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Research Article

Identifying Students' Misconceptions about Chemical Bonding Using a Four-Tier Diagnostic Test

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Abstract
Chemical bonding is an abstract topic that students rarely encounter in their daily lives. Because of the many misconceptions that can arise regarding chemical bonds, it is not surprising that chemical bonds are a topic that has been widely researched. Thus, this study aims to explore students' understanding of chemical bonding. This research is quantitative research using a survey design. The participants were 101 tenth-grade students at a public high school in Indonesia. In this study, the sample was determined using convenience sampling techniques. To collect the required data, the Four-Tier Diagnostic Test for Chemical Bonding (FTDT-CB) was administered. The results indicated that students' understanding of chemical bonding concepts was relatively low with an average score of 18 (out of 100). In addition, 23 misconceptions were identified, of which 20 were genuine misconceptions while the other 3 were spurious misconceptions. It is recommended for future studies to conduct quasi-experimental research to prevent misconceptions that emerged in the current research and also to reveal misconceptions on chemical bonding that may be experienced by pre-service chemistry teachers by using a four-tier diagnostic test.

Keywords: Chemical Bonding, Four-Tier Diagnostic Test, High School Students, Misconceptions

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1. INTRODUCTION

Concepts in chemistry must be arranged hierarchically, from basic to complex concepts (Ealy, 2018; O'Connor, 2015; Seery, 2009). This shows that basic concepts need to be understood so that more complex concepts can be understood (Bilgin & Uzuntirkayi, 2003; Shing & Brod, 2016). One of the fundamental basic concepts in chemistry is chemical bonding (Atkins et al., 2016; Holme et al., 2015). Chemical bonds need to be understood so that other concepts, such as chemical reactions and the relationship between chemical properties and structure, can be mastered properly (Ozmen, 2004).

Chemical bonding is a complex topic. According to Tan and Treagust (1999), chemical bonds are an abstract topic where students rarely encounter this topic in their daily lives. In addition, because of the connection between the topic of chemical bonds and the particulate matter theory, many students still do not understand the particulate matter theory, and also have difficulty understanding the concept of chemical bonds (Novick & Nussbaum, 1982).

Apart from the abstract nature of the topic of chemical bonds, the way teachers present this material can also make it difficult for students to understand the concept of chemical bonds (Nahum et al., 2013). Teachers' teaching methods that tend to simplify the concept of chemical bonds can cause misconceptions (Dhindsa & Treagust, 2014). For example, in high school, students are taught that chemical bonds are categorized into covalent and ionic bonds, which as a result gives rise to a dichotomy. In fact, based on a scientific view, most compounds do not have 'pure' covalent or ionic bonds, but rather the nature of the bonds are intermediate, that is, they have various covalent and ionic characteristics (Allan et al., 2019). Apart from that, teachers often explain the concept of chemical bonds with anthropomorphism, for example in the octet rule, the teacher explains that atoms "want" or "like" their valence electrons to have octets and chemical reactions take place so that atoms can reach octets (Taber, 2011).

The difficulties faced by students in understanding the concept of chemical bonds mean that many students have a different understanding from the scientific view accepted by the scientific community in general (Skelly, 1993). This different understanding has been given many names by previous researchers, for example preconceptions (Hashweh, 1988), alternative conceptions (Driver & Easley, 1978), naive conceptions (Klopfer et al., 1983), pseudo-conceptions (Vinner, 1997) and misconceptions (Cho et al., 1985). In this research, the term misconception is used.

Misconceptions can form in various ways. Misconceptions can form because students combine two concepts that they understand correctly into an incorrect concept (Jang, 2003). Sometimes students also form illogical concepts due to lack of information (Gudyanga, 2014; Pedrosa & Dias, 2000). Language is also a factor that can give rise to misconceptions. According to Gudyanga (2014) chemical bonding is a complex topic because studying it requires knowledge of foreign terms that are not used in everyday life, such as the term 'covalent'.

Because of the many misconceptions that can arise regarding chemical bonds, it is not surprising that chemical bonds are a topic that has been widely researched, some of which are Peterson et al. (1989), Tan and Treagust (1999), Coll and Taylor (2001), and Taber et al. (2012). Taber et al. (2012), used a diagnostic instrument previously used in England by Taber (1997) to identify misconceptions that occur among students in Turkey and Greece about ionic bonds. They found that many students in both countries still experience misconceptions, such as the number of ionic bonds that can be formed depends on valence electrons and is related to the octet rule, ionic bonds only occur between 2 atoms, also other ions that are not ionically bonded are attracted. by style alone. Their findings are consistent with Taber's (1997) findings. A similar study was also conducted in Croatia by Vladušić, Bucat, and Ožić (2016) and their findings were consistent with Taber et al. (2012).

