine atom and the two bond.	70	High
Coordinate Covalent Bonding	9	There are only covalent bonds in ammonium chloride because the compound NH_4Cl consists of non-metal atoms	45	Moderate
	10	In the CO compound, there is one polar covalent bond and one coordinate covalent bond with electrons more attracted to the O atom	30	Moderate

Based on Table 4, it is known that students experience the most misconception about covalent bonding in questions No. 7, 8, and 15. Based on question No. 7 it is known that as many as 55% of students think that HI compounds tend to be ionic rather than

covalent. Students assume that because HI is composed of cations and anions, HI is an ionic compound. Students do not understand that ionic compounds have a difference in electronegativity of >1.7. Based on question No. 8, it was found that 65% of students thought that $AlCl_3$ came from cations and anions. Students do not understand that $AlCl_3$ is a covalent compound because the difference in electronegativity is <1.7. The same result was obtained from the research of Mellyzar and Muliaman (2020) which stated that students did not understand the mechanism for the formation of ionic bonds and covalent bonds.

Based on question No. 15, it is found that 70% of students thought that the NaCl compound was composed of molecules because the sodium atom gave its valence electron to the chlorine atom, then the two bonded. Similar results were found in Pabucu and Geban (2012), Vrabec and Proksa (2016), and Perez et al. (2017). Students do not understand that the particles of ionic compounds are ion pairs. Compounds whose particles are molecules are covalent compounds. Students understand that NaCl is an ionic compound, but assume that NaCl is composed of molecules. Students do not understand the particles that make up the compound. It is because students do not understand the concept of material and change correctly and even experience misconceptions about the matter and its changes (Rohmah, 2019; Rohmah et al., 2020).

Misconceptions about coordinate covalent bonding most often occur in problem No. 9, as shown in Table 4. As many as 45% of students considered that only there is a covalent bond in ammonium chloride because the compound NH_4Cl consists of non-metallic atoms. Students do not understand that in NH_4^+ there is a coordinate covalent bond. This is the same as the results in the study of Openhotman et al. (2017), which states that as many as 18.07% of students do not understand the concept of coordinate covalent bonds because they cannot determine the valence electron from each atoms in chemical bonding.

Misconceptions must be corrected so that students can understand the concept correctly and there are no misconceptions in other related concepts. To reduce misconceptions, Conceptual Change Text can be used. In previous research, Conceptual Change Text was effective in reducing misconceptions about the matter and its changes (Rohmah et al., 2020) and acid-base (Rohmah & Virtayanti, 2021).

4. Conclusion

Based on the result and discussions, basic chemistry students had misconceptions about chemical bonding. Students who had misconceptions about ionic bonding were 48.9%, covalent bonding were 53.0%, and coordinate covalent bonding were 37.5% which is considered a moderate category of misconceptions. The highest students' misconception about chemical bonding was ionic compounds are composed of metals and non-metals.

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