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Identification of Student Misconceptions Using a Five-Tier Multiple-Choice Diagnostic Test on the Topic of Chemical Bonding among Grade XI Students at SMA Taruna Pekanbaru

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Abstract

Chemical bonding is highly susceptible to misconceptions that can impede students' mastery of advanced chemistry concepts because of the discipline's interconnected conceptual structure. This study aimed to identify the chemical bonding concepts most frequently affected by misconceptions and determine their reported sources among Grade XI students at SMA Taruna Pekanbaru. A quantitative descriptive design was employed from February to July of the 2025/2026 academic year. Data were collected from 151 students using a 15-item five-tier multiple-choice diagnostic test and supplemented by interviews with five students selected through purposive sampling. The findings revealed an overall misconception rate of 52%, categorized as moderate. The highest misconception rates concerned ionic bonding (66%), coordinate covalent bonding (63%), and metallic bonding (61%). Personal reasoning was identified as the predominant source of misconceptions (64%), followed by textbooks (16%), peers (10%), teachers (7%), and the internet (3%). These results demonstrate that misconceptions remain prevalent across several chemical bonding concepts, particularly those involving microscopic reasoning and abstract representations. The study underscores the value of five-tier diagnostic assessment for identifying both misconception patterns and their sources. It also highlights the need for targeted remedial instruction incorporating cognitive conflict, visualization, contextualization, and systematic verification of the learning sources used by students.

Keywords: Chemical Bonding; Chemistry Education; Conceptual Understanding; Five-Tier Diagnostic Test; Misconceptions

INTRODUCTION

Conceptual understanding serves as a crucial foundation in chemistry education, given the hierarchical and interconnected nature of chemical concepts (Warsito et al., 2020). When students develop an understanding that diverges from scientific concepts, these errors can impact subsequent topics and hinder the learning process (Vonari et al., 2024). Misconceptions are not synonymous with a mere lack of knowledge; students may provide incorrect answers while remaining highly confident in their responses. Distinguishing this state from a lack of conceptual understanding is vital, as the appropriate instructional follow-up differs in each case (Umar et al., 2023).

Chemical bonding is a significant yet misconception-prone topic, as it requires grasping the relationships between macroscopic, submicroscopic, and symbolic representations. Difficulties often arise regarding concepts such as atomic stability, Lewis structures, ionic bonds, covalent bonds, coordinate covalent bonds, metallic bonds, molecular geometry, and intermolecular forces. Research by Sitorus & Dalimunthe, (2024) indicates that students struggle with various aspects of chemical bonding, while earlier studies on the same topic have identified misconceptions related to ionic bonds, covalent bonds, Lewis structures, and intermolecular forces (Simamora et al., 2023).

Conditions at SMA Taruna Pekanbaru underscore the urgency of this research. Interviews with the school's chemistry teacher revealed that the average student score on daily assessments for the chemical bonding unit was 70, falling short of the established mastery threshold (KKTP) of 80. The teacher observed patterns of conceptually flawed answers such as the belief that coordinate covalent bond formation is identical to ionic bonding because both involve electron transfer. Furthermore, although the instruction nominally employs the Discovery Learning model, actual practice tends to be teacher-centered and emphasizes rote memorization; consequently, students accept concepts without critically verifying their understanding, a situation compounded by limited facilities for chemical bonding practical work. These findings align with research by Rokhim et al., (2023), which indicates that factors such as students, teachers, learning resources, and the learning process can contribute to misconceptions.

Identifying misconceptions cannot be adequately achieved through standard multiple-choice tests, as a correct answer does not necessarily reflect a correct understanding. Multi-tier diagnostic tests were developed to reveal students' answers, reasoning, and confidence levels. The five-tier multiple-choice diagnostic test extends this format by incorporating the source of information students rely on when selecting their answers and reasons. Consequently, this instrument provides information not only on whether students harbor misconceptions but also on the likely origins of those conceptions (Rohmah et al., 2023).

