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Identification of learning difficulties and misconceptions of chemical bonding material: A review

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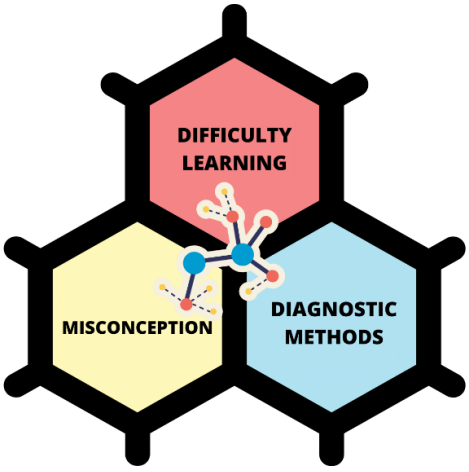
Abstract

Chemical bonds are one of the materials in chemistry that are abstract in nature so that many students have difficulty learning chemical bonding material. This study aims to identify the learning difficulties frequently faced by students in understanding chemical bonding materials and various misconceptions that commonly occur in their understanding. Data collection was carried out using a systematic literature review method with several predetermined criteria. The result is that the learning difficulties experienced by students are caused by many factors, one of which is conceptual error or misconception. At present, many methods have been developed to identify students' misconceptions about chemical bonding material such as diagnostic tests such as two-tier, three-tier and four-tier diagnostics.



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Highlights

- Misconceptions about chemical bonding include mastery of concepts and introduction media.
- The difficulty in chemical bonds lies in the abstract complexity of the material.
- Identify misconceptions in chemical bonding using two-, three-, and four-level diagnostics.

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1. Introduction

Chemistry is a science focused on matter, structure, properties, changes and reactions accompanying it. The scope of scientific studies tends to be invisible and abstract, making it difficult to understand a concept. Chemistry learning has an important role in forming students' understanding and competence in complex concepts. However, along the way, many students face difficulties in understanding and applying basic concepts such as chemical bonds. If the concepts in chemistry are not well understood, students will experience learning difficulties, one of the impacts of which is the occurrence of conceptual errors commonly called misconceptions (Margaretha *et al.*, 2022). The initial knowledge or concept that students have based on an individual's understanding is called conception. Concepts that do not follow scientific concepts are referred to as misconceptions (Rokhim *et al.*, 2023b). The misconception is one of the obstacles to concept mastery that needs to be minimalized (Widarti *et al.*, 2016). Misconceptions are still a problem in the learning process because they can reduce the effectiveness of student learning and hinder students from understanding new knowledge. If misconceptions continue to develop and are not immediately resolved, it will result in students' difficulties in understanding subsequent concepts (Muchtar and Harizal, 2012).

This article aims to provide an in-depth review of the learning difficulties that are often faced by students in understanding chemical bonding material, as well as to analyze various misconceptions that are common in their understanding. Through a comprehensive review, it is hoped that this article can provide better insight into the sources of learning difficulties and conceptual errors that may arise at the learning stage of chemical bonding. By understanding the root causes that often arise, a more effective and appropriate learning approach can be designed to help students overcome obstacles in understanding chemical bonds.

2. Experimental

This study uses the method of Systematic Literature Review (SLR). A systematic literature review aims to identify and understand relevant research with implications for the topics studied (Synder, 2019). This method is carried out by searching for academic publications in national and international journals using online academic publications databases on ERIC and Google Scholar. The search uses the keywords "Difficulty Learning of Chemical Bonding" and "Misconception of Chemical Bonding".

The academic publications obtained are then reduced based on the abstract and title by considering the suitability of the content. The academic publications were selected based on predetermined criteria including (1) academic publications on the analysis of misconceptions and learning difficulties in chemical bonding material; (2) Publication between 2018 and 2023; (3) Full text and accessible. From the selection process, 11 academic publications met all the criteria.