Broadly speaking, misconceptions have a negative impact on student learning for 2 reasons. Firstly, misconceptions disrupt the learning process because they will make students interpret new information received incorrectly and not understand the concepts being taught (Erman, 2016). Second, most students who experience misconceptions do not realize that they are wrong and when the teacher says they are wrong, students find it difficult to forget the misconceptions. This is because students are usually emotionally attached to the misconceptions they have built. As a result, it is difficult for teachers to get students to let go of misconceptions (Guzzetti, 2000). Therefore, misconceptions are a serious problem that must be addressed.

The first step to overcome misconceptions is of course to identify the misconceptions that occur in a valid and reliable manner first (Kaltakci et al., 2015).

However, unfortunately the misconception diagnosis methods that are generally applied in Indonesia currently cannot identify misconceptions. According to Nahum, Mamlok-Naaman, and Hofstein (2013), diagnostic methods using multiple choice questions in general cannot identify misconceptions well. This is because students can give the right answer by guessing or just by memorizing several things (Uzuntiryaki & Geban, 2005).

Several previous researchers have proposed several methods that can reveal whether students have appropriate conceptual understanding or not. Several methods for identifying misconceptions include making concept maps (Novak, 1996), interviews (Carr, 1996) and using multi-tier diagnostic instruments (Treagust, 1988). A multi-tier diagnostic instrument is a method of identifying misconceptions using multi-level multiple choice questions (Kaltakci et al., 2015). This method was developed to overcome the weaknesses of multiple-choice questions

There are 3 types of diagnostic instruments, namely two-tier, three-tier and four-tier. At four-tier, there are four levels of questions for each item that ask students' answers (level 1), the reasons for these answers (level 3) and the level of confidence for the answer level and reason level. The four-tier diagnostic test has the advantage of being able to accurately identify whether students have misconceptions or not. However, the four-tier diagnostic test also has a weakness, namely that when compared to two-tier and three-tier, this type requires quite a long processing time (Caleon & Subramaniam, 2009).

One example of a diagnostic test used to identify misconceptions in the concept of chemical bonding is the two-tier multiple-choice items developed by Peterson, Treagust and Garnett (1989) and Tan and Treagust (1999). The first tier of the diagnostic test asks students about the concept of chemical bonds, then the second tier contains reasons for the answers in the first tier.

Based on a literature review, the author found that four-tier diagnostic instruments, especially in chemical bonding materials, are still limited in their development and implementation. Therefore, researchers want to adapt and modify the two-tier diagnostic test developed by Peterson, Treagust and Garnett (1989) and Tan and Treagust (1999) into a four-tier diagnostic test. This instrument was designed to identify misconceptions that occur among high school students regarding the concept of chemical bonds.

2. METHODS

2.1 Research Design

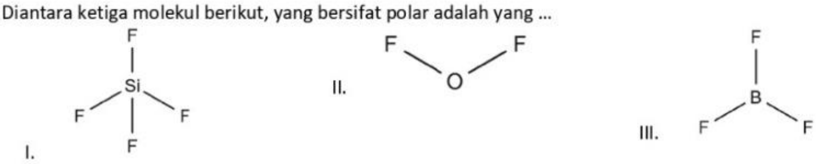
This research is quantitative research using survey design. Survey design, according to Creswell (2015) is a procedure in quantitative research, where researchers conduct surveys on samples or entire populations to obtain descriptions of attitudes, opinions, behavior or characteristics of the population. Through this procedure, researchers collect quantitative data, then analyze the data through statistics and interpret it.

Survey design is different from experimental design because in this procedure there is no treatment from the researcher. Because there is no treatment, this procedure cannot explain causality as well as experimental design. The survey was applied cross-sectionally, that is, it was applied once at a specified time (Creswell & Creswell, 2018).

2.2 Participants

The respondents of this research were 101 students at a public high school in Jakarta in the even semester of the 2021/2022 academic year. In this study, the sample was determined using convenience sampling techniques. By using this technique, researchers determine participants based on certain goals and criteria (Fraenkel et al., 2011). Based on the sampling process, the sample used was all 10th grade students who had studied the topic of chemical bonds.

5. Diantara ketiga molekul berikut, yang bersifat polar adalah yang ...



Tingkat Keyakinan	1	2	3	4	5	6
	Hanya Menebak	Sangat Tidak Yakin	Tidak Yakin	Yakin	Sangat Yakin	100% Yakin

Alasan:
a. Kepolaran molekul tersebut dikarenakan keelektronegatifan atom F yang besar
b. Molekul yang asimetris membentuk molekul yang polar
c. PEB pada molekul menyebabkan terjadinya momen dipol, sehingga molekul menjadi polar
d. Selisih nilai keelektronegatifan yang besar, yang terjadi antara atom-atom dalam molekul menyebabkan molekul tersebut menjadi polar

Tingkat Keyakinan	1	2	3	4	5	6
	Hanya Menebak	Sangat Tidak Yakin	Tidak Yakin	Yakin	Sangat Yakin	100% Yakin

Figure 1. Example of Questions on the Instrument

2.3 Data Collection Tool

The instrument used in the research was a four-tier diagnostic instrument modified from Peterson et al. (1989) and Tan and Treagust (1999). The instrument consists of 15 items covering bond polarity, molecular geometry, molecular polarity, octet rule, intermolecular forces, covalent bonds and ionic bonds. An example of the instrument can be seen in Figure 1.

