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Original Research

Analysis of Conceptual Readiness in Chemical Bonding Concepts among Pre-Service Chemistry Teachers Using a Three-Tier Diagnostic Test

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ABSTRACT

The conceptual readiness of pre-service chemistry teachers regarding chemical bonding plays a crucial role in supporting pedagogical competence and deep content understanding. This study aims to analyze the level of students' conceptual readiness in understanding chemical bonding concepts using a three-tier diagnostic test. A qualitative research method with a descriptive approach was employed, involving 27 students from the chemistry education program at a private university in North Sumatra. The results indicate that most students are at a partial understanding level, with a dominance of misconceptions, particularly in concepts such as ionic bonding, compound polarity, and valence bond theory. These findings highlight the urgent need to strengthen pedagogical strategies and enhance instructional design to improve conceptual literacy and prepare future teachers to face the challenges of 21st-century science education. The study recommends the integration of diagnostic assessment into teacher education curricula to support the development of chemistry instruction that is conceptually grounded and sustainability-oriented.

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1. INTRODUCTION

Understanding the concept of chemical bonding is a fundamental pillar in chemistry education, as it is inherently abstract and often leads to misconceptions among students and pre-service chemistry teachers (Taber, 2010). Misunderstanding ionic, covalent, or metallic bonding can hinder further learning processes such as molecular shape, reactivity, and thermodynamics. To accurately identify misconceptions, specialized diagnostic instruments are required—ones that can capture not only correct or incorrect answers, but also the underlying reasoning and the level of confidence students have in their responses (Laksono, 2020; Mellyzar, 2021; Şen & Yılmaz, 2017).

The three-tier diagnostic test model consists of three levels: (1) a conceptual question, (2) a justification for the chosen answer, and (3) the student's confidence in that choice. This structure enables an in-depth analysis of conceptual readiness and the presence of misconceptions (Buzzo & Montecinos, 2014). In the context of chemical bonding, several studies have shown a high rate of misconceptions among high school students and pre-service chemistry teachers, with misconception percentages ranging from 40% to

70%, depending on the specific concept indicators used (Ardiansyah et al., 2021; Levy Nahum et al., 2010; Kind, 2014).

Pre-service chemistry teachers in Indonesia are also not exempt from this phenomenon. A study using a two-tier diagnostic test on the concept of chemical equilibrium revealed that 13.85% of students experienced misconceptions related to Le Châtelier's principle, equilibrium constants, and the effect of catalysts (Agatha et al., 2022). Meanwhile, regarding the concept of particle theory, an analysis involving 148 pre-service chemistry teachers using a two-tier test concluded that misconceptions were found in 10 out of 11 test items, with less than 10% consistency between correct answers and correct reasoning—indicating that the concepts had not been thoroughly mastered (Rahmawati et al., 2019).

Although the two-tier diagnostic test has made a significant contribution to identifying misconceptions, the use of a three-tier diagnostic test offers greater depth by adding a confidence dimension, making it more valid and reliable in measuring conceptual readiness (Jusniar et al., 2020; Buzzo & Montecinos, 2014). However, studies that specifically utilize the three-tier diagnostic test to assess the conceptual readiness of pre-service chemistry teachers on chemical bonding topics remain very limited—particularly in the context of chemistry education students in Indonesia.

Based on the aforementioned background, this study aims to explore the level of conceptual readiness of pre-service chemistry teachers regarding chemical bonding concepts using a three-tier diagnostic test. Through this instrument, it is expected that valid data can be obtained concerning the dimensions of conceptual understanding, reasoning behind answer choices, and students' confidence levels—thus supporting the design of more effective instructional strategies and interventions to enhance the quality of future chemistry teachers.

2. METHOD

This study employs a descriptive approach. The descriptive approach aims to systematically and accurately portray facts and characteristics of the population or phenomenon under investigation without manipulating research variables (Nassaji, 2015). In this context, the descriptive approach is used to identify the level of conceptual readiness among pre-service chemistry teachers based on the results of the three-tier diagnostic test. The use of this approach is highly relevant in diagnostic studies of scientific concepts, as it allows researchers to identify misconceptions, partial understandings, and affective dimensions such as the confidence level associated with students' answers (Jusniar et al., 2020).

The study was conducted in June 2025 at one of the universities in North Sumatra. The timing was chosen immediately after the students had completed the chemical bonding topic to ensure that their conceptual readiness was still fresh. The subjects of this study were 27 students from the Chemistry Education program at one of the universities in North Sumatera. The participants were selected using purposive sampling, targeting students who had completed the chemical bonding course and were ready to take the three-tier diagnostic test.

The test items used in this study were three-tier multiple-choice diagnostic questions developed based on the topic of chemical bonds and structure, as well as essay questions derived from the indicators in the semester learning plan. The test consists of multiple-choice questions structured in three levels: the first tier presents a question along with its answer choices; the second tier contains a question about the underlying concept of the first-tier item with corresponding conceptual answer options; and the third tier assesses the student's confidence in the answers selected in both the first and second tiers. This test design enables the identification of students' conceptual understanding categories related to chemical bonding.