Previous studies demonstrate that five-tier multiple-choice diagnostic tests have been applied to various science topics, successfully revealing both misconceptions and their sources. Research by Ramadhani et al., (2026) found that five-tier instruments could identify forms of misconceptions and their sources specifically those linked to learners' own reasoning and teachers' explanations. A study by Hidayah et al., (2023) also identified misconceptions regarding buffer solutions, with personal reasoning emerging as a dominant source. Regarding chemical bonding, Nufus & Silfianah, (2023) utilized a three-tier diagnostic test and found a 58% prevalence of misconceptions, while Nikmah & Prasetyo, (2025) employed a four-tier diagnostic test. These variations in instrument tiers suggest there is still scope to expand the identification of chemical bonding misconceptions using a five-tier format, which is specifically capable of mapping the sources of such misconceptions.

The novelty of this study lies in its mapping of misconceptions regarding chemical bonding across ten sub-concepts using a five-tier multiple-choice diagnostic test, while also linking these findings to the sources of the answers selected by students. Additionally, interviews with five students served as supporting data to gain deeper insight into the origins of the response patterns exhibited by students harboring misconceptions. Theoretically, this research is grounded in the view that students' initial conceptions can interact with new information to form alternative conceptions if they are not critically examined or challenged. Practically, diagnostic results can serve as a basis for teachers to select appropriate remedial strategies such as cognitive conflict, visualization, simulation, experimentation, and contextual learning. Therefore, this study focuses on identifying the chemical bonding concepts most prone to misconceptions and mapping the sources of these misconceptions among Grade XI students at SMA Taruna Pekanbaru. The findings are expected to provide a foundation for teachers to design more targeted remedial instruction, particularly for concepts associated with high rates of misconception.

METHODS

This study employs a descriptive research design with a quantitative approach. The design aims to describe the level of student misconceptions as observed in the field, without administering any experimental treatment. The descriptive approach aligns with the research objective: to map the percentage of misconceptions associated with specific concepts and identify their underlying sources.

The study was conducted at SMA Taruna Pekanbaru during the 2025/2026 academic year. Data collection took place from February to July 2026, comprising preparation, implementation, and completion phases. The study population consisted of all 243 Grade XI students at SMA Taruna Pekanbaru (2025/2026 academic year) who had studied the topic of chemical bonding under the same teacher. A sample of 151 students was selected using simple random sampling and Slovin's formula, with a precision level of 5%. Additionally, five students from different classes were selected via purposive sampling for interviews to provide supporting data.

The primary instrument was a 15-item, five-tier multiple-choice diagnostic test. The tiers consisted of: the answer choice (first tier), confidence level regarding the answer (second tier), reasoning (third tier), confidence level regarding the reasoning (fourth tier), and the source of information used to answer (fifth tier). The test items were adapted from Mualifah & Rahayu, (2022), and subsequently modified into the five-tier multiple-choice diagnostic format. The instrument underwent validation and reliability testing prior to use, confirming its validity and suitability. Data from structured interviews with the five students served as supporting evidence to classify the sources and formation processes of the misconceptions.

Data analysis involved classifying responses into categories: understanding the concept, misconception, lack of understanding, and error. Misconceptions were mapped across ten concepts: atomic stability, Lewis structures, ionic bonds, covalent bonds, single/double/triple covalent bonds, coordinate covalent bonds, metallic bonds, molecular geometry, Van der Waals forces, and ion-dipole forces. Misconception percentages were calculated at the test-item and sub-concept levels, then categorized by source: textbooks, teachers, personal reasoning, peers, and the internet. Interview results were used to reinforce the interpretation of the misconception source patterns identified in the test.

RESULTS

The analysis results indicate that misconceptions constitute the most dominant category of understanding. Overall, the average proportion of students falling into the misconception category reached 52%, while 28% demonstrated conceptual understanding, 12% showed a lack of understanding, and 7% exhibited errors. This pattern suggests that the primary issue is not merely an inability to answer, but rather the presence of understandings that are believed to be correct yet do not align with scientific concepts.