Before the instrument is given to the research sample, the instrument is tested first to determine its validity and reliability. The validity of the instrument content was determined through a review process by 3 expert lecturers. Based on the results of the review, the V Aiken value of each question is determined to determine its validity. Meanwhile, the reliability of the instrument is determined by calculating the Cronbach's alpha value.

Based on the data obtained through the pilot study, the Cronbach's alpha coefficient was calculated using IBM SPSS statistics 25. The results of the Cronbach's alpha coefficient calculation are shown in Table 1.

Table 1. Alpha Values of the Instrument

Tier	Alpha
Answer	0.102
Reason	0.334
Answers and Reasons	0.445
Confidence Level (Answer)	0.938
Confidence Level (Reason)	0.947

It can be seen that the alpha value obtained for the answer tier and reason tier is relatively low (not reliable). When the answer and reason tiers are combined, the alpha value obtained is higher than when the two tiers are separated, however the instrument is still classified as unreliable based on the interpretation guidelines of Cohen et al. (2017).

According to Adams and Wieman (2010), low alpha values are normal for diagnostic instruments because they measure imperfect student understanding. Apart from that, low alpha values can also be due to the nature of diagnostic instruments which are criterion-referenced (Popham & Husek, 1969). Criterion-referenced instruments are instruments that measure an individual's ability against certain criteria. Because individual abilities are compared against a certain criterion and not against the abilities of other individuals, the variability of instrument scores is not relevant to discuss. Finally, a low alpha value can also be because the diagnostic instrument is not uni-dimensional (Sreenivaslu & Subramaniam, 2013). This means that there are several sub-topics that are independent of each other on the topic of chemical bonds, for example the sub-topics of the octet rule and VSEPR theory are 2 independent sub-topics and are not related to each other.

Low alpha values were also obtained by Caleon and Subramaniam (2009), Sreenivaslu and Subramaniam (2013), and Yan and Subramaniam (2018). The alpha values they obtained are summarized in Table 2.

Table 2. Summary of Alpha Values from the Literature

Reference	Answer	Reason	Both
Caleon and Subramaniam (2009)	0.40	0.19	0.50
Sreenivaslu and Subramaniam (2013)	0.40	0.43	-
Yan and Subramaniam (2018)	0.22	0.23	0.44

From Table 2 it can also be observed that the alpha value for the confidence level is much higher than the answer and reason tiers. This result was also found by Caleon and Subramaniam (2009), Sreenivaslu and Subramaniam (2013), and Yan and Subramaniam (2018). This difference in alpha value can be caused by the scale used for the level of confidence is much larger than the scale for answers and reasons. The confidence level scale is 5 Likert points while answers and reasons are binary (0 and 1).

2.4 Data Analysis

From students' answers, it can be determined whether they have misconceptions, understand the concept well or are just guessing. Categorization of student answers was carried out according to Caleon and Subramaniam (2009), namely tier 1 and tier 3 were assessed separately first with the correct answer coded as 1 and the incorrect answer coded as 0. Next, tiers 1 and 3 were assessed together. If students answer tiers 1 and 3 correctly, then the item is given a score of 1, conditions other than this are given a score of 0. Students who understand the concept correctly are students who get a score of 1 and show a high level of confidence (> 3.5). Students who get a score of 1 but show a low level of confidence (3.5 or below) are categorized as lacking knowledge or guessing.

It can be said that there is a misconception if the misconception is experienced by at least 10% of the sample (Caleon & Subramaniam, 2009). Misconceptions are then divided into several groups. Misconceptions with a high level of confidence (> 3.5) are referred to as genuine misconceptions. This misconception is caused by students' lack of understanding of the concept or due to inappropriate implementation of the explanation. Spurious misconceptions are misconceptions that are accompanied by a low level of confidence (< 3.5). These misconceptions can occur due to a lack of knowledge or guessing. The categorization of student understanding is summarized in Table 8.

3. FINDINGS

3.1 Misconceptions, Mean Scores, and Confidence Levels

Based on data analysis, it was found that there were 23 misconceptions about chemical bonds among students. 20 of them are classified as genuine misconceptions, while the other 3 are classified as spurious misconceptions. Apart from that, it can also be observed that each instrument question identifies at least 1 misconception. The misconceptions that occur are summarized in Table 5.