3. Results and discussion

From the findings of the academic publications, the topic of discussion in this review article is divided into 3 parts, including difficulty learning chemical bonds, development of chemical bonding misconception diagnostic methods, and identification of chemical bonding misconceptions.

3.1. Difficulty learning chemical bonds

Difficulty is a difficult situation, difficulty or distress (Big Indonesian Dictionary). Difficulty is a condition that shows the characteristics of obstacles in activities to achieve goals so that a greater effort is needed to overcome them. Learning difficulties are obstacles or challenges faced by students in mastering learning material or concepts. According to Subini (2012), learning difficulties are synonymous with students' difficulties in receiving or absorbing lessons at school. This can cover various aspects, both in terms of understanding the concept, applying it, and developing skills. Learning difficulties can be temporary or more chronic, depending on certain factors such as the complexity of the material, student learning styles, learning environment, and so on. Some academic publications related to learning difficulties in chemical bonding material are presented in **Table 1**.

Based on the results of the research above, the learning difficulties experienced by students in chemical bonding material were caused by several factors. Lack of student interest in learning because of the assumption that chemical bonding material is complicated, the learning process is less interesting and not suitable for students, students' weak ability to remember concepts due to lack of practice questions, lack of student understanding regarding prior knowledge that supports understanding of chemical bonding material, and there are still many concept errors or misconceptions that students experience in chemical bonding material. The learning difficulties experienced by these students certainly hurt student learning outcomes if an effective solution is not immediately given. Low student learning outcomes can be caused by learning problems, for example, lack of understanding of a concept and misconceptions experienced by most students (Warsito *et al.*, 2020).

3.2. Development of chemical bonding misconception diagnostic methods

Misconception is a term used when students' ideas are not relevant to a scientific perspective. Misconceptions should be identified and corrected immediately, so as not to interfere with the further learning process (Margaretha *et al.*, 2022). Misconceptions can be an obstacle for students to acquire complete knowledge, therefore this problem must be addressed (Arslan *et al.*, 2012). Misconception analysis requires instruments that can reveal the causes of misconceptions in depth (Rokhim *et al.*, 2023a). According to Firman, misconceptions can be diagnosed using standardized tests that use valid and reliable instruments (Utami *et al.*, 2019). Various studies have used multiple-choice diagnostic tests to analyze students' misconceptions (Sen and Yilmaz, 2017). Diagnostic tests can help teachers to identify students' misconceptions (Uyulgan *et al.*, 2014).

The high level of students' learning difficulties in chemical bonding material is caused by one of the misconceptions experienced by students. Chemical bonds are one of the subject matter with abstract concepts. Chemical bonding is a difficult concept for students that can lead to misconceptions (Meltafina *et al.*, 2019). To find out the level of students' misconceptions about chemical bonding material, a diagnostic test to analyze and identify misconceptions about

chemical bonding is a must (Utami *et al.*, 2019). Several multiple-choice-based diagnostic tests currently being developed include: four-tier multiple-choice, three-tier multiple-choice, and two-tier multiple-choice. The instrument is considered effective because students can give students freedom to describe the representations that exist in their minds (Rokhim *et al.*, 2023b). Some academic publications regarding the diagnostic methods for chemical bond misconceptions are presented in **Table 2**.

From the several studies showed in **Table 2**, it is known that the multiple-choice diagnostic tests currently being developed are in the form of four-tier multiple-choice, three-tier multiple-choice, and two-tier multiple-choice. The difference between the three lies in the division of categories to analyze student misconceptions. Diagnostic test results using four-tier multiple choice have a higher level of sensitivity than diagnostic tests using three-tier multiple choice and two-tier multiple choice so they will be more thorough in identifying misconceptions in students (Qodriyah *et al.*, 2020). The two-tier diagnostic test was unable to distinguish between students who lacked knowledge and those who had misconceptions, however, the three-tier diagnostic test had an unequal score ratio between students who had misconceptions and students who lacked knowledge (Kaltakci-Gurel *et al.*, 2017).