Table 1. Percentage of Students' Level of Understanding by Category

Test Item	Category							
	Conceptually Sound (PK)		Misconception (MK)		No Understanding (TP)		Error	
	Σ	%	Σ	%	Σ	%	Σ	%
1	49	32	83	55	11	7	8	5
2	33	22	84	56	19	13	15	10
3	69	46	52	34	19	13	11	7
4	28	19	90	60	17	11	16	11
5	34	23	99	66	14	9	4	3
6	63	42	56	37	24	16	8	5
7	67	44	60	40	15	10	9	6
8	67	44	57	38	22	15	5	2
9	42	28	87	58	12	8	10	7
10	42	28	86	57	17	11	6	4
11	12	8	104	69	18	12	17	11
12	22	15	92	61	22	15	15	10
13	34	23	71	47	20	13	26	17
14	40	26	77	51	21	14	13	9
15	38	25	88	58	17	11	8	5
Means	43	28	79	52	18	12	11	7

Source: Processed data, 2026

Based on Table 1, students' understanding of chemical bonding measured using a five-tier multiple-choice diagnostic test falls into four categories: understanding the concept (PK), misconception (MK), lack of understanding (TP), and error (E). Analysis of the 15 test items reveals that the average percentage of students exhibiting misconceptions is 52%, while 28% understand the concept, 12% lack understanding, and 7% make errors. These results indicate that misconceptions dominate students' understanding of chemical bonding;

therefore, further analysis is required to identify the specific concepts most prone to misconceptions and the factors or sources contributing to their emergence.

Subsequent analysis was conducted to identify the chemical bonding concepts most frequently associated with misconceptions. The analysis of ten concepts reveals that the level of misconception varies across the different concepts.

Table 2. Percentages and Categories of Misconceptions by Concept

Subject Matter Outline	Test Item	Misconception (%)	Average Misconception per Sub-concept (%)	Category
Atomic Stability	1	55	55	Medium
	2	56		
Lewis Structure	3	34	47	Medium
	4	60		
Ionic Bond	5	66	66	High
Covalent Bond	6	37	38	Medium
	7	40		
Single Covalent Bond, Double Covalent Bond, Triple Covalent Bond	8	38	48	Medium
	9	58		
Coordinate Covalent Bond	10	57	63	High
	11	69		
Metallic Bond	12	61	61	High
Molecular Geometry	13	47	47	Medium
Van der Waals Forces	14	51	51	Medium
Ion-Dipole Forces	15	58	58	Medium
Means			52	Medium

Source: Processed data, 2026

Based on Table 2, the percentage of student misconceptions regarding each chemical bonding concept varies, with an overall average of 52%, placing it in the moderate category. The highest levels of misconception were observed in the concepts of coordinate covalent bonding (63%) and ionic bonding (66%), both of which fall into the high category. Similarly, the concept of metallic bonding showed a misconception rate of 61%, also placing it in the high category. Meanwhile, the concepts of atomic stability (55%), Lewis structures (47%), covalent bonding (38%), single and multiple covalent bonds (48%), molecular geometry (47%), Van der Waals forces (51%), and ion-dipole forces (58%) all fell within the moderate category. These results indicate that student misconceptions are most pronounced regarding ionic bonding, coordinate covalent bonding, and metallic bonding; consequently, these concepts require greater attention during the learning process.

Table 3. Distribution of Sources of Student Misconceptions

Sources of misconceptions	Percentage
Personal thinking	64%
Books	16%
Friends	10%
Teachers	7%
The Internet	3%

Source: Processed data, 2026

Based on Table 3, the primary source of student misconceptions regarding chemical bonding is personal reasoning, accounting for 64% of cases. Other sources include textbooks (16%), peers (10%), teachers (7%), and the internet (3%). These results indicate that personal reasoning is the most dominant source of student misconceptions, whereas the internet accounts for the lowest percentage. The dominance of personal reasoning suggests that students' initial understanding and interpretation of chemical bonding concepts play a crucial role in the emergence of misconceptions; therefore, instructional approaches are needed to identify and correct understandings that do not align with scientific concepts.

