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ANALYSIS OF STUDENTS' CHEMICAL BONDING MISCONCEPTIONS USING TWO-TIER DIAGNOSTIC TEST

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Abstract
This study aims to identify the misconceptions of 10th-grade students of a Senior High School (SMA N 1) Ciawi Bogor on chemical bonding by using a two-tier diagnostic test consisting of nine questions. The research method that was carried out was quantitative research with a descriptive approach. The participants of this study were classes X-2, X-4, and X-8 of *SMAN 1* Ciawi in the academic year 2023/2024, with a total sample of 96 students taken from three classes using purposive sampling. Moderate misconceptions concerning ionic bonding have been discovered in the responses provided by the students for questions 1 and 2, with percentages of 37.50 and 34.38%, respectively. In Question 3, which covered lattice and intermolecular forces on silicon carbide, misconceptions among students were found to be 72.92%, indicating a high level of misconception. The percentage of students experiencing misconceptions about ionic bonding in question 4 (58.33%) was considered moderate. Students' misconceptions about bonding and intermolecular forces on magnesium oxide were determined to be relatively low, at 30.21%. Students who experienced misconceptions about the conductivity of graphite (Question 6) were 43.75%, which can be categorized as moderate misconceptions. In Question 7 about sulfur, student misconceptions were observed at 15.63%, but there were 47.92% who did not have prior knowledge about sulfur as a simple molecular compound. When asked about the differences in intermolecular forces on water and hydrogen sulfide, the percentage of students who had misconceptions was observed at 50.00%, then on the concept of lattice and intermolecular forces on macromolecules at 25.00%. These results are also influenced by students' prior knowledge of macromolecules, which is quite limited. Teachers and educators can employ potential futuristic instructional methods to help students understand chemical bonding more efficiently, such as implementing VR and AR simulations, gamification and game-based learning integration, and virtual field trips and interactive demonstrations.

Keywords: *chemical bonding; diagnostic test; misconception; two-tier*

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INTRODUCTION

Understanding chemical bonding is fundamental in chemistry, yet many high school students need help to grasp its intricacies. Misconceptions about chemical bonding can hinder students' comprehension of subsequent chemistry topics and ultimately impact their academic performance. Research has shown that students often attribute macroscopic properties of particles, incorrectly predict boiling points, and need clarification on the nature of hydrogen bonds, among other misconceptions [1]. These misconceptions can be attributed to various factors, including limited conceptual knowledge and low visual-spatial abilities [2]. To address these misconceptions and improve student learning outcomes, educators have employed multiple strategies, such as the 5E learning cycle model, which has been shown to reduce student misconceptions and increase student learning activities [3]. Additionally, innovative tools like augmented reality-based learning modules have been found to enhance student interest and motivation in learning chemical bonding [4]. This study aims to investigate the misconceptions of high school students regarding chemical bonding and explore effective methods to overcome these misconceptions and improve student learning.

Chemical bonding is a fundamental concept in chemistry that refers to the attractive forces between atoms that result in the formation of molecules. It is a crucial topic in learning and teaching chemistry because it provides the basis for understanding various chemical reactions and properties of substances [1], [2], [5]. Chemical bonding is essential for understanding chemical reactions, which are the foundation of chemistry. Chemical reactions involve the formation or breaking of chemical bonds, and understanding these bonds is critical to comprehend the reactions [1], [5]. Chemical bonding also plays a crucial role in determining the properties of substances, such as their color, boiling points, solubility, and conductivity. These properties are directly related to the chemical bonds present in the substance [1], [2]. Chemical bonding is also closely related to intermolecular forces, which are the forces that act between molecules. Understanding these forces is essential for understanding substances' physical and chemical properties [1], [2]. Chemical bonding is also crucial for understanding the geometry and polarity of molecules. This is important because the shape and polarity of molecules can significantly impact their properties and behaviors [1], [2]. Chemical bonding is a challenging topic for many students, and addressing misconceptions and misunderstandings in this area is essential. Effective teaching strategies, such as visual aids and hands-on activities, can help students better understand chemical bonding [4].

Alternative conceptions or misconceptions in learning and teaching chemistry refer to the incorrect or incomplete understanding of chemical concepts, often resulting from students' prior knowledge, experiences, and cultural backgrounds. These misconceptions can hinder students' ability to comprehend subsequent chemistry topics and impact their academic performance [6], [7], [8]. Students' understanding of newly acquired concepts can differ from scientifically acceptable knowledge due to their prior knowledge and experiences. This can lead to the development of alternative conceptions inconsistent with scientific concepts [6], [7]. Traditional teaching methods, such as the use of textbooks, can contribute to the development of misconceptions. On the other hand, active learning approaches can help students overcome these misconceptions by providing meaningful connections between new and prior knowledge [8]. Failure to construct conceptions on a logical framework and to make links among relevant conceptions can result in misconceptions inconsistent with scientific ideas [7]. Their cultural and environmental backgrounds can also influence students' understanding of chemical concepts. For example, students may have preconceived notions about certain chemical reactions or properties based on their everyday experiences [6]. Teachers' own misconceptions can also influence students' understanding of chemical concepts. Teachers should focus on both their own and students' misconceptions as well as gaps in definitions to ensure that knowledge conveyed is consistent with prior conceptions and experiences [6]. Chemical bonding is an abstract concept that can be difficult for learners to grasp, leading to misconceptions. Errors in understanding this concept can interfere with the learning of other interrelated concepts [1], [5].

