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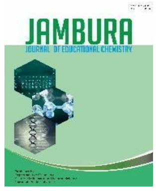

Analysis of Senior High School Students' Misconceptions on Chemical Bonding Using a Three-Tier Diagnostic Test

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Abstract

Chemical bonding remains a challenging topic in chemistry due to its abstract nature, which often leads students to develop misconceptions about electron interactions and bond formation. Despite the widespread use of diagnostic assessments, research on misconception patterns among Madrasah Aliyah students remains limited. This study investigated the forms and levels of misconceptions among Grade XI students at MAN 1 Gorontalo City using a three-tier diagnostic test. A descriptive quantitative method was employed involving 72 students and a 15-item instrument. The results showed that conceptual understanding reached 82.78%, while misconceptions accounted for 12.97%, with the highest percentage in basic chemical bonding concepts (17.36%). Misconception Type 1 (MK1) was the most dominant, indicating the need for instructional strategies emphasizing conceptual clarification and multiple chemical representations.

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1. INTRODUCTION

Chemical bonding is a fundamental topic in chemistry that explains how atoms interact to form molecules and compounds. Understanding chemical bonding is essential because it provides the conceptual foundation for many other chemical topics, such as molecular geometry, intermolecular interactions, reaction mechanisms, and material properties (Effendy, 2013; Cooper et al., 2020). In addition, chemical bonding concepts are closely related to various phenomena in everyday life, including environmental processes, biological systems, and technological applications. Therefore, a comprehensive understanding of chemical bonding is crucial for students to develop scientific literacy and to connect chemical knowledge with real-world contexts (Widiastuti, 2019; Pikoli, 2020).

Despite its importance, chemical bonding is widely recognized as one of the most difficult topics for students in chemistry education. The complexity of this topic arises from the need to understand abstract concepts at the submicroscopic level, such as electron interactions, atomic orbitals, and molecular structures. Students are required to integrate multiple levels of chemical representation, including macroscopic phenomena, symbolic representations, and submicroscopic models (Cooper et al., 2020; García-Franco & Taber, 2021). However, many students struggle to connect these representations, which often leads to misunderstandings and incorrect conceptual interpretations.

One of the most common learning difficulties encountered by students in chemistry is the emergence of misconceptions. Misconceptions refer to students' alternative conceptions that differ from scientifically accepted explanations but are strongly believed to be correct by learners (Vrabec & Prokša, 2016). difficulty in understanding the basic concepts of chemical bonding. This difficulty often leads to misconceptions, especially regarding the formation of ionic and covalent bonds and the process of electron interaction between atoms. Research using diagnostic instruments based on the Certainty of Response Index (CRI) shows that some students give incorrect answers but with a high level of confidence. This condition indicates that students not only do not know the concepts, but have also developed a misunderstanding of the material being studied. Therefore, the use of diagnostic instruments that can identify students' confidence levels is very important to more accurately map the structure of students' understanding of chemical bonding concepts (Karim et al., 2022). These misconceptions can significantly hinder the learning process because they interfere with students' ability to construct accurate scientific knowledge. When misconceptions persist, students may incorrectly interpret chemical phenomena and struggle to understand more advanced chemistry concepts.

Various factors can contribute to the development of misconceptions in chemistry learning. These factors may originate from students' prior knowledge, instructional strategies, learning materials, or the inherent abstractness of chemical concepts (Yuliana et al., 2013; Monita & Suharto, 2016). According to Rahayu (2021), Misconceptions about chemistry concepts, particularly chemical bonding, are still frequently found among students at various levels of education.

A literature study conducted by Zulkhairi (2022) indicates that misconceptions often occur because students already possess prior knowledge that is inconsistent with scientifically accepted concepts. This prior knowledge subsequently becomes the basis for interpreting new information, which may lead to the formation of incorrect conceptual understanding. Therefore, learning approaches that facilitate conceptual change are needed to help students reconstruct their initial understanding. This approach emphasizes that students actively construct knowledge through interaction with their environment and learning experiences, so instructional processes should be designed to challenge and restructure students' existing conceptions (Zulkhairi et al., 2022). misconceptions can arise from several sources, including incorrect personal experiences, misunderstandings of scientific terminology, inaccurate interpretation of conceptual relationships, and incomplete factual knowledge. In addition, traditional teaching methods that emphasize memorization rather than conceptual understanding may also reinforce misconceptions among students.