3.3. Identification of chemical bonding misconceptions

Misconceptions or conceptual errors are defined as an erroneous understanding of a concept so that it does not follow scientific concepts or those that are understood and approved by experts in a particular field (Suparno, 2013). Misconception is a condition where students' understanding deviates from the correct concept, but students tend to maintain the wrong understanding (Margaretha *et al.*, 2022). Misconceptions can prevent students from obtaining correct concepts and have the potential to hinder progress in further learning (Horton, 2007). Misconceptions experienced by students have been identified in most of the concepts studied in chemistry, especially at the atomic and molecular level concepts which are indeed abstract (Taber, 2009), such as one of the chemical concepts that often causes misconceptions in students, namely the concept of Chemical Bonds. The concept of chemical bonds underlies most of the concepts in advanced sciences in chemistry such as inorganic chemistry, organic chemistry, and physical chemistry (Gudyanga and Madambi, 2014).

More than 50% of students experience misconceptions about chemical bonding materials (Fadillah and Salirawati, 2018). Misconceptions have been recognized as the main factor influencing understanding of the material, and teachers also have misconceptions about certain concepts (Utomo *et al.*, 2018). Misconception can affect learning effectiveness and significantly impact learning achievement (Chen *et al.*, 2020).

From the studies in **Table 3**, misconceptions about chemical bonding identified by researchers are presented in **Table 4**.

Based on the data described in **Table 4**, many misconceptions about chemical bonds among students occur in all material sub-chapters, especially in ionic and covalent bonds. This is in line with several research results which show a high percentage of misconceptions about ionic bonds and covalent bonds (Rohmah *et al.*, 2022; Setiawan *et al.*, 2017). Most higher education students still have difficulty distinguishing the two types of bonds due to misunderstanding the concept of the formation of the two bonds.

3.4. Future perspectives

Misconceptions can become difficulties for students in the future. Misconceptions allow students to instil wrong concepts and be unable to accept correct concepts. Chemical bonding is one of the basic materials in chemistry. When students experience misconceptions about chemical bonding material, it will cause mistakes and difficulties in understanding further chemical material. After identifying and finding several misconceptions that are still often experienced by students, it is hoped that there will be a solution to reduce the risk of misconceptions or even solve the problem. A complete understanding of chemical bonding is very important to reduce the percentage of misconceptions among students (Safitri *et al.*, 2018).

The solutions offered can be in the form of developing models, media, or other learning tools. The innovations carried out are expected to be able to direct students to build the correct concept so that students will not experience learning difficulties and obstacles to obtaining learning outcomes that follow expectations.

4. Conclusions

Chemical bonds are one of the materials that form the basis of advanced chemical materials. As with chemistry, chemical bonding material is also abstract so many students experience learning difficulties in this material. Learning difficulties experienced are caused by many factors such as a lack of interest in student learning, an inappropriate learning process, a lack of practice questions, a lack of student understanding regarding prior knowledge that supports understanding of chemical bonding material, and there are still many conceptual errors or misconceptions. Based on the results of the last 5 years of studies, many students still find learning difficulties due to misconceptions about chemical bonding material.

There have been many developments in methods for identifying students' misconceptions about chemical bonding material such as diagnostic tests such as two-tier, three-tier, and four-tier diagnostics. As a result, it is known that there are many students' misconceptions that spread to all chemical bonding sub-materials, especially in ionic bonding and covalent bonding materials.

After identifying and finding several misconceptions that are still often experienced by students, it is hoped that there will be a solution to reduce the risk of misconceptions or even solve the problem.

Table 1. Difficulty learning chemical bonds.