A two-tier test is a diagnostic assessment tool used to identify students' misconceptions in chemical bonding. It consists of two levels of questions: the first tier is a multiple-choice question that tests students' surface-level understanding of the concept, and the second tier is a multiple-choice question that tests students' more profound understanding of the concept by providing additional context or information [5], [9]. Two-tier tests have proven valid and reliable in detecting students' misconceptions about chemical bonding. This ensures the assessment accurately reflects students' concept understanding [9]. Two-tier tests can identify misconceptions about various aspects of chemical bonding, including element stability, ionic bonding, covalent bonding, and metallic bonding [5]. Research has shown that two-tier tests can detect misconceptions in students from different school levels, including high, medium, and low levels, based on national test scores for chemistry [5]. Two-tier tests can provide information about students' conceptual understanding of chemical bonding, essential for addressing misconceptions and improving learning outcomes [2], [10].

Recent research has developed computer-based two-tier multiple-choice diagnostic tests, which can be used to identify misconceptions about chemical bonding. This approach can be more efficient and effective in assessing large numbers of students [2] [9]. Recent studies have continued to refine the use of two-tier tests in investigating student misconceptions in chemical bonding. For example, a study in 2020 used a four-tier diagnostic test to identify misconceptions in chemical bonding and found that students encountered the most misconceptions when determining bonds in microscopic scale [2]. Another study in 2022 used a three-tier multiple-choice diagnostic test to identify misconceptions in chemical bonding and found that 91.17% of students had misconceptions [10]. In summary, two-tier tests are a valuable tool for investigating student misconceptions in chemical bonding. They provide a valid and reliable assessment of students' understanding of the concept and can identify misconceptions in various aspects of chemical bonding. The latest research has continued to refine the use of two-tier tests, including the development of computer-based implementations, to improve the accuracy and efficiency of assessing student misconceptions.

Referring to the introduction that has been described, we have conducted an investigation on class X students at SMAN 1 Ciawi, Bogor Regency to identify misconceptions that occurred on the topic of chemical bonding, with the research title "Analysis of Students' Chemical Bonding Misconceptions with Two-Tier Diagnostic Test".

METHOD

The research method that was carried out was quantitative research with descriptive approach to identify students' misconceptions on chemical bonding. The overall population in this study was all 10th grade students, which consists of ten classes. The participants of this study were class X-2, X-4, and X-8 of SMAN 1 Ciawi in the academic year 2023/2024 with a total sample of 96 students taken from three classes using purposive sampling. Purposive sampling is a non-probabilistic sampling technique used in education research where the researcher selects participants based on specific criteria or characteristics that are relevant to the research question or objectives. Purposive sampling allows researchers to select participants who are most likely to provide valuable insights or information relevant to the research question. This targeted selection ensures that the participants represent the population of interest [11], [12]. Class X-2, X-4, and X-8 were selected to be participants in this study because they all have certain characteristics, like the same of a chemistry teacher, the method that is used in the teaching and learning process, and the student's study profile. After deliberate consideration, it is concluded that these three classes of data can represent all populations.

Data collection in this study was accomplished by distributing a two-tier diagnostic test that has been developed and used previously reported by Nimmermark et al. (2016) [13] (question number 1) and by Tan and Treagust (1999) [14] for questions 2 to 9. Three chemistry teachers translated and tested the instrument for content validity. The validity results were then evaluated using the Content Validity Index (CVI). The Content Validity Index is used to ensure that the items on a test are relevant and representative of the topic being assessed. This is important because a test that is not content-valid may not accurately measure the knowledge or skills of the test-takers. The CVI helps to identify items that may need revision or removal to improve the overall validity of the test. The value of CVI obtained was 0,95, which indicates that the item is highly relevant and representative of the topic, and it can be considered satisfactory [15].

The reliability of the test was calculated with Cronbach Alpha, which resulted in 0,707 for the answer and reason tiers when considered together, which remain in the category of "acceptable". Cronbach Alpha measures the degree to which the items within a test are correlated with each other. This is important in two-tier diagnostic tests, where the first tier presents multiple-choice options, and the second tier requires students to justify their answers. Cronbach Alpha helps to ensure that the items are consistent in their difficulty and relevance, providing a reliable measure of student understanding.

Students' responses to each test item were compiled according to their selection of particular response combinations. If a student did not select a response to both parts of an item, it was not included in the analysis. Afterward, students' answers were categorized into four categories: sound understanding (SU), partial understanding (PU), misconception (M), and no understanding (NU) [16]. This type of categorisation is also used in research studies conducted by [39, 40, 41].

Table 1. Criteria for analyzing the two-tier test items (adapted from [16]).

Categories			*Criteria*
First tier	*Second tier*		
True answer	True reason	(T-T)	SU
False answer	True reason	(F-T)	PU
True answer	False reason	(T-F)	M
False answer	False reason	(F-F)	NU

RESULTS AND DISCUSSION

To identify students' misconceptions in this study, a two-tier diagnostic test was used, which has been developed and used previously reported by Nimmermark et al. (2016) [13] (question number 1) and by Tan and Treagust (1999) [14] for questions 2 to 9. Each item of the test instrument highlights areas of alternative conception by students, as shown in Table 1. Question 1 and Question 2 both ask about ionic bonding and are differentiated by the type of compound, with Question 1 asking about potassium chloride and Question 2 about sodium chloride.

Table 2. Areas of alternative conception highlighted by each item of the test instrument [14].