The average score obtained by students when only the answer tier is calculated is 51 (out of 100), while if only the reason tier is calculated the average student score decreases, to 28 (out of 100). The decrease in the average score shows that for students, the reason tier is much more difficult than the answer tier. If both tiers are calculated, the average student score decreases again, to 18 (from 100). By considering 2 tiers, the possibility of students guessing the answer correctly becomes smaller, therefore it is natural that there will be a decrease in the average score when both tiers are considered. In general, the average score obtained by students in both tiers shows that students' conceptual understanding is still very low. Apart from that, this also proves the weakness of multiple choice questions which are generally used in schools to evaluate learning outcomes. Scores when only answer tiers are considered do not represent well whether students have appropriate conceptual understanding or not.

The average level of confidence of students when answering correctly (CFC), is 3.21 (out of 5). This shows that when students answer correctly, students do not have a high level of confidence. Then, the average level of student confidence when answering incorrectly (CFW) is 3.26 (out of 5). This shows that even when students answer incorrectly, students still provide a fairly high level of confidence. This fairly high CFW value is also an indication that the majority of students' wrong answers are due to misconceptions and not just random guessing.

Table 4. Mean Scores, CFC, CFW and CDQ

Item	Proportion of Correct Answers			Both Tier			
	Answer	Reason	Both	CF	CFC	CFW	CDQ
1	0.28	0.06	0.04	3.49	3.45	3.49	-0.051
2	0.33	0.28	0.08	3.16	3.07	3.16	-0.074
3	0.52	0.30	0.20	3.20	3.05	3.20	-0.133
4	0.67	0.38	0.33	3.51	3.52	3.51	0.008
5	0.35	0.12	0.04	3.14	3.02	3.16	-0.117
6	0.72	0.15	0.11	3.31	3.31	3.31	0.000
7	0.64	0.13	0.09	3.21	3.13	3.21	-0.074
8	0.50	0.31	0.25	3.21	3.20	3.21	-0.008
9	0.72	0.71	0.51	3.49	3.48	3.49	-0.008
10	0.32	0.33	0.14	2.93	2.91	2.93	-0.016
11	0.68	0.23	0.19	3.37	3.38	3.37	0.008
12	0.65	0.11	0.02	3.01	2.92	3.01	-0.068
13	0.26	0.40	0.14	2.99	2.90	2.99	-0.072
14	0.26	0.23	0.11	3.55	3.44	3.55	-0.091
15	0.79	0.54	0.46	3.36	3.36	3.35	0.007
Mean	0.51	0.28	0.18	3.26	3.21	3.26	-0.050

Apart from that, there were 3 questions with CDQ that had a positive value, 1 question had a value of 0 and 9 questions had a negative value. The average CDQ itself is -0.05. From these results, it can be seen that in general, students are more confident when they answer incorrectly than when they answer correctly. Furthermore, according to Lundeberg et al. (2000), a negative CDQ average indicates that students do not know what they do not know. Average scores, CFC, CFW, CDQ, and several other analysis results are summarized in Table 5.

Table 5. Identified Misconceptions

No	Option	Misconceptions	% of Sample	CF	Classification
1	1b	The bonding pair of electrons in a covalent bond is always right in the middle	37	3.80	Genuine
	1d	The size of the atom affects the position of the bonding electron pair in a covalent bond	17	3.38	Genuine
	1a	The lone pair of electrons affects the position of the bonding electron pair in a covalent bond	17	3.44	Genuine
2	1a	The shape of the molecule is only due to the repulsion of the bonding electron pair	41	3.40	Genuine
	3b	Lone pairs of electrons are considered to be included in molecular geometry	18	2.86	Spurrious
3	1b /2d	Inverted in understanding the partial charge symbol	33	3.12	Genuine
4	2c	Lone pairs of electrons do not affect the geometry of the molecule	23	3.75	Genuine
	1b	The geometry of the molecule is only affected by the lone pair of electrons	13	3.73	Genuine
5	2c	Lone pairs of electrons cause polarity in a molecule	18	3.42	Genuine
	3d	Polar molecules will form when there is a large difference in electronegativity in the atoms that make up the molecule	11	3.73	Genuine
6	1b / 1a	Chemical bonds are forces between molecules	43	3.40	Genuine
	1d	H_2S is a non-polar molecule	19	3.50	Genuine
7	2a	The electronegativity of an atom affects the geometry of the molecule	12	3.25	Genuine
8	2d	Polar molecules are formed when the difference in electronegativity between atoms is small	19	3.08	Genuine
	1a	Molecules become polar when the bonds formed between atoms are polar	15	3.33	Genuine
9	1a	The octet rule is used to determine molecular geometry	20	3.20	Genuine

