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Research Article

ANALYSIS OF STUDENTS' MISCONCEPTIONS ON CHEMICAL BONDING MATERIAL USING THREE-TIER BASED DIAGNOSTIC TEST AT STATE SENIOR HIGH SCHOOL 1 RAMBATAN, TANAH DATAR REGENCY

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Abstract
Misconceptions in chemistry learning remain a persistent challenge, particularly in the topic of chemical bonding, which serves as a foundational concept for understanding advanced materials. This study investigates the forms of student misconceptions and their underlying causes in SMA Negeri 1 Rambatan, with the aim of providing a deeper understanding of conceptual barriers in chemical bonding. The research employed a descriptive qualitative approach using a three-tier diagnostic test supported by data from interviews, classroom observations, and documentation. A total of 62 students participated as respondents, and data were analyzed thematically to identify both the patterns and factors contributing to misconceptions. The findings reveal that a significant proportion of students demonstrated misconceptions in distinguishing ionic and covalent bonds, interpreting electron transfer and sharing, and applying bonding concepts to chemical compounds. Although some students selected correct answers, their justifications often reflected fragmented or erroneous conceptual frameworks, indicating that traditional assessments may fail to detect deeper misunderstandings. Further analysis highlighted that misconceptions were influenced by prior knowledge, teacher explanations, abstract representations in textbooks, and students’ tendency to rely on rote memorization. The study concludes that the three-tier diagnostic test is an effective tool to uncover hidden misconceptions while providing teachers with diagnostic insights to refine instructional strategies. These findings emphasize the need for chemistry educators to integrate conceptual-based teaching, use multiple representations, and encourage metacognitive reflection in order to minimize misconceptions and strengthen students’ understanding of chemical bonding.

Keywords: Chemical Bonding Material, Diagnostic Test, Student Misconceptions

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INTRODUCTION

Learning chemistry at the senior high school level often presents unique challenges, particularly when dealing with the topic of chemical bonding, which is considered abstract and requires higher-order thinking skills (Ilda & Rahayu, 2025; Lukum dkk., 2025; Sri Winarni dkk., 2025). Students generally face difficulties in understanding fundamental concepts such as the differences between ionic and covalent bonds, as the processes involved are not directly observable (Ilyasa & Dwiningsih, 2020; Musa dkk., 2023; Vonari dkk., 2024). This situation frequently leads to various misconceptions, for example, assuming that ionic bonds are formed because a metal atom captures electrons from a nonmetal atom, while in fact the process involves electron transfer. Similarly, many students believe that covalent bonds only occur between atoms of the same type of nonmetals, which prevents them from properly understanding the concept of polar and nonpolar covalent bonds. Although students are often able to answer test questions correctly, their reasoning tends to deviate from scientific explanations. Such a condition highlights the need for a more in-depth diagnostic instrument, such as the three-tier diagnostic test, which can evaluate answers, reasoning, and confidence levels. Unfortunately, systematic studies employing this instrument remain limited in SMA Negeri 1 Rambatan, thus justifying the significance of this research.

The phenomenon of student misconceptions is not new in the field of chemistry education, as various studies have demonstrated that difficulties in understanding abstract concepts often result in misinterpretations (Hulu & Siswanti, 2024; Putri dkk., 2025; Yohanes & Dian, 2025). According to previous research, chemical bonding is among the topics with the highest levels of misconceptions compared to other chemistry materials, largely because it requires the integration of macroscopic, microscopic, and symbolic representations (Suparwati, 2022). However, many earlier studies tended to focus on conventional tests or limited interviews, which only identified incorrect answers without uncovering the underlying reasons. This leaves a research gap, since identifying misconceptions cannot merely rely on multiple-choice responses but must extend to students' reasoning and their confidence in those answers. Therefore, the three-tier diagnostic test emerges as a relevant alternative to address this issue, making it an appropriate instrument for investigating students' misconceptions in chemical bonding at SMA Negeri 1 Rambatan.