No	Author, Title, Journal	Research purposes	Research methods	Research result
1.	Sahriani (2019) Analysis of Learning Difficulties of Class X MIPA Students of SMA Negeri 3 Tanjungpinang on Chemical Bonding Material. Raja Ali Haji Maritime University Thesis	The purpose of this study was to see the learning difficulties of class X students on chemical bonds.	Student learning difficulties are measured from the results of student test questions and are supported by interviews, while the questionnaire aims to look at the factors that cause student learning difficulties.	The study showed that students had difficulty understanding high-category terms with a percentage of 70%, students had difficulty understanding high-category calculations with percentage of 68%, and students had difficulty understanding high-category concepts with a percentage of 71%. The factors that influence student learning difficulties are (1) internal factors in the sufficient category with a percentage of 57.5% including aspects of interest (57%) and aspects of motivation (58%), (2) external factors in the sufficient category with a percentage of 59, 5% includes aspects of teacher teaching methods/methods (5.9%), facilities and infrastructure (60%).
2.	Haris and Wahidah (2018) Analysis of Difficulties in Learning Chemical Bonds in View of Misconceptions of Grade X Students of SMA Negeri 3 Mataran. MIPA Incandescent Journal	This study aims to identify and explain the conceptual errors of class X SMA Negeri 3 Mataram in studying chemical bonding.	Data collection uses a test that contains 12 concepts of chemical bonding.	This research showed that very few students (1-20%) had conceptual errors of electron configuration, ion formation, metals / non-metals, ionic bonds / covalent bonds covalent compounds, and chemical formulas for chloride compounds. Few students (21-40%) experienced misconceptions about the compounds formed and the chloride ion formula. Quite students (41-60%) experienced misconceptions about Lewis structures and ionic compounds. Many students (61-80%) experienced misconceptions about covalent compounds and the atomic numbers of the elements. In general, 62.5% of students experienced difficulty in studying chemical bonds, 20% experienced quite difficulty and 17,5% experienced less difficulty.
3.	Sabrina (2018) Identification of Student Learning Difficulties in Chemical Bonding Material at SMAS Muslimat Samalanga Bireuen. UIN Ar-Raniry Banda Aceh	To analyze students' learning difficulties in chemical bonding material at SMAS Muslimat Samalanga Biruen.	Data was collected through tests and interviews, then the data was analyzed through student mastery and student difficulties.	The results showed that class X students of SMAS Muslimat Samalanga Bireuen still experienced mistakes and difficulties in solving chemical bond problems, namely 80% of students had difficulty distinguishing between covalent and metallic physical properties, 76% of students had difficulty estimating the polarity of a molecule, and 37% of students had difficulty distinguishing between ionic bonds, covalent bonds, coordinate covalent bonds, and metallic bonds. This is caused by material that is difficult for students to understand, low student abilities, and a lack of practice working on questions. As well as students have a weak ability to remember the concept of the material being taught.
4.	Yani (2018) Diagnostics of the Relationship of Prior Knowledge with Learning Difficulties in Class X High School Chemical Bonds, Solok City. Padang State University	Aims to reveal the relationship between learning difficulties and students' prior knowledge of chemical bonding material at SMAN Kota Solok.	The research was conducted through two two-tier diagnostic tests for initial knowledge of chemical bonding and chemical bonding.	The results showed that students at SMAN Kota Solok had learning difficulties in understanding the concept of chemical bonding material with very high learning difficulty criteria in (1) bond formation, (2) ionic bonds, (3) covalent bonds, single bonds, double bonds, double bonds triple, (4) coordinate covalent bonds, (5) polar and non-polar bonds, (6) ionic and covalent bonds. Initial knowledge that most influences students' learning difficulties in chemical bonding material is (1) electron configuration, (2) group and period, (3) periodic properties of an element based on radius, ionization energy, electron affinity and electronegativity. Students' initial knowledge that does not follow scientific understanding causes students' learning difficulties in understanding the concept of chemical bonds.

Table 2. Diagnostic methods of misconception.