No	Option	Misconceptions	% of Sample	CF	Classification
	2b	Valence electrons determine the number of bonds that can be formed	16	3.16	Genuine
10	2a	Chemical bonds are forces between molecules	24	2.98	Spurrious
11	2d	Molecular geometry is caused by the repulsion of bonded atoms	30	3.65	Genuine
	1a	VSEPR theory is used to determine the polarity of molecules	13	3.08	Genuine
12	1a	Electronegativity is defined as the ability of an atom to donate electrons	40	3.19	Genuine
	2b	The ability to form ions determines the partial charges of atoms in covalent bonds	15	3.70	Genuine
13	1a	The electronegativity of an atom affects the bonds that can form	13	2.69	Spurrious
14	1a/1b/1c/1d	NaCl is a molecule	75	3.67	Genuine
15	1a	Metal and non-metal elements can form covalent compounds	25	3.34	Genuine

4. DISCUSSION

Below is a discussion of the data description that was explained previously. Discussion will be given based on the topic of misconceptions that occur.

4.1 Bond Polarity

Questions 1, 3, and 12 test students' conceptual understanding of bond polarity. In general, there were 7 misconceptions on this topic, and the percentage of students who could answer Questions 1, 3, and 12 correctly was relatively low, respectively 4%, 20%, and 2%. Based on these results, it can be said that students do not understand bond polarity well.

Question 1 asks about the position of bonding electron pairs in the HF molecule. HF is a polar molecule, so it can be concluded that the use of bonding electron pairs is not balanced and is influenced by the electronegativity values of the H and F atoms (Chang, 2010). Because the F atom has a greater electronegativity value than the H atom, the bonding electron pairs are closer to the F atom. Students still do not seem to understand the relationship between the electronegativity value and the position of the bonding electron pairs and bond polarity. This is reflected in the identification of 3 misconceptions on this question, as well as the low percentage of students who could answer both tiers (4%; 4 students).

37% of students think that bonding electron pairs in covalent bonds is always right in the middle, with a CF of 3.80 (genuine misconception). Similar findings were also observed by Peterson, Treagust, and Garnett (1989). Students seem to understand that covalent bonds occur due to the sharing of electron pairs. But unfortunately, they don't understand that bond polarity is a result of the unbalanced position of the bond electrons. This misconception can occur because teachers usually only explain the concept of bond polarity as an abstract thing and students only need to calculate the difference between the electronegativity of the constituent atoms. In fact, bond polarity is not an abstract thing and is related to the position of the bonding electron pairs, where atoms closer to the bonding electron pairs will have a greater electron density. As a result of this greater electron density, the atom has a more negative charge. This is what causes the formation of positive and negative poles (polar bonds are formed).

A number of students understand that bonding electron pairs in covalent bonds is not always in the middle. Unfortunately, they explained that the position of bonding electron pairs is influenced by the size of the atom (17%) or the number of lone electron pairs (17%). Each has a CF of 3.38 and 3.44; which means this misconception is a genuine misconception. As previously explained, the position of bonding electron pairs is actually influenced by the electronegativity value of the atoms that make up the molecule.

Question 3 asks about the bond polarity in the OF molecule. In this question, students must choose the correct pictorial representation of OF bond polarity, so that apart from testing students' understanding of the concept of bond polarity, this question will also test whether students understand the symbols for positive and negative partial charges. Because the F atom has a greater electronegativity value than the O atom, in the OF molecule, the O atom will have a partial positive charge while the F atom will have a partial negative charge (Chang, 2010).

From this question, a misconception was identified that the ability to form ions affects bond polarity (12%), which is a genuine misconception (CF = 3.33). The findings in this question support the findings in question 1, where students do not understand the relationship between electronegativity values and bond polarity. In addition, 33% of students identified confusion in using the partial charge symbol to represent bond polarity. It is possible that this was caused because the teacher did not emphasize this during teaching and learning activities, because when the researcher checked the textbook used by the students, it clearly stated the use of partial charges to symbolize bond polarity.

Question 12 asks which atoms have a partial positive charge in the SCl_2 molecule. Because the S atom has a lower electronegativity value than the Cl atom, the S atom will have a lower electron density than the Cl atom, in other words, the S atom will have a partial positive charge (Chang, 2010). From this question, the misconception was again identified that the ability to form ions affects bond polarity. This result was also found by Peterson, Treagust, and Garnett (1989).

Then it was also identified that 40% of students thought that in the SCl2 molecule, there was a transfer of electrons from the S atom to Cl, so that the S atom had a partial positive charge. The CF for this misconception is 3.19. This is certainly concerning because it shows that students do not yet understand well what covalent bonds are.

The percentage of students who can answer both tiers in questions 1, 3, and 12 correctly, respectively, is 4%, 20%, and 2%. This result is quite interesting because question 3 has a much higher percentage of correct answers than questions 1 and 12, even though the question in question 3 is not much different from question 12. It is not known for certain why question 3 is considered by students to be more difficult.

4.2 Ionic Bonds

Questions number 14 and 15 test students' conceptual understanding of ionic bonds. In total, there were 2 misconceptions on this topic, and the percentage of students who could answer question 14 was low (11%) while question 15 was quite high (46%). Based on these results, it can be said that students do not understand bond polarity well.