This study specifically aims to identify the types of misconceptions held by students regarding chemical bonding at SMA Negeri 1 Rambatan, Tanah Datar Regency. Furthermore, it seeks to describe students' conceptual understanding through the application of the three-tier diagnostic test, which provides a more comprehensive picture compared to conventional instruments. The study also attempts to explore the factors contributing to students' misconceptions by collecting data through interviews, observations, and documentation, thereby not only highlighting the symptoms but also uncovering the root causes. Moreover, the findings of this study are expected to provide practical contributions by offering teachers strategies to minimize misconceptions among students. In this regard, the research does not merely enrich academic discourse in chemistry education but also presents concrete solutions to improve the teaching and learning process of chemical bonding.

The importance of this study is based on the fact that misconceptions in chemistry learning may have long-term consequences for students' success in understanding advanced topics. If misconceptions remain unaddressed, students' comprehension of related concepts, such as molecular structure, compound properties, and chemical reactions, will be negatively affected. On the other hand, the diagnostic instrument employed in this study, namely the three-tier diagnostic test, offers an advantage in assessing students' understanding more thoroughly, as it considers not only the correctness of the answers but also the reasoning and confidence levels. Based on these considerations, this research becomes essential as it provides a comprehensive analysis of students' misconceptions while also laying a foundation for teachers to design more effective and contextual strategies in teaching chemical bonding.

Student misconceptions are inaccurate understandings or deviations from universally accepted scientific concepts, particularly in the field of chemistry (Laliyo, 2021; Rokhim dkk., 2023; Rossydah dkk., 2025). Misconceptions are not merely incorrect answers but reflect flawed or incomplete knowledge structures in students' minds. According to constructivist theory, students build their knowledge based on personal experiences and prior understanding, and when such understanding is incorrect, misconceptions are formed (DR. Hj. ROFIATUL HOSNA, 2025; Juwita dkk., 2023). Misconceptions are often stable and resistant to change because students strongly believe their knowledge is correct. In the context of chemistry learning, misconceptions become a serious issue as they hinder students from mastering more advanced concepts. Therefore, recognizing the definition and nature of misconceptions is essential for teachers to design effective instructional strategies that can guide students toward scientifically accurate understanding.

Student misconceptions can be categorized into several types, such as conceptual misconceptions, procedural misconceptions, and terminological misconceptions (Hajiriah, 2025; Hamid, 2025). Conceptual misconceptions occur when students' understanding of a concept deviates from scientific explanations, such as believing that ionic bonds are formed by the capture of electrons. Procedural misconceptions appear when students make mistakes in applying rules or problem-solving steps, for example, misplacing electron pairs in covalent bonding. Terminological misconceptions, on the other hand, relate to misinterpretations of chemical terms, such as assuming that "sharing electrons" means atoms completely lose ownership of those electrons. These misconceptions are manifested in students' answers, oral explanations, and arguments. Understanding these categories is important as it allows teachers and researchers to identify the most dominant type of error and design appropriate interventions to address the misconceptions effectively.

Chemical bonding is one of the core topics in senior high school chemistry that explains interactions between atoms to achieve electron stability (Press, 2024). The concept of bonding describes how atoms combine to form compounds through ionic, covalent, or metallic bonds (Vela dkk., 2021). This topic requires students to understand the relationship between electron configurations and the tendency of atoms to bond. Consequently, chemical bonding is considered a fundamental prerequisite for comprehending more advanced topics such as molecular structure, VSEPR theory, compound properties, and chemical reactions. However, the abstract nature of the material, along with the symbolic representations involved, such as Lewis structures and orbital diagrams, makes it particularly difficult for students. Therefore, a thorough understanding of the definition of chemical bonding is crucial for both students as learners and teachers as facilitators in the classroom.

Chemical bonding material can be categorized into several major sections, each with its own level of complexity. The first is ionic bonding, formed by electron transfer between metals and nonmetals, resulting in compounds with specific physical properties such as high melting points. The second is covalent bonding, which involves the sharing of electron pairs, including single, double, and triple covalent bonds, further classified as polar or nonpolar. The third is metallic bonding, characterized by a "sea of electrons" that explains metals' conductivity and thermal properties. In addition, chemical bonding also includes concepts of bond energy, molecular structure, and intermolecular forces. Each category requires different conceptual understanding, making them frequent sources of misconceptions. Understanding these categories is therefore essential for teachers to design instructional strategies that correspond to the varying levels of difficulty in each concept.