No	Author, Title, Journal	Research purposes	Research methods	Research result
1.	Mahmudah *et al.* (2020) Identification of students' misconceptions in chemical bonding topic using the four-tier diagnostic test. Journal of Physics: Conference Series	Identifying misconceptions by measuring students' level of understanding in the topic of chemical bonds using a four-tier multiple choice diagnostic test.	The research method is descriptive and involves 77 students from SMA Tangerang Selatan.	The results of the study stated that the overall level of students' misconceptions about chemical bonds was in the low category (15.14%). Misconceptions on the concept of determining ionic and covalent bonds microscopically results in the moderate category (41.56%), and metallic bonds in the moderate category (37.66%).
2.	Setiawan and Ilahi (2022) Identification of Misconceptions in Chemical Bonding Materials Using Three Tier Diagnostic Tests. Journal of Natural Science of Integration	Knowing whether there is, and the percentage of misconceptions about chemical bonding materials using three tier diagnostic test.	Qualitative research with a descriptive approach using purposive sampling technique	Research on students of SMA Negeri 1 Teluk Kuantan class X on chemical bonding material showed that 72.53% of students experienced misconceptions, 14.98% of students did not understand the concept, and the remaining 12.48% of students understood the concept of chemical bonds.
3.	Ebiati *et al.* (2020) Sensitivity of two-tier and three-tier tests in detecting student's misconceptions of chemical bonding. Journal of Chemistry Education	Knowing how the two-tier and three-tier test sensitivity is on detect students' misconceptions about chemical bonding material.	This research is a quantitative study with a total sampling technique measured using three-tier multiple-choice with modified certainty of response index (CRI).	This study concluded that the three-tier multiple-choice was more sensitive than the two-tier multiple-choice in detecting students' misconceptions about chemical bonds.
4.	Utami *et al.* (2019) Development of a computer based two-tier multiple choice diagnostic test to identify misconceptions on chemical bonding. Journal of Physics: Conference Serie	This study aims to find a computer-based two-tier multiple-choice diagnostic test for students' misconceptions about chemical bonding material.	The development process is carried out by analyzing literature, identifying targets, analyzing misconceptions through essays, and analyzing misconceptions through two-tier multiple choice.	A computer-based two-tier multiple-choice diagnostic test was produced on chemical bonding materials which include ionic bonds, covalent bonds, metallic bonds, and coordination bonds. The effectiveness of the developed diagnostic tests will then be tested by conducting trials, identifying misconceptions about feedback and being retested again.

Table 3. Identification of chemical bonding misconceptions.

No	Author, Title, Journal	Research purposes	Research methods	Research result
1.	Warsito *et al.* (2020) Identification of Students' Misconceptions on the Topic of Chemical Bonds and Their Improvements with the ECIRR Learning Model (Elicit, Confront, Identify, Resolve, Reinforce). Journal of Education: Theory, Research, and Development	The purpose of this study was to (1) identify and analyze students 'misconceptions on the topic of chemical bonding with the Three-Tier diagnostic test (2) to determine the effectiveness of the ECIRR model in improving student misconceptions (3) to determine the retention of students' conceptual understanding 3 weeks after remedies.	This research is a descriptive and quasi-experimental study with the design of One Group Pre - Test Post - Test Design. The research subjects were 33 students of class X IPA in a high school outside Java.	The results showed that (1) found 41 types of misconceptions on the topic of chemical bonding (2) remedial learning with the ECIRR model was able to reduce student misconceptions from 61.5% to 22.4%, and (3) retention of students' understanding of remedial results by 82.5 % with very good criteria.
2.	Islami *et al.* (2019) Identification of Students' Misconceptions on the Concept of Chemical Bonds using the Four-Tier Multiple-Choice Test (4TMC). JRPK: Research Journal of Chemistry Education	This study aims to identify student misconception on the concept of Chemical Bonding.	The method used in this research is quantitative descriptive. The misconception identification was performed using a four-tier multiplechoice (4TMC) test instrument.	The results showed the existence of a misconception of 30.31% (low category). Significant misconceptions are identified as 8 out of 13 sub-concepts of Chemical Bonding they are Lewis Structure and the Octet Rule (33.33%), Metal Bond and Metal Properties (20.83%), Ionic Compounds and Covalent Compounds (27.08%), Theory of VSEPR (20.83%), Electron Domain-Theory (18.75%), Polarity of Molecul (27.08%), Van der Waals Forces (14.58%), and Hydrogen Bond (29.17%).
3.	Rohmah *et al.* (2022) Analysis of Student's Chemical Bonding Misconception with A Four-Tier Diagnostic Test. Journal Tadris Chemistry	This study aimed to investigate basic chemistry students' misconceptions of chemical bonding.	This study used a descriptive research design with a four-tier diagnostic test. The research subjects were basic chemistry students.	The results showed that students who had misconceptions about ionic, covalent, and coordinate covalent bonding were 48.9%, 53.0%, and 37.5%, respectively. The misconception in this course is that students need to learn about ionic bonds formed by electrostatic forces between cations and anions. As a result, students cannot determine the difference in electronegativity values in ionic and covalent bonds and the number of valence electrons of each atom in a chemical bonding. Therefore, the misconception is in the moderate category.