Item No	*Areas of alternative*
1	bonding, lattice
2	bonding, lattice
3	lattice, intermolecular forces
4	Bonding
5	bonding, intermolecular forces
6	electrical conductivity of graphite
7	Lattice
8	intermolecular forces
9	lattice, intermolecular forces

Students' responses to each test item were compiled according to their selection of particular response combinations. If a student did not select a response to both parts of an item, it was not included in the analysis. The results of this scoring process are given in Table 3.

Table 3. The percentage of 10th grade students (*n* = 96) selecting each response combination [14].

Item	*Answer chosen*	*Reason chosen*			
		A	B	C	D
1	I	5.21	4.17	6.25	7.29
	II*	9.38	12.50	39.58*	15.63
2	I	11.46	8.33	9.38	6.25
	II*	9.38	12.50	30.21*	12.50
3	I	4.17	4.17	5.21	1.04
	II*	7.29	12.50*	17.71	47.92
4	I*	27.08	5.21	32.29*	26.04
	II	4.17	1.04	3.13	1.04
5	I*	12.50	14.58	3.13	48.96*
	II	2.08	3.13	15.63	0.00
6	I*	43.75*	10.42	16.67	16.67
	II	2.08	7.29	1.04	2.08
7	I	3.13	2.08	14.58	30.21
	II*	7.29	34.38*	4.17	4.17
8	I*	42.71	2.08	5.21	3.13*
	II	31.25	10.42	3.13	2.08
9	I*	10.42	9.38	12.50*	5.21
	II	16.67	15.63	26.04	4.17

Note: *indicates the correct answer for the item.

Afterward, students' answers were categorized into four categories: sound understanding (SU), partial understanding (PU), misconception (M), and no understanding (NU) [16]. They have sound knowledge when students answer correctly and choose the right reason. If the student selects an answer that is not correct but chooses the proper reason, then the student is classified as partially understanding. Misconception is experienced by students who have answered correctly but have yet to select the right reason. Students were in the category of no understanding if they answered incorrectly and chose incorrect reasons. The results of this categorization can be observed in Table 4.

Table 4. The percentage of four categories based on students' answers (adapted from [16]).

Item no.	*Criteria*			
	SU	PU	M	NU
1	39.58	6.25	37.50	16.67
2	30.21	9.38	34.38	26.04
3	12.50	4.17	72.92	10.42
4	32.29	3.13	58.33	6.25
5	48.96	0.00	30.21	20.83
6	43.75	2.08	43.75	10.42
7	34.38	2.08	15.63	47.92
8	3.13	2.08	50.00	44.79
9	12.50	26.04	25.00	36.46
Mean	28.59	6.13	40.86	24.42

Note: SU (Sound Understanding), PU (Partially Understanding), M (Misconception), and NU (No Understanding).

Based on students' answers to questions 1 and 2, 39.58% and 30.21% of students can be classified as having sound understanding. The misconceptions observed from questions 1 and 2 were 37.50 and 34.38%, respectively. Based on these results, they can be classified as moderate misconceptions because they range from 31-60% [17]. Students who could comprehend Question 3 correctly were 12.50%, and students who experienced misconceptions were observed to be 72.92%. Based on the results of this percentage, the misconceptions that have occurred can be categorised as high misconceptions because they are in the range of 61–100% [17].

The misconception that was observed from Question 4 was 58.33%; this result is classified as a moderate misconception because it is in the range of 31-60% [17]. Meanwhile, in Question 5, students who were able to answer correctly were 48.96%, while students who experienced misconceptions were 30.21%. Based on the results of this percentage, the misconceptions that have occurred can be categorized as low misconceptions because they are in the range of 0–30% [17]. The number of students who answered Question 6 correctly and those who experienced misconceptions were the same at 43.75%, which can be categorized as moderate misconceptions because they are in the range of 31–60% [17].

Students who can be categorized as having sound understanding in Question 7 are 34.38%, and those who experience misconceptions are 15.63% of students. However, 47.92% of students could not answer Question 7 correctly because they needed to gain prior knowledge about the question. A total of 3.13% of students could answer Question 8 accurately, and students who experienced misconceptions in this question were observed at 50.00%. Similar to Question 7, 44.79% of students could not answer Question 8 correctly because they needed to gain prior knowledge about the question. A different result was obtained in Question 9, where as many as 12.50% of students could answer the question correctly, and 26.04% of students could be classified as partially understanding. Low misconceptions were observed in Question 9, which was 25.00%. This result was thought to be influenced by the number of students who did not have prior knowledge of the question, which was 36.46%.

Both questions 1 and 2 were posed to determine if potassium chloride and sodium chloride are molecules. The correct answer for both questions is false. 38 students (39.58%) correctly answered and then selected the correct reason in question 1, followed by 29 students (30.21%) who answered and selected the correct reason in question 2. Students who selected the correct answer and the right reason can be said to have a sound understanding. A sound understanding refers to a student's ability to correctly comprehend and apply chemical bonding. This includes understanding the formation of ions, the transfer of electrons, and the resulting electrostatic attraction between ions. Students with a sound understanding can accurately describe the bonding between atoms and molecules and can apply this knowledge to solve problems and explain chemical reactions [2], [5].

Some students chose the wrong answers but chose the correct reasons, with six (6.25%) choosing question number 1 and nine (9.38%) choosing question number 2. Those students who chose incorrect answers but gave correct reasons can be considered to have partial understanding. Partially understanding refers to a student's ability to grasp some aspects of chemical bonding but not others. For example, a student might understand the concept of ionic bonding but struggle to comprehend covalent bonding. Students with a partial understanding may be able to describe some aspects of chemical bonding but need help to apply this knowledge to solve problems or explain chemical reactions [2], [5].