Previous studies have consistently reported that misconceptions related to chemical bonding remain prevalent among secondary school students. For instance, students often misunderstand the mechanism of electron transfer in ionic bonding, incorrectly assume that covalent bonds occur due to large differences in electronegativity, or fail to distinguish between intermolecular forces and intramolecular interactions (Cooper et al., 2020; García-Franco & Taber, 2021). Furthermore, students frequently experience difficulties in interpreting Lewis structures and applying the octet rule correctly, which may lead to incorrect conclusions about molecular structure and bonding (Çalık et al., 2021; Rohmah et al., 2023). Recent studies also indicate that misconceptions related to metallic bonding and intermolecular forces often arise because students cannot visualize particle interactions at the microscopic level (Sutton et al., 2024).

Misconceptions in chemical bonding are widely reported in chemistry education research. Many students experience difficulties in understanding the mechanisms underlying chemical bond formation because the concepts involve abstract microscopic interactions between atoms and electrons. Research conducted using a three-tier diagnostic test has shown that students often possess incorrect conceptual frameworks related to ionic and covalent bonding. These misconceptions include misunderstanding electron transfer in ionic bonding, misinterpreting the role of electronegativity in bond formation, and confusion between intermolecular forces and chemical bonds themselves. Such misconceptions can persist even after instruction because students tend to maintain prior conceptions that conflict with scientific explanations (Setiawan et al., 2022).

Difficulties in learning chemical bonding concepts are often associated with the emergence of persistent misconceptions among students. Misconceptions occur when students' understanding does not correspond to scientifically accepted concepts. A literature review conducted by Hendrawani (2023) indicates that misconceptions in chemical bonding frequently appear in several subconcepts, including ionic bonding, covalent bonding, Lewis structures, and the concept of electrostatic attraction between atoms. These misconceptions are influenced by various factors, such as the way the material is presented, the learning resources used, and the instructional strategies implemented by teachers. Therefore, mapping and identifying the forms of misconceptions are important steps in determining students' conceptual errors so that more effective learning strategies can be designed (Hendrawani, 2023).

Chemical bonding is considered one of the most complex and abstract topics in chemistry, which often leads to misconceptions among students. Previous research conducted by Islami, Suryaningsih, and Bahriah revealed that students' misconceptions regarding chemical bonding concepts can be effectively identified using diagnostic test instruments designed to analyze students' conceptual understanding in depth. The findings of the study indicate that misconceptions occur in several subconcepts of chemical bonding, including Lewis structures, the octet rule, metallic bonding, and VSEPR theory. These results suggest that students' conceptual understanding of chemical bonding still needs improvement through more effective instructional strategies and appropriate diagnostic assessments (Islami et al., 2019).

Given the persistence of misconceptions in chemical bonding, it is essential to employ appropriate diagnostic instruments that can accurately identify students' conceptual understanding. One instrument that has been widely used in chemistry education research is the three-tier diagnostic test. This instrument consists of three components: a multiple-choice question assessing conceptual knowledge, a reasoning question that evaluates students' understanding of the concept, and a confidence rating that measures the certainty of students' responses (Arslan, 2022).

The three-tier diagnostic test has been widely recognized as an effective instrument for identifying misconceptions in science learning. This diagnostic approach combines multiple-choice answers, reasoning explanations, and students' confidence levels, allowing researchers to distinguish between correct understanding, misconceptions, and lack of knowledge. Previous studies reported that this instrument provides more accurate information about students' conceptual understanding compared with conventional multiple-choice tests because it reveals not only the correctness of answers but also the reasoning and certainty behind them (Istiqomah et al., 2021).