Question 14 asks whether NaCl is a molecule or not. Of course, because NaCl is an ionic compound, it is not a molecule. Ionic compounds always form crystals and do not consist of discrete molecules (Brown et al., 2017). Based on data analysis, it appears that the majority of students think that NaCl is a molecule, with 75% of students experiencing this misconception (CF = 3.67). Only 11% of students had a good conceptual understanding (answering both tiers correctly). Similar results were also found by Taber (1997), Vladušić et al. (2016), and Taber et al. (2012).

This misconception is most likely caused when teaching, teachers only focus on the process of forming ionic bonds but do not discuss the structure of the compounds formed. Then, when the teacher discusses the process of forming ionic bonds, the examples used also direct students to form this misconception. Below is an example that the researcher got from the relevant teacher which was used to explain the process of forming ionic bonds.

It can be seen from the example that without further explanation from the teacher, students will not be able to understand that NaCl is only an empirical formula and not a molecular formula. Apart from that, from the example above it can also be seen that electron transfer only occurs from 1 Na atom to 1 Cl atom, even though in reality this is not the case. Finally, it is important to consider that there is also the possibility that students do not understand the definition of the molecule itself so students answer that NaCl is a molecule.

$$\mathrm{Na}\cdot + \cdot\ddot{\underset{\cdot\cdot}{\mathrm{Cl}}}: \longrightarrow \mathrm{Na}^{+} + [:\ddot{\underset{\cdot\cdot}{\mathrm{Cl}}}:]^{-} \longrightarrow \mathrm{NaCl}$$

Question 15 asks students to determine whether it is true that a metal element (electron configuration 2,8,18,8,2) reacts with a non-metal element (electron configuration 2.7) to form an ionic compound. Due to the high difference in electronegativity between the two elements ("high" here can be concluded from the fact that it is metal and non-metal elements that react), the compound formed will be ionic.

From this question, it was identified that 25% of students believed that when metal elements are reacted with non-metal elements, covalent compounds can be formed, with a CF of 3.34. It seems that students think that by using pairs of electrons together, non-metal elements will reach an octet, so that the compound formed will be stable. However, students do not consider that metallic elements do not reach octets. This misconception is likely caused by students not properly understanding the difference between ionic and covalent bonds. These results are consistent with the findings of Tan and Treagust (1999) and Peterson, Treagust, and Garnett (1989).

One interesting thing was also observed in this question, namely that the percentage of students who could answer both tiers correctly was quite high (46%). This is thought to be due to students being quite familiar with the type of questions given. This assumption is supported by the statement that the researcher received from the teacher, that questions of this type had already been discussed in class.

4.3 Molecular Geometry

There are 3 questions that test students' conceptual understanding of the concept of molecular geometry, namely questions 2, 4, and 7. In total, there are 5 misconceptions on this topic, and the percentage of students who can answer questions 2, 4, and 7 respectively is 8%, 33%, and 9%. In general, it appears that students have not been able to apply VSEPR theory to predict molecular geometry well. In addition, the misconceptions identified on this topic are in accordance with those found by Peterson et al. (1989)

Question 2 asks about the molecular geometry of NBr_3. Based on VSEPR theory, the molecular geometry of NBr_3 is trigonal pyramidal, with a Br-N-Br angle of less than 109.5^o. This is because lone electron pairs on the nitrogen atom have a stronger repulsion than bonding electron pairs (Petrucci et al., 2016). In this question, it was identified that 44% of students believed that molecular geometry was only influenced by bonding electron pairs with CF = 3.40, so this was a genuine misconception. These results can be interpreted as an indication of an imperfect understanding of VSEPR theory. Then 18% of students were also identified as considering that lone electron pairs are included in molecular geometry with CF = 2.86, so it is a spurious misconception. Because it is classified as a spurious misconception, it is quite likely that 18% of students are just guessing and do not indicate that there is a misconception.

Question 4 asks about the geometry of the SCl_2 molecule. Because the S atom in SCl_2 has 2 lone electron pairs and 2 bonding electron pairs, the geometry of SCl_2 based on VSEPR theory is V-shaped (bent) (Petrucci et al., 2016). This question identifies 2 misconceptions among students. First, the misconception that molecular geometry is only influenced by bonding electron pairs is identified again. This misconception occurs in 23% of students with a CF of 3.75. It was also identified that 13% of students believed the opposite, namely that molecular geometry was only influenced by lone electron pairs with a reported CF of 3.73. Both misconceptions are reported with very high levels of CF and are classified as genuine misconceptions.