A total of 36 students (37.50%) answered question number 1 correctly but chose the wrong reason; this also happened to question number 2 by 33 students (34.38%). A group of nine students (9.38%) answered that sodium chloride, NaCl, exists as a molecule because the sodium atom shares a pair of electrons with the chlorine atom to form a simple molecule; this proves that there is a misconception among students that atoms of metal and non-metal share electrons to form molecules. Then there are also twelve students (12.50%) who chose the wrong reason, i.e., after donating its valence electron to the chlorine atom, the sodium ion forms a molecule with the chloride ion, which proves that there is a misconception among students that metals and non-metals combine to form molecules consisting of oppositely charged ions.

Misconception is experienced by students who have answered correctly but have yet to choose the right reason. A misconception refers to a student's incorrect understanding of chemical bonding. This can include beliefs that are inconsistent with scientific concepts, such as the idea that atoms share electrons to form bonds or that ionic compounds are molecular in nature. Misconceptions can be attributed to various factors, including prior knowledge, teaching methods, and cultural and environmental factors [2], [5], [6].

Subsequently, 16 students (16.67%) in question number 1 and 25 students (26.04%) in question number 2 provided incorrect answers and selected the wrong reason, indicating a need for a sufficient understanding of ionic bonds (no understanding). No understanding refers to a student's lack of comprehension of chemical bonding. This can include a complete lack of knowledge about the concept or a failure to understand the fundamental principles of chemical bonding. Students with no understanding may need help to describe or apply chemical bonding concepts and may require additional support to develop their knowledge [2], [5].

Some students mistakenly believe that when metal and non-metal atoms combine, they form covalent bonds by sharing electrons. They focus on the non-metal atoms completing their octet of outermost shell electrons but overlook the metal atoms' outermost shell. To correct this misconception, students need to visualize the ionic compound as a molecule and understand that metal atoms cannot achieve a stable octet by forming covalent bonds [14]. Teachers can use analogies and examples that emphasize the transfer of electrons in ionic bonding rather than sharing. This can help students understand ionic and covalent bonding [6]. Teachers could also use visual aids, such as diagrams or models, to help students visualize the formation of ions and the transfer of electrons in ionic bonding. Additionally, teachers can encourage active learning by providing opportunities for students to engage in hands-on activities, such as building models of ionic compounds [2]. By addressing these misconceptions and using effective teaching strategies, teachers can help students develop a deeper understanding of ionic bonding and reduce the frequency of misconceptions.

Question 3 was provided to students who inquired about the difference between intermolecular and intra-molecular forces. A group of twelve students (12.50%) had the correct answer and selected the correct reason, i.e., silicon carbide has a high melting point and boiling point because the bonds in silicon carbide are strong. The proper reason for this statement is that silicon carbide is a macromolecule composed of covalently bonded atoms. Students who selected the correct answer and the right reason can be said to have a sound understanding.

Silicon carbide (SiC) exhibits several properties that help illustrate chemical bonding concepts. SiC's high thermal conductivity allows it to efficiently transfer heat, which can be used to demonstrate the role of thermal energy in chemical bonding [18]. SiC can form different types of bonds with various materials, such as polymers, bentonite, and other substances, which can be used to illustrate different chemical bonding concepts [19], [20]. SiC's electronic structure and properties, such as its direct bandgap semiconductor nature, can be used to illustrate chemical bonding concepts related to electronic properties and bonding [21]. SiC can be synthesized using different methods, such as gas-emitting chemical reactions, which can be used to illustrate chemical bonding concepts related to synthesis and bonding [19]. These properties make silicon carbide a versatile material for illustrating various chemical bonding concepts, allowing researchers to explore different aspects of chemical bonding and its applications.

A group of four students (4.17%) answered that the bond in silicon carbide is weak but chose the correct reason. A total of 17 students (17.71%) chose the wrong reason that silicon carbide is a macromolecule composed of covalently bonded molecules, which proves that there is a misconception among students that a macromolecule is composed of covalently bonded molecules. Furthermore, a large number of 46 students (47.92%) chose the wrong reason, i.e., that a large amount of energy is required to break the intermolecular forces in silicon carbide, which proves that there is a misconception among students that there are strong intermolecular forces in a macromolecule. Students who experienced these misconceptions needed to understand the nature of continuous covalent lattices and the forces in such lattices. Another possible explanation is that they were unaware that silicon carbide is a macromolecule; they assumed that silicon carbide formed simple molecules with one atom of silicon sharing four electrons with one carbon atom. This could lead to the idea that silicon carbide has significant intermolecular forces, which explain its high melting and boiling points [14].

Continuous covalent lattices are abstract concepts that can be difficult for learners to grasp. The idea of a constant lattice of atoms or molecules can be challenging for students to visualize and understand [8], [22]. Students' prior knowledge and experience can influence their understanding of continuous covalent lattices. For example, students may have limited knowledge of chemical bonding or may have learned about covalent bonding in a way that does not accurately represent the nature of continuous lattices [6], [22]. The teaching methods that introduce continuous covalent lattices can also impact students' understanding. For example, if teachers use overly complex or abstract models, students may need help understanding the concept [5], [22]. Teachers can use real-life examples to help students understand the concept of continuous covalent lattices. For example, they can use examples of materials that exhibit continuous covalent bonding, such as graphite or diamond [6], [22].