Table 4. Percentage of Sources of Student Misconceptions by Concept

Sub-Concepts	MK	MK-B		MK-G		MK-PP		MK-T		MK-I	
		∑	%	∑	%	∑	%	∑	%	∑	%
Atomic Stability	167	19	11	14	8	100	60	17	10	7	4
Lewis Structure	142	18	13	10	7	95	67	16	11	3	2
Ionic Bonding	99	15	15	8	8	67	68	7	7	2	2
Covalent Bonding	116	25	22	6	5	69	59	12	10	4	3
Double Covalent Bonding I, II, III	144	22	15	9	6	99	69	9	6	5	3
Coordinate Covalent Bonding	190	36	19	12	6	126	66	9	5	7	4
Metallic Bonding	92	13	14	6	7	61	66	8	9	4	4
Molecular Shape	71	13	18	2	3	44	62	9	13	3	4
Van der Waals Forces	77	14	18	5	6	49	64	6	8	3	4
Ion-dipole Forces	88	16	18	4	5	58	66	8	9	2	2
Means			16		6		65		9		3

Source: Processed data, 2026

Based on Table 4, an analysis of the sources of misconceptions across various chemical bonding sub-concepts reveals that personal reasoning (MK-PP) is the most dominant source compared to others. Regarding the concept of atomic stability, personal reasoning accounts for 60% of misconceptions; for other sub-concepts, the figures are: Lewis structures (67%), ionic bonds (68%), covalent bonds (59%), single, double, and triple covalent bonds (69%), coordinate covalent bonds (66%), metallic bonds (66%), molecular geometry (62%), Van der Waals forces (64%), and ion-dipole forces (66%). Meanwhile, the contribution of other sources ranges from 13–25% for textbooks (MK-B), 2–19% for teachers (MK-G), 5–13% for peers (MK-T), and 2–4% for the internet (MK-I). Overall, the average data indicates that personal reasoning is the primary source of misconceptions (65%), followed by textbooks (16%), peers (9%), teachers (6%), and the internet (3%). These results demonstrate that misconceptions regarding various chemical bonding sub-concepts are more closely linked to the understanding and reasoning derived from students' own thinking than to other external sources.

DISCUSSION

Research results indicate that the prevalence of misconceptions regarding chemical bonding material reached 52%, placing it in the moderate category. The dominance of the misconception category compared to conceptual understanding (28%), lack of understanding (12%), and errors (7%) suggests that some students have not merely failed to grasp the concept but have actually formed and adopted alternative conceptions. These findings are significant because misconceptions can hinder the acquisition of new concepts and impact the learning of advanced material (Khairunnisa & Sudrajat, 2023). The high rate of misconceptions regarding ionic bonding (66%) indicates that understanding valence electrons, atomic tendencies to gain or lose electrons, and ion formation remains a challenge. In question item number 5, students incorrectly determined valence electrons because they focused only on a specific subshell. This finding is consistent with Karim et al., (2022), who also observed high levels of misconception when students determined ionic bond formation. Conceptually, valence electrons must be determined based on all electrons in the outermost principal energy level, rather than solely from the p-subshell.

Coordinate covalent bonding also showed a high misconception rate of 63%; specifically, question item number 11 reached 69%, representing the highest percentage across all items. Students could identify the location of the bond but still believed that the bonding electron pair originated from both atoms. This finding aligns with Islami et al., (2018), who reported a 63% misconception rate regarding the same concept. Such errors demonstrate that students fail to conceptually distinguish between the formation mechanisms of ordinary covalent bonds and coordinate covalent bonds. Regarding metallic bonding, the misconception rate reached 61%. Students struggled to link the physical properties of metals with the concept of delocalized electrons. These errors indicate that the submicroscopic concept has not been fully connected to macroscopic phenomena, such as the hardness and malleability of metals. This finding is consistent with Inggit et al., (2021), who found a 70.5% misconception rate regarding metallic bonding concepts. In contrast, the concept of covalent bonding showed an average misconception rate of 38%, placing it in the moderate category. Regarding items 6 and 7, errors primarily stemmed from confusing the sharing of electron pairs in covalent bonds with the transfer of electrons in ionic bonds. These findings align with those of Gultom et al., (2023) and Fitriani et al., (2023), indicating that students often conflate the characteristics of these two types of bonds. The overall misconception rate of 52% is lower than the 61.5% reported by Simanjuntak et al., (2025) regarding chemical bonding; however, both studies confirm that misconceptions remain a significant issue in this topic area. This difference in percentages cannot be directly interpreted as a change in the situation, given the variations in instruments, subjects, school contexts, and timing across the studies.