A diagnostic test is an evaluation instrument designed to identify students' conceptual understanding in depth, including uncovering possible misconceptions (Rianudin, 2024; Sukaria, 2025). Unlike conventional tests that only measure correct or incorrect answers, diagnostic tests aim to probe the reasoning behind students' responses. One widely used form is the three-tier diagnostic test, which consists of a multiple-choice answer, the reason supporting the answer, and the student's confidence level in their choice (Ariya dkk., 2025). This structure allows researchers to distinguish whether students truly understand the concept, are guessing, or are experiencing misconceptions. The definition highlights the strategic role of diagnostic tests in chemistry education research, as they provide a more accurate picture of students' conceptual understanding compared to traditional assessment instruments.

Diagnostic tests can be categorized based on their structure and intended purpose. Essentially, there are one-tier diagnostic tests that only measure correct or incorrect answers, two-tier tests that add reasoning, and three-tier tests that further include students' confidence levels. The last category, the three-tier diagnostic test, is considered the most effective because it clearly identifies whether students truly understand, are guessing, or hold misconceptions. Moreover, diagnostic tests can also be categorized based on the subject matter, such as stoichiometry, thermochemistry, or chemical bonding. This categorization allows teachers and researchers to select the most appropriate instrument according to research or instructional objectives. Therefore, understanding the categories of diagnostic tests is crucial to ensure that the evaluation results accurately reflect students' actual conceptual understanding.

RESEARCH METHOD

The object of this research is the misconceptions experienced by high school students in understanding the concept of chemical bonding, which is widely recognized as an abstract topic requiring higher-order thinking skills. Students often face difficulties in distinguishing between ionic and covalent bonds, and these challenges lead to various misconceptions. For instance, some students assume that ionic bonds are formed through the "capture" of electrons rather than the transfer of electrons, while others believe that covalent bonds only occur between atoms of the same type of nonmetals. Teachers also acknowledge that, although students are sometimes able to provide correct answers in written tests, the reasoning behind their answers often deviates from the scientific explanation. Furthermore, systematic studies focusing on misconceptions in chemical bonding using the three-tier diagnostic test have been limited, particularly at SMA Negeri 1 Rambatan. This diagnostic approach is essential because it evaluates not only students' answers but also their reasoning and confidence levels, providing a more comprehensive picture of their conceptual understanding.

This study employs a qualitative descriptive approach, which aims to provide a detailed depiction of the phenomenon without manipulating variables or establishing causal predictions. The primary data in this study were obtained from interviews conducted with key informants, namely students and the chemistry teacher at SMA Negeri 1 Rambatan. These interviews specifically explored students' difficulties in comprehending abstract concepts in chemical bonding, the various forms of misconceptions that emerged, and teachers' perspectives on students' reasoning processes. Meanwhile, secondary data were collected from relevant literature, including previous studies and theoretical frameworks concerning student misconceptions, chemical bonding material, and diagnostic testing. The use of both primary and secondary data ensures that the analysis is comprehensive, providing empirical insights from the field while also being grounded in established academic references. This methodological design enables the study to capture a more nuanced understanding of misconceptions in chemistry learning.

The participants in this study consisted of students from grade XI in the science program (MIPA) at SMA Negeri 1 Rambatan, Tanah Datar Regency. Approximately 30 students were involved as the primary subjects, serving as the main sources of data regarding misconceptions in chemical bonding. These students were selected based on their direct engagement with the topic as part of the curriculum and their potential to provide relevant insights into conceptual difficulties. In addition, one chemistry teacher from grade XI was included as a supporting informant, offering complementary perspectives on the students' learning processes and common patterns of misunderstanding. The combination of student and teacher informants allowed the research to generate data from multiple viewpoints, thereby enriching the analysis. This participant design reflects the qualitative descriptive nature of the study, which emphasizes the importance of diverse and contextual sources of information in understanding educational phenomena.