Misconceptions in chemistry learning represent a complex issue because they are closely related to how students construct knowledge based on their prior learning experiences. One approach that has been widely used to identify students' misconceptions is the three-tier diagnostic test, which consists of three components: answer choices, reasoning for the selected answers, and the level of students' confidence in their responses. Through this approach, researchers are able to distinguish between students who truly understand the concept, those who hold misconceptions, and those who still lack sufficient conceptual understanding. Previous research has shown that misconceptions frequently occur in several aspects of chemical bonding, including atomic stability, the mechanism of chemical bond formation, and the role of valence electrons in the formation of compounds (Halim et al., 2017).

The three-tier diagnostic test instrument has also been developed as a more comprehensive evaluation tool for revealing students' conceptual understanding of chemistry concepts. This instrument enables researchers to analyze more deeply the patterns of students' reasoning when responding to conceptual questions. Previous studies have shown that three-tier diagnostic tests are capable of classifying students' levels of understanding into several categories, including correct conceptual understanding, misconceptions, and lack of conceptual knowledge. Therefore, the information obtained from this instrument can serve as an important basis for designing more effective instructional strategies to address and reduce students' misconceptions in chemistry learning (Setiawan et al., 2017). By combining these three elements, researchers can distinguish between students who truly understand the concept, those who hold misconceptions, and those who lack conceptual knowledge.

In addition to identifying misconceptions, several studies have also emphasized the importance of implementing instructional strategies specifically designed to address students' conceptual errors. One approach involves learning models that encourage students to reflect on their understanding and reconstruct their knowledge through discussion and the confrontation of misconceptions. Research findings indicate that instructional approaches focusing on the correction of

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misconceptions can significantly improve students' conceptual understanding of chemical bonding. Through such learning processes, students not only learn the correct answers but also develop a deeper understanding of the scientific reasoning underlying the concepts being studied (Warsito et al., 2020).

The use of three-tier diagnostic tests has been shown to be effective in identifying the nature and level of students' misconceptions. Compared to conventional multiple-choice tests, this instrument provides deeper insight into students' cognitive structures and the degree of confidence in their answers (Setiawan & Ilahi, 2022). Through this approach, misconceptions can be classified into several categories, such as misconception type 1, misconception type 2, and misconception type 3, depending on the combination of students' answers, reasoning, and confidence levels.

Although previous studies have explored misconceptions in chemical bonding, research focusing on the mapping of misconceptions among Madrasah Aliyah students is still relatively limited. Educational contexts, learning environments, and instructional practices may influence students' conceptual understanding in different ways. Therefore, investigating misconceptions in specific educational contexts is important to obtain a clearer picture of students' conceptual difficulties and to design appropriate instructional strategies.

Based on these considerations, this study aims to analyze the forms and levels of misconceptions among Grade XI students at MAN 1 Gorontalo City on the topic of chemical bonding using a three-tier diagnostic test. The results of this study are expected to provide valuable information for chemistry educators in identifying students' conceptual difficulties and in developing instructional strategies that can effectively address misconceptions and improve students' conceptual understanding of chemical bonding.

2. METHOD

3.1. Research Design and Participants

This study employed a descriptive quantitative research design aimed at identifying and describing the forms and levels of students' misconceptions on the topic of chemical bonding. The research was conducted at MAN 1 Gorontalo City, located at Jalan Poigar No. 26, Molosifat Village, Sipatana District, Gorontalo City, Indonesia. The study was carried out during the odd semester of the 2025/2026 academic year.

The research participants consisted of 72 Grade XI students who had previously studied the topic of chemical bonding. The participants were selected because they had completed the learning material related to chemical bonding, enabling the researchers to evaluate their conceptual understanding and identify possible misconceptions regarding the topic.

3.2. Research Instrument

Data in this study were obtained using a three-tier diagnostic multiple-choice test aimed at identifying students' conceptual understanding and misconceptions related to chemical bonding. The test instrument consisted of 15 questions that covered several topics in chemical bonding, including the basic concepts of bonding, ionic bonding, covalent bonding, metallic bonding, Lewis structures, and intermolecular forces.