Question 7 asks about the geometry of the $COCl_2$ molecule. Considering that the C atom has 3 bond domains (1 double bond domain and 2 single bond domains), then based on VSEPR theory, $COCl_2$ has a trigonal planar geometry (Brown et al., 2017). From this question, it was identified that 12% of students thought that the electronegativity of each atom affected the geometry of the molecule (CF = 3.25). It seems that students do not understand that electronegativity only affects the ability of an atom to attract lone electron pairs and molecular geometry is influenced by repulsion between electron domains.

An interesting thing was seen in the percentage of students who answered both tiers correctly on the four questions related to the topic of molecular geometry. Question 4 has a much higher percentage rate than questions 2 and 7 (33% vs 8% and 9%). This is interesting because if the level of difficulty of the question is related to the student's familiarity with the molecule being asked about in the question, then question 2 should also have a high percentage of correct answers (NBr_3 is not much different from NH_3). However, question 2 does not have a high percentage level. This shows that there are other factors that influence the level of difficulty of the questions.

4.4 Molecular Polarity

Questions number 5 and 8 test students' conceptual understanding of molecular polarity. In total, there were 4 misconceptions on this topic, and the percentage of students who could answer questions 5 and 8 correctly was relatively low, respectively 4% and 25%. Based on these results, it can be said that students do not understand molecular polarity well. Because of the close relationship between molecular polarity and bond polarity and research results show that students do not understand bond polarity well, it is not surprising that students also do not understand the topic of molecular polarity.

In question 5, students are asked to choose a molecule that is polar from 3 options, with the options given being SiF_4, OF_2, and BF_3. Of the three molecules, the one that is polar is OF_2, because the only one with an asymmetrical geometry is OF_2. Apart from the geometry of the molecule, it must also be considered whether the bond that occurs is polar (the difference in electronegativity between atoms is > 1.5) (Brown et al., 2017), but specifically for question 5 it is not necessary because only 1 molecule has an asymmetrical geometry, the answer is automatic. is OF_2. In total, 2 misconceptions were identified regarding this question.

18% of students believe lone electron pairs influence whether a molecule is polar or not, with CF = 3.42. These results show that students do not understand well what factors influence molecular polarity. Students are thought to understand that bond polarity is one of the factors that influence molecular polarity, but it seems that students think that lone electron pairs influence bond polarity, so students answer that lone electron pairs also affect molecular polarity.

Then, 11% of students believe molecules are polar when the bonds formed in the molecules are polar bonds, with CF = 3.73. It appears that students understand the importance of polar bonds so that molecules can be polar, but do not consider molecular geometry as another factor that determines molecular polarity. This shows an incomplete understanding of the concept of molecular polarity.

Question 8 asks about the polarity of the ClF_3 molecule. By considering the geometry of the molecule (letter T) and the difference in electronegativity between the Cl and F atoms which is quite large (0.8), it can be concluded that this molecule is polar. From this question, it was identified that 19% of students had the misconception that non-polar molecules are formed when the difference in electronegativity between atoms is small. Apart from that, the misconception that a molecule is polar is identified again when the bonds formed in the molecule are polar bonds (15%, CF = 3.33). The findings in this question strengthen the findings in question 5, where students appear to have an incomplete understanding of the concept of molecular polarity. This can be caused by several causes, for example, teachers who do not emphasize enough that there are 2 factors that influence molecular polarity, students who do not pay attention when the teacher explains or students who forget.

4.5 Intermolecular Forces

In total, there were 2 questions that asked about intermolecular forces, namely questions 6 and 10. Three misconceptions were identified with the percentage of students who answered both tiers correctly, respectively 11% and 14%. In general, students' conceptual understanding of the topic of intermolecular forces is still low. The misconceptions identified on this topic are in accordance with the findings of Peterson et al. (1989)

Question 6 asks students to determine between H_2S and H_2O, which one has stronger intermolecular forces, based on the facts of their phases at room temperature. Water has a liquid phase at room temperature, while hydrogen sulfide has a gas phase, so it can be concluded that water has stronger intermolecular forces. This strong intermolecular force can be explained by comparing the molecular polarities of the two compounds (Chang, 2010). Water is a very polar molecule while hydrogen sulfide, although it is a polar molecule, is quite weak because the difference in electronegativity between the H and S atoms is not too large. This causes the intermolecular forces in hydrogen sulfide to not be as strong as those in water. It seems that students understand well the relationship between the strength of intermolecular forces and their phases. This can be seen from the high percentage of students who were able to answer the tier answers correctly, 72%. However, there are quite a lot of students who cannot differentiate between intermolecular forces and chemical bonds (43%, CF = 3.40). Apart from that, it was also identified that 19% of students considered hydrogen sulfide to be a non-polar molecule, with a CF of 3.50. This misconception is most likely due to the fact that the difference between the H and S atoms is not very large, so students who do not really remember the limits of the electronegativity difference assume that the H-S bond is non-polar.