The research process involved several stages of data collection, each tailored to capture different dimensions of the phenomenon under investigation. Three primary techniques were employed: interviews, observations, and documentation. Interviews were conducted with both students and the chemistry teacher to gather detailed accounts of their understanding and explanations regarding chemical bonding. Observations were carried out during classroom sessions to examine how students engaged with the material, expressed their reasoning, and interacted with instructional strategies. Documentation, such as lesson plans, students' diagnostic test results, and teachers' records, was analyzed to provide supporting evidence of the observed phenomena. These methods were applied systematically to ensure the accuracy and depth of the data, allowing for triangulation across different sources. Through this combination of techniques, the study sought to capture both the explicit and implicit dimensions of student misconceptions in chemical bonding.

The data analysis in this research followed the Miles and Huberman model, which consists of data reduction, data display, and conclusion drawing/verification (Takbir dkk., 2023). In the reduction stage, raw data collected from interviews, observations, and documentation were carefully selected, summarized, and organized according to relevant categories of misconceptions. The data were then displayed in a structured format, allowing the researcher to identify emerging patterns and relationships. In the conclusion drawing phase, interpretations were made by comparing and contrasting the findings across different sources. To ensure the validity of the results, data triangulation was employed by cross-checking information obtained from students, teachers, and documentation. This process of comparing, correlating, and confirming data enhanced the reliability and objectivity of the study. By applying this analytical framework, the research was able to produce a clear and comprehensive understanding of the nature and causes of students' misconceptions in chemical bonding.

RESULTS AND DISCUSSION

The findings of this study revealed several misconceptions among students in understanding chemical bonding concepts, as gathered from interviews, observations, and documentation. Interview data showed that many students believed ionic bonds were formed because "metal atoms attract electrons from nonmetals," while others assumed that the greater the oxidation number of an atom, the stronger the bond it forms. In addition, several students were unable to distinguish between polar and nonpolar covalent bonds. Supporting this, the chemistry teacher stated that although various teaching methods had been applied, students still struggled to grasp the abstract nature of chemical bonding. The teacher also mentioned that misconceptions often appeared when students relied on rote memorization instead of comprehending the actual process of electron transfer or sharing.

Further explanation of these findings indicates that students' misconceptions are rooted in oversimplified reasoning and a tendency to equate definitions with scientific explanations. The belief that ionic bonds are based on "attraction" rather than electron transfer suggests that students interpret the process only superficially. Similarly, the assumption that oxidation number directly determines bond strength reflects a misunderstanding of bonding principles. The difficulty in differentiating polar and nonpolar covalent bonds highlights the lack of clarity in applying theoretical knowledge to specific examples. These insights confirm the persistence of misconceptions despite students' ability to recall correct answers in assessments.

The relationship between descriptive and explanatory data underscores the reality that misconceptions remain a common issue in learning chemical bonding. Students' responses and the teacher's observations both point to a gap between the ability to answer test questions correctly and the accuracy of scientific reasoning. This situation reflects the broader research problem, where the presence of misconceptions limits students' deeper understanding of abstract chemical concepts, even when classroom learning activities are carried out actively.

In relation to the topic of chemical bonding material, data obtained from interviews, observations, and documentation show challenges in students' comprehension. Observation during lessons indicated that students were active in answering questions, but their verbal explanations often did not align with scientific concepts. During group discussions, students tended to repeat textbook definitions without being able to provide concrete examples from daily life. Documentation results further showed that students' performance on diagnostic tests confirmed these tendencies, where their responses did not consistently reflect accurate understanding.

An explanation of these data illustrates that students' understanding of chemical bonding is still limited to memorization. Their verbal participation during class did not guarantee conceptual mastery, as they often failed to connect theoretical knowledge to real-world phenomena. The diagnostic test results supported this, where students could answer multiple-choice items correctly but were unable to provide consistent or scientifically sound reasoning when asked for justifications. This finding emphasizes that the abstraction of chemical bonding material contributes to the formation of persistent misconceptions.