A group of 31 students (32.29%) answered Question 4 correctly and also chose the right reason. Element C (electronic configuration 2,8,18,8,2) and element E (electronic configuration 2,7) react to form an ionic compound, CE_2; this statement is true because atoms of C will each lose two electrons and twice as many atoms of E will each gain one electron to form an ionic compound, CE_2. A total of 26 students (27.08%) answered correctly but chose the wrong reason, which is that an atom of C will share one pair of electrons with each atom of E to form a covalent molecule, CE_2. Based on these answers, it can be concluded that students have the misconception that ionic compounds exist as molecules formed by covalent bonding [14].

A group of five students (5.21%) answered correctly but chose the wrong reason, which is that a macromolecule consists of covalently bonded atoms of C and E. Subsequently, 25 students (26.04%) also answered correctly. Still, they chose the wrong reason, which is that an atom of C will lose one electron to an atom of E to form an ionic compound CE. Based on these answers, it can be concluded that students experience misconceptions; that is, in ionic bonding, the number of electrons transferred depends only on the number of electrons that the atoms of the non-metal need to achieve a stable octet [14]. The students did not fully understand the octet rule in ionic bonding. They were able to use it to make sure that the metal and non-metal ions had stable octets of electrons, but they neglected to take into account the necessary ratio of metal to non-metal ions [14].

The octet rule is an abstract concept that can be difficult for learners to grasp. It requires students to understand the electronic structure of atoms and how electrons are arranged in energy levels [8], [22]. Students' prior knowledge and experience can influence their understanding of the octet rule. For example, students may have a limited knowledge of atomic structure or may have learned about the octet rule in a way that does not accurately represent the concept [8], [22]. The teaching methods used to introduce the octet rule can also impact students' understanding. For example, if teachers use overly complex or abstract models, students may need help understanding the concept [8], [22]. Furthermore, students may need help understanding the electronic structure of atoms, which can make it difficult for them to differentiate between metal and non-metal bonds [8], [22]. Teachers can introduce chemical bonding as an electrostatic phenomenon, focusing on the interactions between positively and negatively charged non-metal ions. This approach can help students understand the octet rule and the differences between metal and non-metal bonds [23]. A teacher could also use Lewis structures to illustrate the octet rule and bond formation between metal and non-metal atoms. This approach can help students visualize the bonding process and understand the differences between ionic and covalent bonds [24]. Additionally, teachers can use real-life examples to illustrate the differences between metal and non-metal bonds. For example, discuss the properties of metals and non-metals, such as their reactivity and conductivity, to help students understand the differences between these two categories of elements [23]. By using these teaching methods, educators can help students develop a deeper understanding of the octet rule and the differences between metal and non-metal bonds, improving their overall knowledge of chemical bonding concepts.

A total of 47 students (48.96%) answered Question 5 correctly and selected the correct reason as well. The compound formed between magnesium and oxygen can be used as a heat-resistant material to line the walls of furnaces. This statement is true because there are strong ionic forces between magnesium and oxide ions in the lattice. A total of 14 students (14.58%) believed that this statement was correct but chose the wrong reason, i.e., the covalent bonds between magnesium and oxygen atoms are strong. This corresponds to research by Tan and Treagust (1999) [14], which states that 14.3% of students experience misconceptions, i.e., that metals and non-metals form strong covalent bonds. Furthermore, there are 15 students (15.63%) who believe that the statement in Question 5 is wrong because the intermolecular forces between the magnesium oxide molecules are weak. This was also in accordance with research by Tan and Treagust (1999) [14], which stated that 24.5% of students considered metals and non-metals to form molecules with weak intermolecular forces. A study by Fahmi and Irhasyuarna (2017) [25] found that students often hold misconceptions about intermolecular forces, including the idea that metals and non-metals form molecules with weak intermolecular forces. This misconception can be attributed to a need for an understanding of the electronic structure of atoms and the bonding properties of metals and non-metals.

The statement "metals and non-metals form molecules with weak intermolecular forces" is incorrect because metals and non-metals do not form molecules with weak intermolecular forces. Metals and non-metals have different electronic structures and bonding properties that lead to different types of chemical bonds. Metals typically form ionic bonds with non-metals, where the metal loses electrons to become a positively charged ion, and the non-metal accepts those electrons to become a negatively charged ion. This type of bonding is characterized by strong electrostatic forces between the ions rather than weak intermolecular forces [22]. Non-metals, on the other hand, typically form covalent bonds with other non-metals, where they share electrons to form a molecule. This type of bonding is characterized by strong covalent bonds between the atoms rather than weak intermolecular forces [24]. Weak intermolecular forces, such as van der Waals forces, are typically found between molecules of non-polar substances, such as noble gases or hydrocarbons. These forces are much weaker than the electrostatic forces between ions in ionic bonds or the covalent bonds between atoms in covalent bonds [22].

Magnesium oxide (MgO) is used to demonstrate interactions between metals and non-metals because it is a well-studied example of an ionic compound, where magnesium (a metal) and oxygen (a non-metal) combine to form a crystalline solid. This compound is particularly useful for illustrating the electrostatic interactions between metals and non-metals, which are crucial in understanding the properties of materials [26].