Table 4. Misconceptions of chemical bonding.

Sub Matter of Chemical Bonds	Misconception Analysis	References
Lewis Structure and the Octet Rule	The Lewis structure of the molecule before electron transfer is written by adding the charge of the ion.	Warsito *et al.* (2020)
	In the Lewis structure of the HCl molecule, Lone pair of electrons is balanced between the H and Cl atoms.	Islami *et al.* (2019)
Ionic Bonds	Determining the type of bond that is formed is due to referring to the type of bonding elements, namely metals and non-metals.	Warsito *et al.* (2020)
	Ionic bonds are formed from metal and non-metal elements.	Rohmah *et al.* (2022)
	The formation of ionic bonds involves the transfer of electrons between atoms.	Rohmah *et al.* (2022)
	The calcium atom donates its valence electrons to the oxygen atom, then bonds.	Rohmah *et al.* (2022)
Covalent Bonds	Coordinate covalent bonding is the same as the process by which ionic bonds occur, namely the handover of electrons.	Warsito *et al.* (2020)
	NaCl has covalent bonds because the sodium atom donates valence electrons to the chlorine atom.	Rohmah *et al.* (2022)
	$AlCl_3$ compounds are derived from cations and anions.	Rohmah *et al.* (2022)
Metal Bond	The larger the metal atomic radius, the stronger the metallic bond so that the melting point is low.	Warsito *et al.* (2020)
Molecular Polarity	The bonds between atoms in water are polar covalent bonds but the molecules are non-polar.	Warsito *et al.* (2020)
	The CF bond is nonpolar so that the CF_4 molecule is nonpolar.	Islami *et al.* (2019)
Molecular Shape	The molecular shape of XeF_4 is tetrahedral due to the presence of four bonding pairs of electrons.	Warsito *et al.* (2020)
Intermolecular Forces	H_2O and HF have hydrogen bonds because there is a bond between the positive dipole of the H atom and the negative dipole of the very electronegative atom, namely O and group 17.	Warsito *et al.* (2020)
	Hydrogen bonds are formed when the N atoms of one molecule interact with the H atoms of another molecule.	Islami *et al.* (2019)

Authors' contributions

Conceptualization: Dian Nuriyanti; **Data curation**: Dian Nuriyanti; **Formal Analysis**: Antuni Wiyarsi; **Funding acquisition**: Hayuni Retno Widarti; **Investigation**: Dian Nuriyanti; Meyga Evi Ferama Sari; **Methodology**: Deni Ainur Rokhim; **Project administration**: Hayuni Retno Widarti; **Resources**: Hayuni Retno Widarti; **Software**: Deni Ainur Rokhim; **Supervision**: Hayuni Retno Widarti; **Validation**: Sri Yatimah; **Visualization**: Dian Nuriyanti; **Writing – original draft**: Dian Nuriyanti; **Writing – review & editing**: Deni Ainur Rokhim.

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