The students' responses, correct reasoning, and confidence levels will be scored based on the scoring rubric corresponding to the combination of answers in the three-tier diagnostic test. Data analysis was carried out using a descriptive qualitative approach by categorizing students' responses into several types of understanding, namely: (1) conceptual understanding, (2) misconception, and (3) lack of understanding. These categories were determined based on the alignment between the answer, the reasoning, and the level of confidence. Table 1 presents the classification of conceptual understanding types in the CBMT (Chemical Bonding Multiple-Tier Test).

Table 1. Classification of Conceptual Understanding Types in CBMT

No	Tier 1	Tier 2	Tier 3	Category	Code
1	Correct	Correct	Confident	Conceptual Understanding	CU
2	Correct	Correct	Not Confident	Lack of Understanding	LU
3	Correct	Incorrect	Confident	Misconception	MC
4	Correct	Incorrect	Not Confident	Lack of Understanding	LU
5	Incorrect	Correct	Confident	Misconception	MC
6	Incorrect	Correct	Not Confident	Lack of Understanding	LU
7	Incorrect	Incorrect	Confident	Misconception	MC
8	Incorrect	Incorrect	Not Confident	Lack of Understanding	LU

The combination of Tier 1, Tier 2, and Tier 3 provides a detailed overview of the students' conceptual status:

1. Conceptual Understanding (CU)

Students who answer both Tier 1 and Tier 2 correctly and express high confidence in Tier 3 are categorized as having a complete conceptual understanding. This indicates that the student not only understands the concept factually but also possesses logical reasoning and confidence in their comprehension.

2. Misconception (MC)

If a student answers either or both of the first two tiers (Tier 1 and/or Tier 2) incorrectly but demonstrates high confidence in their response, this indicates the presence of a misconception. Misconceptions are particularly problematic because they are not simply a lack of knowledge but rather represent alternative conceptions that are incorrect yet strongly held by the learner. This aligns with the theory of alternative conceptions in science education, where learners construct their own interpretations that deviate from scientifically accepted concepts (Taber, 2018).

3. Lack of Understanding (LU)

Answer combinations that reflect uncertainty, whether in selecting the correct answer or its justification, are categorized as a lack of understanding. This may occur even if the answer is correct; however, without the correct reasoning and with low confidence, the student cannot be considered to have truly understood the concept. According to Jusniar et al. (2020), low confidence in one's own answers may indicate weak cognitive construction or a lack of self-assurance in a particular conceptual domain.

3. RESULTS AND DISCUSSION

This study aims to analyze the conceptual readiness of pre-service chemistry teachers in understanding chemical bonding concepts using a three-tier diagnostic test instrument. The instrument consists of 20 items representing essential subtopics such as the octet rule, the formation of ionic and covalent bonds, molecular polarity, Lewis structures, and the physical properties of compounds. The analysis was conducted based on the percentage of student responses categorized as misconceptions (MC), lack of understanding (LU), and conceptual understanding (CU). The research findings are presented in Table 2.

The data in Table 2 show that the majority of pre-service chemistry teachers are still categorized under misconceptions and lack of understanding, particularly in subtopics such as ionic bonding, Lewis structures, and molecular geometry. In contrast, the level of conceptual understanding is very low, with only one or two items exceeding 40%, for example, item 7 related to the octet rule.

This condition indicates that students have not yet developed an adequate conceptual framework regarding core topics in chemical bonding. It reinforces the view that abstract concepts in chemistry—especially those involving symbolic and microscopic representations—remain a major challenge in the learning process (Johnstone, 1991). The following is an Analysis Based on Subtopics.

Table 2. Distribution of Student Responses Based on Conceptual Understanding Criteria

Item No.	Subtopic	Misconception (%)	Lack of Understanding (%)	Conceptual Understanding (%)
1	Octet Rule Concept	33	11	56
2	Formation of Covalent Bonds	41	18	41
3	Formation of Covalent Bonds	48	10	42
4	Octet Rule Concept	48	37	15
5	Molecular Polarity	59	30	11
6	Types of Chemical Bonds Based on Lewis Structure	52	36	12
7	Octet Rule Concept	8	15	77
8	Molecular Geometry	56	36	8
9	Types of Chemical Bonds Based on Lewis Structure	37	30	33
10	Octet Rule Concept	44	27	29
11	Ionic Bonds and Their Properties	59	30	11
12	Ionic Bonds and Their Properties	59	17	24
13	Ionic Bonds and Their Properties	59	17	24
14	Metallic Bonds and Their Properties	52	33	15
15	Ionic Bonds and Their Properties	48	41	11
16	Types of Chemical Bonds Based on Lewis Structure	30	59	11
17	Octet Rule Concept	44	15	41
18	Ionic Bonds and Their Properties	30	59	11
19	VSEPR and Electron Pair Concepts	56	37	7
20	Types of Bonds Based on Chemical Reactions	48	37	15

3.1. Subtopic octet rule

Five test items (1, 4, 7, 10, 17) addressed the concept of the octet rule. The majority of students demonstrated misconceptions (up to 48% on item 4) or a lack of understanding (up to 37%), except on item 7, where 77% of students showed a good understanding of the concept. This gap indicates that students' comprehension is highly dependent on the context of the question. They tend to generalize the octet rule without understanding its exceptions, such as elements in group 13 or molecules with an odd number of electrons (Cooper et al., 2012).