42 students (43.75%) answered and selected the correct reason for Question 6. Graphite can conduct electricity because it has delocalized electrons. This statement is true because only three of the four valence electrons of a carbon atom are involved in bonding, and the fourth electron is delocalized. The misconceptions observed from students' answers were 43.75%, consisting of 10 students (10.42%) choosing the incorrect reason that electrons escape from the covalent bonds in graphite and are free to move within the molecule. Then, 16 students (16.67%) chose the incorrect reason that graphite can conduct electricity because it has layers of carbon atoms that can slip over each other; this is in accordance with research by Tan and Treagust (1999) [14], which states that a total of 21.5% of students experience misconceptions on this statement. This might be because they were taught that mobile electrons and ions conduct electricity, and therefore, the layers of atoms could also conduct electricity because they could move [14]. Meanwhile, a total of 16 students (16.67%) chose the incorrect reason that graphite can conduct electricity because in graphite, some carbon atoms are delocalized and they conduct electricity; this is in accordance with research by Tan and Treagust (1999) [14], which states that as many as 31.4% of students experience misconceptions on this statement. Tan and Treagust (1999) [14] also discovered that the students in the sample did not have an understanding of the concept of electron delocalization in graphite, as demonstrated by their different conceptions of the substance's electrical conductivity.

Student misconceptions about the conductivity of graphite are common and often stem from a lack of understanding of the electronic structure of graphite. Many students believe that graphite is a non-conductor of electricity because it is a non-metal. However, graphite is actually a semiconductor, meaning it can conduct electricity under certain conditions. This is due to the unique electronic structure of graphite, which consists of a lattice of carbon atoms arranged in a hexagonal pattern. Each carbon atom has three valence electrons involved in forming covalent bonds with neighboring atoms. This leads to a partially filled band of electrons, which allows graphite to conduct electricity [26]. To address these misconceptions, educators can use hands-on activities and real-world examples to illustrate the conductivity of graphite. For instance, students can perform simple experiments involving the reaction of graphite with acids or bases to demonstrate its semi-conducting properties. Additionally, incorporating multimedia resources like videos and animations can help students visualize the electronic structure of graphite and its role in conductivity. Another example of delocalized electrons in the classroom is the benzene molecule. Benzene is a planar, hexagonal molecule with six carbon atoms and six hydrogen atoms. The molecular orbitals (MOs) of benzene are a combination of the atomic orbitals of the carbon atoms, resulting in a delocalized pi bond.

33 students (34.38%) answered and selected the correct reason for Question 7. Sulfur is a simple molecular compound because sulfur atoms form rings consisting of eight atoms (S_8) covalently bonded together. The correct reason for this statement is that simple molecular solids consist of molecules with weak intermolecular forces between molecules. 10 students (10.42%) chose the incorrect reason, i.e., simple molecular solids consist only of small molecules made up of two to four atoms; this is consistent with research by Tan and Treagust (1999) [14], which states that about 11.3% of students experience misconceptions on this statement. In addition, 18 students (18.75%) chose the incorrect reason, i.e., macromolecules contain molecules that are covalently bonded together; this is following research by Tan and Treagust (1999) [14], which states that about 27.8% of students experience misconceptions in this statement. A group of 33 students (34.38%) also chose the incorrect reason, i.e., when atoms of an element are covalently bonded, they will form macromolecules according to research by Tan and Treagust (1999) [14], which states that as many as 12.4% of students experience misconceptions on this statement. Most of the students could not differentiate between macromolecules and simple molecular compounds and had even just heard the two terms for the first time.

Macromolecules and simple molecular compounds are crucial topics to teach students because they form the foundation of understanding molecular structures and interactions. Macromolecules are large molecules composed of many repeating units, while simple molecular compounds are smaller molecules composed of fewer atoms. Macromolecules and simple molecular compounds participate in various chemical reactions, such as enzyme-catalyzed reactions and chemical synthesis. Understanding these reactions is vital for developing new medicines, materials, and technologies [27]. To demonstrate macromolecules, teachers can use examples like hemoglobin, which carries oxygen in the blood, or enzymes like lactase, which breaks down lactose in milk. This helps students understand the diverse roles of proteins in biological processes [28]. When explaining simple molecular compounds, teachers could highlight the importance of water in biological processes like hydration, temperature regulation, and the solubility of nutrients. This helps students understand the fundamental role of water in biological systems [29]. By emphasising the importance and relevance of macromolecules and simple molecular compounds and using visual aids and real-life examples, educators can effectively reduce misconceptions among students and foster a deeper understanding of these fundamental concepts.

Based on the students' answers, three students (3.13%) can be categorised as having sound understanding because they were able to answer and choose the correct reason for Question 8. Water (H_2O) and hydrogen sulphide (H_2S) have similar chemical formulas and structures. At room temperature, water is a liquid, and hydrogen sulphide is a gas. This difference in state is due to forces between molecules. The correct reason for this statement is because the forces between water molecules are stronger than those between hydrogen sulphide molecules. A group of two students (2.08%) were categorised as partially understanding because they chose the answer: forces within molecules, but chose the correct reason.

The misconception that occurred in Question 8 was 50.00%, consisting of 41 students (42.71%) who selected the incorrect reason, i.e., the difference in the forces attracting water molecules and those attracting hydrogen sulfide molecules is due to the difference in the strength of the O-H and the S-H covalent bonds; then, two students (2.08%) chose the incorrect reason, which is that the bonds in hydrogen sulfide are easily broken whereas those in water are not; and there were also five students (5.21%) who selected the incorrect reason, which is that the hydrogen sulfide molecules are closer to each other, leading to more significant attraction between molecules. These results are based on research by Tan and Treagust (1999) [14], which states that about 21.4% of students have misconceptions that the strength of intermolecular forces is determined by the strength of the covalent bonds present in the molecules. About 21.4% of students believe that covalent bonds are broken when a substance changes state. According to Tan and Treagust (1999) [14], the students lack understanding of intermolecular interactions in molecular solids, the intensity of these forces about covalent bonds within molecules, and the changes occurring when a substance experiences decomposition or changes states. A group of 43 students (44.79%) did not understand the concept; hence, they answered and selected the wrong reason.