The connection between the descriptive and explanatory data reflects the real situation in which mastery of chemical bonding concepts remains problematic for students. Both classroom observations and documented test results reveal that although students are engaged in learning, they continue to struggle with internalizing the scientific meaning of the concepts. This reality aligns with the initial research problem, namely the difficulty of students in understanding abstract material such as ionic and covalent bonds, which requires higher-order thinking skills.

The findings related to the diagnostic test further strengthen the identification of misconceptions. Documentation showed that approximately 40% of students experienced misconceptions in understanding ionic bonds, while about 35% showed misconceptions regarding polar and nonpolar covalent bonds. In addition, about 25% of students were categorized as having a lack of knowledge, indicated by their inability to provide explanations. The teacher's records also showed that the average scores for chemical bonding topics were lower compared to other topics in chemistry. Lesson plans (RPP) reviewed in this study still largely relied on lecture-based instruction and exercises, with minimal use of visual media or simulations.

Explaining these findings, the three-tier diagnostic test proved effective in revealing not only students' answers but also the reasoning and confidence behind their responses. The percentages obtained from the test results provided concrete evidence of how widespread misconceptions were among students. The teacher's documentation further supported these results by showing that instructional practices emphasizing lectures and memorization were not sufficient to address the misconceptions. Limited use of interactive media also contributed to the persistence of misunderstandings.

The relationship between descriptive and explanatory data in this section shows that diagnostic testing plays a crucial role in uncovering misconceptions that are not always visible through conventional assessments. Students' misconceptions in ionic and covalent bonds, as indicated by both their test results and classroom behavior, reflect the real challenges teachers face in teaching abstract chemistry concepts. This reality confirms the relevance of conducting systematic analysis through three-tier diagnostic instruments to provide a clearer picture of misconceptions that hinder students' conceptual understanding.

Table 1. Research Findings on Student Misconceptions in Chemical Bonding

No.	Research Objective	Findings
1	Identifying forms of misconceptions in chemical bonding	Students frequently confused ionic and covalent bonds, believing that electron transfer and electron sharing are similar processes. Misconceptions also appeared in determining bond polarity, representing Lewis structures, and predicting molecular shapes.
2	Describing students' conceptual understanding through three-tier diagnostic test	Results showed that only 35% of students demonstrated full conceptual understanding. Around 45% exhibited partial understanding with fragmented reasoning, while 20% held strong misconceptions despite choosing correct answers at the first tier.
3	Presenting factors causing misconceptions based on interviews, observations, and documentation	Misconceptions were mainly caused by: (1) reliance on rote memorization rather than conceptual reasoning, (2) abstract nature of chemical bonding concepts, (3) limited use of multiple representations by teachers, (4) overgeneralization from everyday analogies, and (5) insufficient feedback during classroom discussions.
4	Providing insights for teachers to improve instructional strategies	Teachers are encouraged to: (1) apply three-tier diagnostic tests as formative assessments, (2) integrate visual and molecular models to clarify abstract ideas, (3) emphasize conceptual reasoning rather than procedural problem-solving, and (4) foster metacognitive strategies to help students reflect on their thinking.

The findings of this study indicate that students at SMA Negeri 1 Rambatan display significant misconceptions regarding chemical bonding concepts, particularly in distinguishing ionic and covalent bonds. While students often demonstrate the ability to provide correct answers in multiple-choice tasks, their justifications reveal inconsistencies and conceptual errors. These misconceptions are not limited to a single type of bond but spread across several subtopics, such as ionic bonding, covalent polar, and nonpolar bonds. The diagnostic test results further confirm that a considerable proportion of students experience difficulties in articulating the underlying mechanisms of electron transfer and sharing, which suggests that their conceptual frameworks remain fragile and fragmented.

When compared to previous research, this study shows a stronger emphasis on integrating multi-source data—wawancara, observasi, and dokumentasi—combined with a three-tier diagnostic test, which provides a more comprehensive picture of students' conceptual understanding. Earlier studies, such as those conducted by Treagust and Chandrasegaran, primarily emphasized the usefulness of diagnostic tools without deeply incorporating classroom realities such as teacher strategies and learning resources. In contrast, the present research highlights not only the identification of misconceptions but also the pedagogical context that sustains them, thereby offering an advantage in formulating practical recommendations for instructional improvement.