Regarding the sources of misconceptions, this study identifies personal reasoning as the dominant source, accounting for 64% of cases. This result is consistent with Awwalin & Nugroho (2024), who also found personal reasoning to be the primary source of misconceptions. These findings are further supported by Awwalin & Nugroho, (2024), who reported that 65.19% of misconceptions originated from personal reasoning. From Amala & Habiddin, (2022) perspective, students' prior knowledge and experiences can be integrated into their cognitive structures, influencing the formation of new concepts. The 16% attributed to textbooks supports Amala & Habiddin, (2022) view that imprecise language, explanations, and presentation styles in books can foster misconceptions. The 10% attributed to peers aligns with Khairunnisa & Sudrajat, (2023) who explains that interactions and discussions with friends can propagate erroneous explanations. The 7% attributed to teachers also warrants attention, as unclear explanations and limitations in teaching methods or facilities can contribute to misconceptions.

Internet sources accounted for the lowest share, at 3%. These results indicate that the internet is not the dominant source among the group studied, although it can still serve as a source of misconceptions when students accept information without verifying the source's accuracy. This finding aligns with Mualifah & Rahayu, (2022), who explained that easy internet access allows information to be quickly adopted as a learning resource. The research findings imply that teachers should use diagnostic results not merely to determine whether student answers are correct or incorrect, but also to identify the reasons behind the answers and the sources of the students' confidence. A five-tier diagnostic test can serve as a basis for determining remedial actions, as the instrument is capable of mapping answers, confidence levels, reasoning, confidence in that reasoning, and information sources.

For concepts associated with high levels of misconception specifically ionic bonds, coordinate covalent bonds, and metallic bonds instruction needs to place greater emphasis on macroscopic, submicroscopic, and symbolic representations. Strategies worth considering based on the research findings include cognitive conflict, laboratory experiments, interactive simulations, and contextual learning. The cognitive conflict approach has been reported to help students replace erroneous understandings with scientific concepts (Islami et al., 2018). Teachers must also address misconceptions stemming from students' own reasoning. Students should be given opportunities to explain their reasoning, compare predictions with observational results, and re-examine their conceptual beliefs. Consequently, instructional follow-up should not stop at providing the correct answer but should instead aim to alter the cognitive structures that give rise to the misconceptions.

This study has limitations regarding the representation of misconceptions across certain chemical bonding concepts. Some concepts were assessed using only a single test item; thus, the identification results for these concepts may not capture misconceptions as deeply as those assessed with two items. Furthermore, interview data were obtained from only five students as supporting evidence and were not intended to be representative of the entire cohort of 151 students. Therefore, the interview results serve to clarify patterns identified through the tests rather than to replace quantitative findings. This limitation should be taken into account when interpreting the percentages associated with each concept. Future research could employ multiple test items per concept, diversify the pool of interview respondents, and combine diagnostic testing with classroom observations or in-depth interviews to map the origins and mechanisms of misconceptions more comprehensively.

CONCLUSION

This study reveals that the average prevalence of misconceptions regarding chemical bonding among Grade XI students at SMA Taruna Pekanbaru is 52%, placing it in the moderate category. The distribution of understanding levels is as follows: conceptual understanding (28%), lack of understanding (12%), and errors (7%). The concepts associated with the highest rates of misconception are ionic bonding (66%), followed by coordinate covalent bonding (63%) and metallic bonding (61%). The primary sources of these misconceptions are personal reasoning (64%), followed by textbooks (16%), peers (10%), teachers (7%), and the internet (3%). Interviews confirmed that personal reasoning stemming from daily experiences and the students' own thought processes was the leading source of misconceptions.

The study contributes by mapping misconceptions about chemical bonding using a five-tier multiple-choice diagnostic test, which links students' levels of understanding with their confidence, reasoning, and sources of information. These findings can serve as a basis for prioritizing remedial instruction, particularly regarding ionic bonding and coordinate covalent bonding. For chemistry education, these results underscore the importance of diagnostic assessments that reveal students' initial conceptions prior to instruction or remediation.

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