Another common misconception among students is that water and hydrogen sulfide are both gases at room temperature. Students may assume that water and hydrogen sulfide are both gases because they are both found in gaseous forms under certain conditions. For example, water can be found in its gaseous form as water vapor and hydrogen sulfide can be found in its gaseous form in industrial processes or natural environments like volcanic areas. At room temperature and standard pressure, water is a liquid. It is composed of hydrogen and oxygen atoms bonded together through covalent bonds. This bond is strong enough to keep the molecules together, resulting in a liquid state [30]. At room temperature and standard pressure, hydrogen sulfide is a gas. It is composed of hydrogen and sulfur atoms bonded together through covalent bonds. The bond between these atoms is weaker than in water, resulting in a gas state.

According to the students' answers, twelve students (12.50%) may be categorized as having sound understanding because they can answer and choose the correct reason for Question 9. Then, 25 students (26.04%) may be classified as partially understanding because they picked the wrong answer but selected the correct reason. The misconceptions that were observed in the students' answers were 25.00%. Several ten students (10.42%) selected the incorrect reason because they had a misconception that the high viscosity of a molecular solid is due to the presence of layers of covalently bonded atoms, also reported by Tan and Treagust (1999) [14].

A group of nine students (9.38%) classified the XYZ product as a simple molecular substance because the thick, cream-like texture results from weak covalent bonding throughout the substance. The students experienced the misconception that molecular solids consist of molecules with weak covalent bonding between the molecules, similarly reported by Tan and Treagust (1999) [14]. Also, five students (5.21%) selected the wrong reason, i.e., the bonds within the molecules of the substance break easily to accommodate the changes in the shape of the solid. In addition, 35 students (36.46%) had no understanding because they were not able to answer and choose the correct reason for Question 9.

Macromolecules are large, complex molecules composed of many repeating units of smaller molecules, such as monomers. These repeating units are linked through various chemical bonds, resulting in a much larger and more complex structure than simple molecules [31], [32]. Macromolecules are essential for cellular functions, such as protein synthesis, DNA replication, and cell signaling. Understanding these processes helps students grasp the molecular basis of life and how cells function. Interactive tools like the 3D Memory Game and the REACT strategy can engage students in inquiry-based activities, enhancing their understanding of molecular concepts and promoting critical thinking [33], [34].

Chemistry, too, has its share of different concepts. Atoms are believed to maintain their own distinct identities within molecules, resulting in bonding electrons that are still believed to be connected to (and be a part of) the atom from which they originated. Students are expecting atoms to get back 'their own' electrons when the bond breaks, making it difficult for them to fully comprehend heterolytic bond fission. Some students argue that ions must be discharged by electrons returning to 'their own' atoms before new ionic compounds can be created. Because students sometimes fail to understand the physical (i.e., electrical) foundation of bonding, they define chemical change in anthropomorphic terms: atoms 'desire' or 'need' to have full shells. Of all, there are very few chemical processes where the reactants are atoms with partially filled electron shells; therefore, this only makes sense because students usually associate chemical processes with atoms [35].

Students have difficulty understanding bonding, which is not easily comprehended in terms of obtaining octets or entire shells since bonding is typically defined in these terms. By this point, students will have studied two methods (electron transfer and electron sharing) through which they believe entire shells can be achieved. As a result, the first impression of metallic bonding is frequently that of ionic or covalent connections. Rather than being something in between covalent and ionic bonds, polar bonding is generally thought of as a kind of covalent bond [35].

According to the literature that has been published so far (for example [14] and [36]), students have a tendency to overgeneralize the covalent bond. One could even say that the misunderstandings and misconceptions originate from some students' total lack of understanding of the existence of several bonding types. When it comes to differentiating between forces among different molecules (intermolecular forces) and forces within a molecule (covalent bonds), students also have difficulty. A reasonable explanation for this difficulty could be fundamental to the process involved in determining the strength of an intermolecular force: Students must look for polar bonds—high variations in the electronegativity of two covalently bonded atoms—within a molecule in order to determine which of the three types of intermolecular forces is present. A molecule's entire structure has partial charges on two sides due to single polar covalent connections, which may eventually create a dipole. Next, they must enlarge and see the entire molecule in order to deduce that molecules do, in fact, attract one another or engage in interactions between them.

The fact that students frequently overgeneralize about the existence of intermolecular interactions in metals and salts is another interesting observation. This can be explained through yet another oversimplification: students unintentionally conclude that there must be intermolecular forces because they overgeneralize the covalent bonding model in general and believe molecules are in all substances. Two review publications ([36] and [37]) argue that the literature currently does not address the common misconception that intermolecular forces exist in metals. In investigations using interviews, Taber (1998) [38] discovered that students believe intermolecular forces are present in ionic compounds. Students' misconceptions about chemical bonding that were identified in this study are listed in Table 5.

Table 5. Students' misconceptions about chemical bonding that were identified in this study.