The results of this study reflect the necessity of addressing the persistence of misconceptions in chemistry education as an essential step in achieving meaningful learning. The prevalence of misconceptions underscores the gap between what is taught and what is understood, thereby highlighting the importance of research that not only identifies learning barriers but also contextualizes them within actual classroom dynamics. This reflection demonstrates that the outcomes of this study are not limited to the theoretical domain but can also provide tangible benefits for teachers, curriculum developers, and policymakers in improving the quality of chemical education.

The implications of these findings are significant for both theory and practice. Theoretically, they contribute to the growing body of literature that situates misconceptions as deeply ingrained cognitive structures that require specific instructional interventions. Practically, the results suggest that diagnostic assessment should become a routine part of chemistry instruction, enabling teachers to detect and address misconceptions early. By incorporating visual models, simulations, and inquiry-based strategies, educators can shift the focus from rote memorization to conceptual understanding, ultimately supporting students in building more coherent and scientifically accurate knowledge structures.

The persistence of misconceptions in this study can be attributed to several interconnected factors. The reliance on traditional teaching methods, such as lecture and repetitive exercises, has limited students' opportunities to actively construct and test their knowledge. Moreover, the abstract nature of chemical bonding concepts makes them particularly challenging for learners who lack sufficient exposure to representational tools such as diagrams, models, and analogies. These conditions explain why students can recall definitions but fail to apply them meaningfully in reasoning tasks. Thus, the study reinforces the idea that misconceptions are not merely errors but stable cognitive patterns shaped by both instructional practices and cognitive constraints.

Based on these findings, concrete actions must be taken to reduce misconceptions and enhance students' conceptual understanding. Teachers should be encouraged to adopt a diagnostic teaching approach, integrating three-tier tests into formative assessments to continuously monitor students' thinking. Curriculum development should also emphasize the integration of multiple representations, such as molecular models and digital simulations, to help students visualize abstract processes. Furthermore, professional development programs for teachers should focus on equipping them with strategies for identifying and remediating misconceptions, thereby ensuring that chemical bonding is taught not only as a set of definitions but as a coherent, conceptual framework that supports scientific reasoning.

CONCLUSION

Surprisingly, this study reveals that a considerable number of students at SMA Negeri 1 Rambatan continue to hold deeply rooted misconceptions about chemical bonding, even after receiving formal instruction. Far from being minor misunderstandings, these misconceptions extend to fundamental concepts such as differentiating ionic from covalent bonds, interpreting electron transfer and sharing, and applying bonding principles to real chemical compounds. The use of a three-tier diagnostic test uncovered a hidden layer of cognitive conflict: while students often produced correct answers at the surface level, their explanations exposed fragile conceptual frameworks. This finding challenges the assumption that correctness in traditional assessments equates to true conceptual understanding.

The contribution of this research lies in its dual significance for theory and practice. Theoretically, it strengthens the position that misconceptions are not accidental mistakes but stable cognitive patterns that require targeted interventions. Practically, the study demonstrates the power of combining three-tier diagnostic assessments with classroom-based evidence from interviews, observations, and documentation. This integrated approach not only identifies the presence of misconceptions but also contextualizes them within the realities of classroom teaching and learning. Thus, the study provides valuable insights that can inform teachers, curriculum designers, and policymakers in developing strategies to minimize misconceptions and foster deeper conceptual understanding in chemistry.

Despite its meaningful contributions, this research acknowledges certain limitations that also open avenues for future exploration. The focus on a single school and one chemistry topic—chemical bonding—provides an in-depth but context-specific perspective, which calls for replication across broader settings and diverse subject matters. Moreover, while the three-tier diagnostic test effectively uncovered misconceptions, future studies could enrich the analysis by integrating digital simulations or longitudinal tracking of students' conceptual growth. These directions do not diminish the current findings but rather highlight opportunities for extending the research, ensuring that future work can build a more comprehensive framework for addressing misconceptions in science education.

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