Each question in the instrument was designed with three levels. The first level required students to select an answer that represented their conceptual understanding. The second level asked students to choose the reasoning that best explained their answer in the first level. The third level was used to determine the degree of students' confidence in their responses. The use of this three-tier structure allows researchers to distinguish more clearly between students who truly understand the concept and those who hold misconceptions or lack conceptual understanding.

3.3. Instrument Validity and Reliability

Prior to its implementation in the study, the diagnostic test instrument was subjected to a validation process to ensure its appropriateness in measuring students' conceptual understanding and misconceptions related to chemical bonding. The validation was conducted by three experts, consisting of two university lecturers in chemistry education and one experienced senior high school chemistry teacher. The evaluation focused on three main aspects: content, construction, and language. The content aspect examined the alignment between the test items and the learning indicators of chemical bonding concepts. The construction aspect assessed the clarity of the question structure and the completeness of the three-tier diagnostic test components. Meanwhile, the language aspect evaluated the clarity, readability, and suitability of the wording for senior high school students. The

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validation results showed that the instrument achieved a validity score of 95%, which is categorized as very high validity, indicating that the instrument was appropriate and feasible to be used in this research.

Furthermore, the reliability of the instrument was analyzed to determine the consistency of the test results. Reliability testing was carried out using the Cronbach's Alpha coefficient to evaluate the internal consistency among the test items. The analysis yielded a Cronbach's Alpha value of 0.82, indicating that the instrument possessed a high level of reliability. This result demonstrates that the diagnostic test is sufficiently consistent and reliable for identifying students' misconceptions and evaluating their conceptual understanding of chemical bonding concepts (Fahrunisa & Sudrajat, 2022).

3.4. Data Collection Procedure

Data was collected using a three-level diagnostic test designed to identify students' misunderstandings of chemical bonding concepts. The test was administered to 72 11th grade students at MAN 1 Gorontalo city during regular chemistry lessons based on a schedule agreed upon with the schools. Students took the test individually in class within 90 minutes under the supervision of researchers to ensure the test process ran smoothly and to prevent interaction between students. After the test was completed, all answer sheets were collected and verified to ensure completeness before being recorded, coded, and prepared for further analysis.

3.5. Data Analysis

Students' responses were categorized by integrating the results obtained from the three tiers of the diagnostic test. The combination of students' answers, reasoning selections, and confidence levels was used to determine their conceptual status.

Based on this combination, the responses were grouped into five categories: understanding the concept (PK), misconception type 1 (MK1), misconception type 2 (MK2), misconception type 3 (MK3), and lack of concept understanding (TPK). This categorization provides a clearer picture of students' conceptual conditions and helps identify the specific types of misconceptions that occur in learning chemical bonding concepts.

The data obtained from the test results were analyzed using descriptive statistical methods. The purpose of this analysis was to interpret the collected data and describe the distribution of students' conceptual understanding and misconceptions.

The percentage of students in each conceptual category was calculated using Equation (1) to identify the proportion of conceptual understanding and misconceptions for each indicator assessed.

$$P = \frac{X}{JS} \times 100\% \ x \qquad (1)$$

Description:

P = percentage of students classified into each conceptual category

X = number of students classified as scientific understanding, misconception, false positive, false negative, or lack of understanding

JS = total number of students

According to Arslan et al. (2012), responses from three-tier multiple-choice tests can be analyzed using a classification table to identify students' levels of understanding. Each student response was categorized based on a combination of conceptual answers, reasoning, and confidence levels, as shown in Table 1.

Table 1. Categories of Students' Understanding Levels Based on Three-Tier Diagnostic Test

First Level	Score	Second Level	Score	Third level	Category
Correct	1	Correct	1	Certain	Understanding Concepts (UC)
Correct	1	Incorrect	1	Certain	Misconception 1
Incorrect	0	Correct	0	Certain	Misconception 2
Incorrect	0	Incorrect	0	Certain	Misconception 3
Correct	1	Correct	1	Uncertain	Do not Understand Draf
Correct	1	Incorrect	0	Uncertain	Do not Understand Draf
Incorrect	0	Correct	1	Uncertain	Do not Understand Draf
Incorrect	0	Incorrect	0	Uncertain	Do not Understand Draf

The collected data were analyzed using descriptive statistical analysis. The percentage of students in each conceptual category was calculated for every subtopic of chemical bonding. The results of the analysis were then interpreted to determine the dominant forms of misconceptions and to describe the distribution of students' conceptual understanding across different indicators of chemical bonding concepts.