3.2. Ionic, covalent bonding, and polarity

This subtopic includes items 2, 3, 5, and 11–16. Nearly all of these items show a dominance of misconceptions, with the highest rates found in items 11 and 12 (each at 59%). The low level of conceptual understanding indicates that students are still unable to distinguish bond types based on the electropositive/electronegative nature of the elements, and they also fail to integrate the concept of polarity with molecular structure (Baltieri et al., 2021; Baldi & Pandimiglio, 2022; Taber, 2018; Wuttig et al., 2022). Students often interpret ionic bonding as a mere "transfer of electrons" in a mechanistic way, without recognizing the crucial role of electrostatic attraction as the driving force behind compound formation.

3.3. Lewis structures and types of bonds based on electron configuration

Items 6, 9, 16, and 20 indicate a high level of misconceptions related to Lewis structures and electron representation. Item 6, for instance, recorded 52% misconceptions, with only 12% of students demonstrating conceptual understanding. This finding aligns with the report by Azura et al. (2017), which stated that both high school and university students often struggle to understand concepts such as lone electron pairs, multiple bonds, and the relationship between Lewis structures and molecular polarity.

3.4. Molecular geometry and valence shell electron pair repulsion (VSEPR) theory

Questions 8 and 19, which assess understanding of molecular geometry and the concept of lone pairs (PEB), showed the lowest results: only 8% and 7% of students demonstrated conceptual understanding. This indicates that the spatial representation of three-dimensional molecules is still inadequately mastered—an enduring issue in chemistry education. Bretz (2013) stated that students' failure to visualize molecular structures directly contributes to misconceptions in understanding molecular shapes and bond angles.

From the perspective of Conceptual Change theory, misconceptions accompanied by high confidence indicate that learners possess alternative frameworks that are deeply embedded and resistant to change through conventional teaching methods (Posner et al., 1982). Therefore, instructional approaches that trigger cognitive conflict are necessary, such as thought-provoking questions, interactive molecular simulations, or data-driven discussions. In terms of chemical learning representation, Johnstone (1991) argued that instruction focusing solely on the symbolic level without linking it to the macroscopic and microscopic levels can lead to cognitive overload and representational confusion. The data in this study confirm that the integration of all three levels of representation has not been optimally achieved in students' understanding of molecular structures and bonding.

A study by Prodjosantoso et al. (2019) using a three-tier diagnostic instrument also found that general misconceptions about chemical bonding reached 72.5% among high school students, with the highest indicators occurring in ionic bonding and Lewis structures. Similarly, research by Rahmawati et al. (2019) reported that pre-service chemistry teachers experienced misconceptions in 10 out of 11 test items related to the concept of particulate matter, with the consistency of correct reasoning falling below 10%. This demonstrates that the phenomenon of misconceptions is cross-level and systemic in nature.

These findings indicate the need for a reformulation of instructional strategies for teaching chemical bonding in higher education. This includes the integration of the Three-Tier Diagnostic Test as a formative assessment tool at both the beginning and end of instruction, the strengthening of pedagogical content knowledge (PCK) within teacher education curricula so that pre-service teachers not only understand the content but also recognize potential misconceptions that could be passed on to students and the use of visual aids such as 3D molecular models, Lewis structure animations, and VSEPR simulations using software tools like PhET or ChemSketch

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4. CONCLUSION

Based on the analysis of 20 items from the three-tier diagnostic test on chemical bonding concepts, it can be concluded that the conceptual readiness of pre-service chemistry teachers still needs significant improvement. The high percentage of misconceptions across most subtopics—particularly in metallic bonding, ionic bonding, and molecular polarity—indicates that students' understanding of fundamental chemical bonding concepts remains uneven and distorted. Even the octet rule, although considered foundational, displayed varied levels of understanding, highlighting the need for greater emphasis on concept representation and visualization. The use of the three-tier diagnostic instrument has proven effective in identifying not only whether students' answers are correct or incorrect, but also their confidence in those answers. This provides a more comprehensive picture of the depth of students' conceptual understanding and their level of certainty, valuable information for designing more effective and targeted instructional interventions. Therefore, a more interactive learning approach is needed, one that is grounded in multiple representations and emphasizes formative feedback. Diagnostic instruments such as the three-tier test should also be used continuously in chemistry learning evaluations to ensure that misconceptions are detected early and addressed systematically.

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DECLARATION OF INTEREST

There is no conflict of interest in this study.

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ETHICAL STATEMENT

The research process has complied with ethical standards. All research subjects have agreed to participate in the research activities. The identities of all research subjects have been kept confidential.

AI USE STATEMENT

The ideas in this article are entirely original to the research team. No AI was used in writing the manuscript.

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