Misconception	*Item no.*	*Percentage of students*	*Categories [17]*
Atoms of a metal and a non-metal share electrons to form molecules	1 and 2	9.38%	low
Metals and non-metals combine to form molecules consisting of oppositely charged ions	1 and 2	12.50%	low
A macromolecule is composed of covalently bonded molecules	3	17.71%	low
There are strong intermolecular forces in a macromolecule	3	47.92%	moderate
Ionic compounds exist as molecules formed by covalent bonding	4	27.08%	low
In ionic bonding, the number of electrons transferred depends only on the number of electrons that the atoms of the non-metal need to achieve a stable octet	4	26.04%	low
Metals and non-metals form strong covalent bonds	5	14.58%	low
Metals and non-metals form molecules with weak intermolecular forces	5	15.63%	low
Graphite conducts electricity because it has layers of carbon atoms which can slip over each other	6 [C]	16.67%	low
Graphite conducts electricity because in graphite some carbon atoms are delocalised and they conduct electricity	6 [D]	16.67%	low
Simple molecular solids consist only of small molecules made up of two to four atoms	7 [A]	10.42%	low
When atoms of an element are covalently bonded, they will form macromolecules	7 [C] 7 [D]	18.75% 34.38%	low moderate
The strength of intermolecular forces is determined by the strength of the covalent bonds present in the molecules	8	42.71%	moderate
Covalent bonds are broken when a substance changes state	8	7.29%	low
The high viscosity of a molecular solid is due to the presence of layers of covalently bonded atoms	9	10.42%	low
Molecular solids consist of molecules with weak covalent bonding between the molecules	9	9.38%	low

The impact of student misconception on their study performance is a significant concern in education. Misconceptions can lead to misunderstandings, confusion, and ultimately, poor performance in subjects such as chemistry, physics, and mathematics. A study on chemical bonding among tenth-grade senior high school students found that more than 50% of learners experienced misconceptions, which can interfere with the learning of other interrelated concepts and lead to poor performance in chemistry [5]. Research on the misconceptions of senior high school students in Banjarmasin on chemical bonding found that the percentage of misconceptions experienced by students in SMAN 2 Banjarmasin was 48.52%, indicating the potential for improved performance with effective teaching and learning strategies [25]. Students with uncorrected misconceptions may struggle to apply concepts in real-world situations, as their misconceptions can lead to incorrect solutions and a lack of understanding of the underlying principles.

Teachers and educators can employ some potential futuristic instructional methods to help students understand chemical bonding more efficiently. Instructors can construct immersive and engaging learning experiences that aid students in visualising and comprehending concepts related to chemical bonding by implementing VR and AR simulations. This can lessen misunderstandings by offering a more dynamic and interesting approach to learn about chemical bonding [2] [8]. Chemical bonding lessons can benefit from the integration of gamification and game-based learning techniques by educators [22]. By offering a more participatory and pleasurable learning environment, this can contribute to enhancing the learning process and decreasing misconceptions. In order to give students a more engaging and dynamic manner to investigate and engage with subjects related to chemical bonding, teachers could also plan virtual field trips and interactive demonstrations. This can give students a more engaging and practical learning experience, which can assist lower misconceptions [5] [25].

By employing the following techniques, teachers can adapt their lesson plans to meet students' varying misunderstanding levels. In order to address students' misconceptions, teachers might employ tools for evaluation and feedback to pinpoint the misconceptions that their students may have. For instance, evaluate students' understanding through quizzes or examinations and offer feedback to help them grasp the material better. Additionally, teachers could offer homework in tiers that correspond to students' understanding levels. One way to help students grasp the material better is to give them more difficult tasks, while giving struggling pupils easier ones.

CONCLUSION

Using a two-tier diagnostic test consisting of nine questions, 96 students in the 10th grade SMAN 1 Ciawi Bogor participated in the study to identify their misconceptions about the topic of chemical bonding. Misconceptions in learning and teaching chemistry refer to the incorrect or incomplete understanding of chemical concepts, often resulting from students' prior knowledge, experiences, and cultural backgrounds. Moderate misconceptions concerning ionic bonding have been discovered in the responses provided by the students for questions 1 and 2, with percentages of 37.50% and 34.38%, respectively. In Question 3, which covered lattice and intermolecular forces on silicon carbide, misconceptions among students were found to be 72.92%, indicating a high level of misconception. The percentage of students who misunderstood the concept of bonding in Question 4 (58.33%) was considered to be moderate. Students' misconceptions in Question 5 about bonding and intermolecular forces on magnesium oxide were determined to be relatively low, at 30.21%.

Students who experienced misconceptions on the conductivity of graphite (Question 6) were 43.75%, which can be categorised as moderate misconceptions. In Question 7 about sulphur, student misconceptions were observed at 15.63%, but there were 47.92% who did not have prior knowledge about sulphur as a simple molecular compound. Misconceptions in Question 8 were observed at 50.00%, then in Question 9 at 25.00%. These results are also influenced by students' prior knowledge of macromolecules, which is quite limited. Identifying student misconceptions on chemical bonding is essential to ensure that students have a deep understanding of the subject matter, can apply concepts in real-world situations, and develop critical thinking and problem-solving skills. Students with uncorrected misconceptions may struggle to apply concepts in real-world situations, as their misconceptions can lead to incorrect solutions and a lack of understanding of the underlying principles. Teachers and educators can employ some potential futuristic instructional methods to help students understand chemical bonding more efficiently, such as the implementation of VR and AR simulations, the integration of gamification and game-based learning, and also virtual field trips and interactive demonstrations.

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