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3. RESULT AND DISCUSSION

3.1. Result

This study examined the patterns and levels of misconceptions about chemical bonding among Grade XI students at MAN 1 Gorontalo City, using a three-tier diagnostic test supported by the Certainty of Response Index (CRI). Students' conceptual understanding was categorized into five levels: correct understanding (PK), three levels of misconception (MK1, MK2, MK3), and lack of understanding (TPK). Figures 3 through 8 depict the distribution of students' understanding across six specific topics: fundamental bonding concepts, ionic bonding, covalent bonding, metallic bonding, Lewis structures, and intermolecular forces.

Figure 1 shows students' conceptual understanding of basic chemical bonding concepts. Most students were categorized as understanding the concept correctly (79.17%), while misconceptions were identified in MK1 (17.36%), MK2 (1.39%), and MK3 (2.08%). These findings indicate that although most students understood the basic principles of chemical bonding, several students still experienced misconceptions.

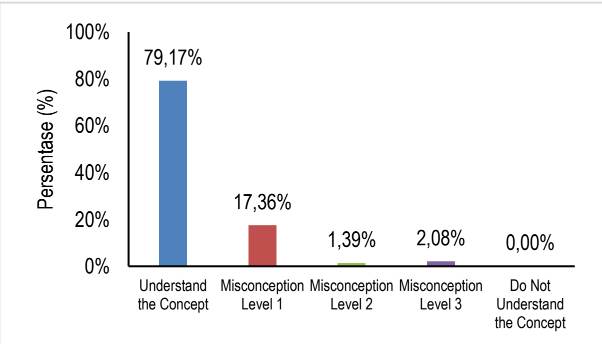

Figure 1. Distribution of students' conceptual understanding in basic chemical bonding concepts

Figure 2 presents students' conceptual understanding of ionic bonding. A total of 81.94% of students demonstrated correct understanding, whereas misconceptions occurred in MK1 (9.72%), MK2 (1.39%), and MK3 (2.08%). This indicates that ionic bonding concepts were generally well understood.

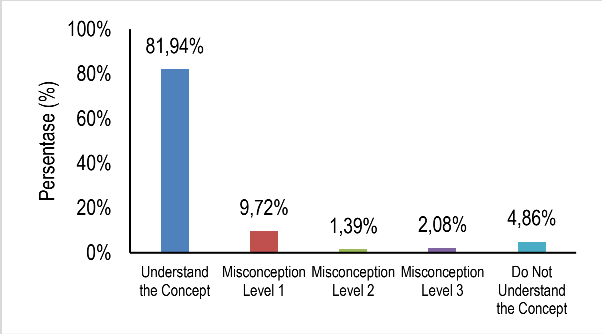

Figure 2. Distribution of students' conceptual understanding in ionic bonding

Figure 3 illustrates students' understanding of covalent bonding. Correct conceptual understanding was found in 79.63% of students, while misconceptions were distributed in MK1 (6.02%), MK2 (2.31%), and MK3 (6.48%). The relatively higher MK3 percentage indicates stronger misconceptions in this subtopic.

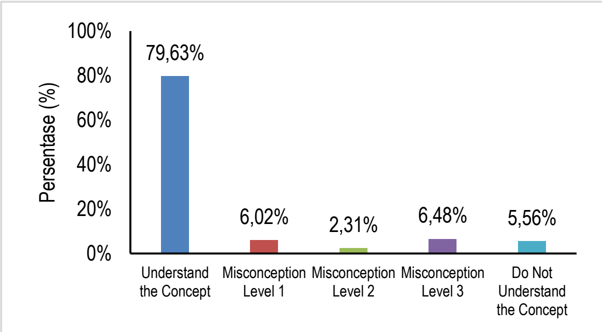

Figure 3. Distribution of students' conceptual understanding in covalent bonding

Figure 4 shows students' conceptual understanding of metallic bonding. Most students (89.58%) demonstrated correct understanding, while misconceptions were found in MK1 (2.78%), MK2 (0.69%), and MK3 (3.47%).