Question 10 asks students to compare the intermolecular forces of CF_4 with OF_2. CF_4 molecules are non-polar, while OF_2 molecules are polar, so it can be concluded that the intermolecular forces of OF_2 will be stronger than CF_4. This question again found that a number of students had difficulty distinguishing between intermolecular forces and chemical bonds, 24% to be precise.

Then, we can also observe the low percentage of students who can answer both tiers of questions correctly (14%). This is not too surprising, because to answer question 10, a good understanding of the concepts of bond polarity and molecular polarity is required and in accordance with the findings in other questions, students do not understand these two concepts well.

4.6 Octet Rule

There are 2 questions related to the octet rule, namely Questions 9 and 13. In total, 3 misconceptions were identified on this topic and the percentage of students who answered correctly was 51% for question 9 and 14% for question 13. In general, students' conceptual understanding was the octet rule isn't so bad.

Question 9 asks students to determine the function of the octet rule and what the octet rule contains. The octet rule is a general guide to stable electron configurations. The octet rule itself states that electrons are shared so that each atom reaches a stable electron configuration, namely the electron configuration of a noble gas with 8 valence electrons. From this question, 2 main misconceptions were identified, namely the octet rule is used to determine molecular geometry (20%, CF = 3.20) and the octet rule states that the number of bonds formed is equal to the number of electrons in the outermost shell. One interesting thing about this question is that a high percentage of students were able to answer both tiers correctly (51%). In fact, this percentage is the highest among the 15 questions given. From this, it can be seen that most likely, the misconceptions that occur are not due to the teacher, but rather due to the students themselves.

Question 13 asks about the correct Lewis structure of the N_2Cl_4 molecule. This question identified 13% of students choosing Lewis structures that do not satisfy the octet rule and believing electronegativity affects the number of bonds formed. This indicates that students do not understand the octet rules well, however, it is necessary to consider that the CF value reported by students is quite low (2.69). So most likely, students are just guessing when answering so it is not an indication that there is a misconception.

4.7 VSEPR Theory

There is 1 question related to VSEPR theory, namely question 11. Question 11 tests whether students understand VSEPR theory well. In this question, students are asked about the function of VSEPR theory and what the contents of VSEPR theory are. VSEPR theory itself, as explained above, is a method used to predict molecular geometry based on the repulsive force of electron pairs (Miessler et al., 2014). From this question, 3 misconceptions that occurred among students were identified. 30% of students believe that the VSEPR theory states that molecular geometry is caused by the repulsion of bonding atoms with a CF of 3.65.

Then it was identified that 13% of students believed that VSEPR theory was used to determine molecular polarity (CF 3.08). Because the percentage and level of confidence of students who experience these misconceptions are not very large, it is very likely that students who experience misconceptions are just guessing when filling in question 11 and are not an indication that there is a misconception.

5. CONCLUSION AND IMPLICATIONS

Even though there has been a lot of research conducted outside Indonesia that examines misconceptions related to chemical bonds, there is still little in Indonesia. Apart from that, the four-tier diagnostic instrument itself is still relatively new so it has not been widely used in research. This research applies a four-tier diagnostic instrument to 10th-grade high school students.

The results of this research indicate that the content of the four-tier diagnostic instrument used is valid and suitable for use in Indonesian high schools. The alpha value of the instrument for the answer tier, reasons and both tiers is low, but the low alpha value for the diagnostic instrument is normal because it is criterion-referenced and also shows that students' understanding is not perfect (misconceptions occur).

This research also shows that students do not have a good conceptual understanding of the topic of chemical bonds. The instrument identified 26 misconceptions with 23 being genuine misconceptions and 3 being spurious misconceptions. The average level of confidence reported by students is relatively high, 3.26, so it is very likely that the misconceptions identified are not the result of students just guessing and actually happening. In addition, based on the analysis of CDQ scores, it appears that students do not know what they do not know.

The results of the validation and reliability tests carried out show that the instruments used in this research can be used by chemistry teachers as a method to identify whether students have a good conceptual understanding of the topic of chemical bonds. Even though direct observations were not made during the learning process, the results of this research clearly show that the learning process that has been carried out has not been effective in encouraging students' conceptual understanding. The results of the research are relevant to the chemistry education process in Indonesia because by knowing the misconceptions that occur and the possible sources of misconceptions, chemistry teachers can develop better learning plans and ways of delivering material to prevent these misconceptions from occurring in other students.

Apart from that, it is important to develop instruments to identify misconceptions on other basic chemistry topics, for example, atomic theory and the periodic system of elements. This is because seeing the many misconceptions that occur on the topic of chemical bonds and the interconnectedness of basic chemical topics, so misconceptions on the topic of chemical bonds can cause misconceptions on other topics.

6. LIMITATION

The sample size which is only limited to one school means that the results of this study cannot be generalized to other schools. Some students may also take part in learning activities outside the classroom such as tutoring and tutoring. This variable is not controlled and can influence the research results.

Conflict of Interest

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