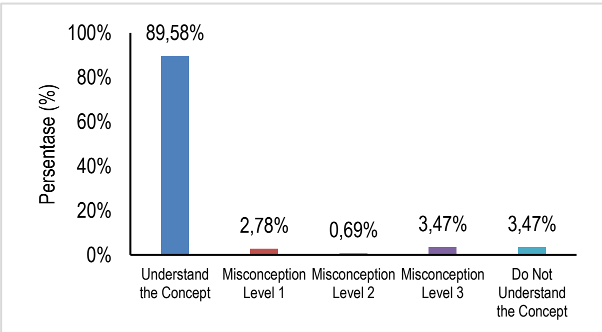

Figure 4. Distribution of students' conceptual understanding in metallic bonding

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Figure 5 presents students' conceptual understanding of Lewis structures. Correct understanding was observed in 82.64% of students, whereas misconceptions occurred in MK1 (4.17%), MK2 (4.17%), and MK3 (1.39%).

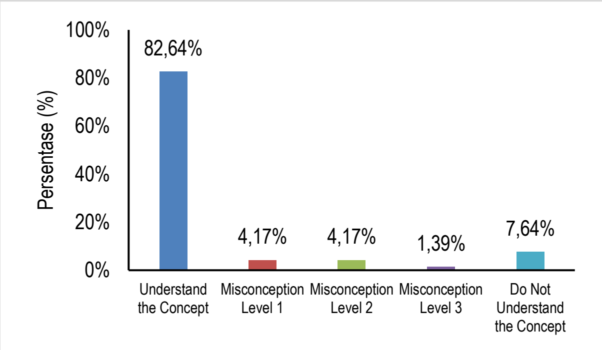

Figure 5. Distribution of students' conceptual understanding in Lewis structures

Figure 6 shows students' conceptual understanding of intermolecular forces. A total of 84.03% of students demonstrated correct understanding, while misconceptions were identified in MK1 (6.60%), MK2 (2.43%), and MK3 (2.08%).

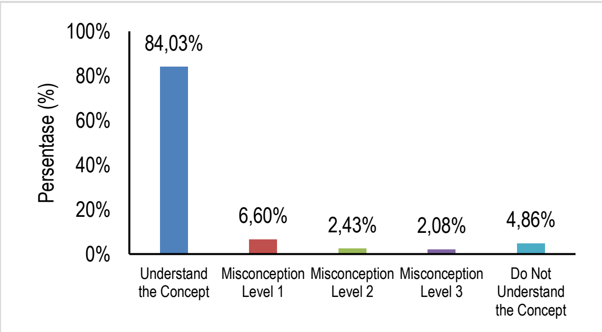

Figure 6. Distribution of students' conceptual understanding in intermolecular forces

3.2. Discussion

The dominance of MK1 in the basic chemical bonding concept indicator suggests that most students experience conceptual uncertainty rather than firmly established misconceptions. This finding indicates that students tend to understand the procedural aspects of the octet rule, but they lack a deeper understanding of electron configuration and energy stability principles. Similar findings were reported by Ardiansyah et al. (2021), who found that students often struggle to distinguish between electron transfer and electron sharing mechanisms in chemical bonding.

In the ionic bonding indicator, several students assumed that ionic bonds occur because atoms share electrons rather than transfer electrons to form positively and negatively charged ions. This misconception indicates that students have difficulty understanding the electrostatic attraction between cations and anions. Similar misconceptions have also been reported by Cooper et al. (2020), who found that students frequently confuse the mechanisms of ionic and covalent bonding due to insufficient emphasis on particle-level representations during instruction.

The relatively high percentage of MK3 in the covalent bonding indicator indicates that some students hold strong misconceptions regarding covalent bonding. For instance, several students believed that NH_3 is formed through electron transfer rather than electron sharing. Similar misconceptions have been reported in previous studies, which revealed that students often misinterpret the octet rule and Lewis structures when explaining covalent bonding mechanisms (Çalık et al., 2021).

Several studies have reported that misconceptions frequently occur in topics related to chemical bonding and molecular structure. For example, research conducted on university students showed that misconceptions commonly appear in covalent bonding concepts, particularly in understanding electron sharing mechanisms and the application of Lewis structures. These misconceptions often arise because students struggle to connect symbolic representations with submicroscopic particle models. As a result, students may correctly answer questions but still possess incorrect reasoning about the underlying chemical processes (Khairunnisa et al., 2020).

Although the level of misconception in the metallic bonding indicator is relatively low, some students assumed that positively charged particles such as protons move freely within the metallic lattice. In fact, electrical conductivity in metals occurs due to the movement of delocalized electrons within the metallic structure. This misconception has also been reported by Sutton et al. (2024), who found that students often incorrectly interpret the particle model of metallic bonding.

In the Lewis structure indicator, some students assumed that CO_2 forms ionic bonds or only single covalent bonds, indicating difficulties in applying the octet rule and distributing valence electrons correctly in Lewis structures. This finding is consistent with the study conducted by Rohmah et al. (2022), which reported that misconceptions in Lewis structures frequently occur because students struggle to integrate symbolic and submicroscopic representations.

In the intermolecular forces indicator, some students assumed that the high boiling point of water is caused by its molecular mass rather than hydrogen bonding. In addition, several students interpreted hydrogen bonds as intramolecular covalent bonds rather than intermolecular interactions. Similar misconceptions have been reported by García-Franco and Taber (2021), who found that students often fail to distinguish between intermolecular forces and intramolecular bonds due to limited understanding of molecular geometry and polarity.

Similar findings were also reported in studies investigating students' misconceptions in other chemistry topics using three-tier diagnostic instruments. The results indicated that misconceptions can occur at various levels depending on the combination of students' answers, reasoning, and confidence levels. Students who show high confidence in incorrect answers are considered to possess strong misconceptions, which require specific instructional strategies to correct. Therefore, identifying misconceptions through diagnostic assessments is essential to support effective conceptual change in chemistry learning (Azura et al., 2017).

Overall, the findings indicate that although most students demonstrate relatively good conceptual understanding of chemical bonding, misconceptions remain present across several subtopics. These misconceptions are primarily associated with students' difficulties in understanding submicroscopic representations and integrating symbolic and conceptual explanations in chemistry learning.

4. CONCLUSION

This study analyzed the forms and levels of misconceptions among Grade XI students at MAN 1 Gorontalo City on the topic of chemical bonding using a three-tier diagnostic test assisted by the Certainty of Response Index (CRI). The results indicate that students' overall conceptual understanding is relatively high, reaching 82.78%, while the overall level of misconceptions reaches 12.97%. The misconceptions consist of misconception type 1 (7.50%), misconception type 2 (2.41%), and misconception type 3 (3.06%), while 4.54% of students were categorized as not understanding the concept.

The highest misconceptions were found in the indicators of basic chemical bonding concepts and covalent bonding, indicating that students still experience difficulties in understanding electron interactions and the application of the octet rule in explaining bond formation. Several misconceptions were also identified in ionic bonding, Lewis structures, metallic bonding, and intermolecular forces, particularly related to students' difficulties in distinguishing electron transfer and electron sharing mechanisms, interpreting molecular structures, and understanding interactions between particles at the microscopic level.

These findings indicate that although students generally demonstrate a relatively good conceptual understanding, misconceptions remain present in several subtopics of chemical bonding. Therefore, chemistry instruction should emphasize the integration of macroscopic, symbolic, and submicroscopic representations, as well as the use of visualization-based learning strategies to help students develop a more accurate understanding of chemical bonding concepts.

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