

Misconceptions of Intermolecular Forces in General Chemistry Courses

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Abstract. The misconception is the most topic in chemistry learning that is important to analyze. There are many advantages for lecturers and students to know about misconceptions. This research aims to describe misconceptions in general chemistry courses, especially intermolecular forces (IMFs) topic. The two-tier multiple-choice tests have played an important role in helping researchers determine students' level of understanding and in identifying specific misconceptions. The project used a convenience sample of 88 students (76 female and 12 male) chemistry education program that studied IMFs as participants. Misconception knew from the test's second tier, which is the student's reason for the answer. Surprisingly, 29 misconceptions were acquired from the test about IMFs concepts. This needs to be a special concern for lecturers of basic chemistry courses in order to evaluate the learning process that has been carried out. Students misconceptions in basic chemistry courses will have an impact on organic chemistry courses because the concept of intermolecular forces will be studied in depth in organic chemistry courses. The success of students in organic chemistry courses is highly dependent on the initial knowledge of students, especially in basic chemistry courses

Keywords: Misconceptions, Two-tier test, Intermolecular Forces

Introduction

General chemistry is a challenging subject for many students, with difficulties often stemming from the complexity of the material and the learning process (Febaliza & Yulis, 2018; Sirhan, 2007). Specific topics such as chemical bonding, stoichiometry, and colligative properties are particularly problematic (Febaliza & Yulis, 2018). A range of studies have highlighted the prevalence of misconceptions in general chemistry, particularly among high school teachers (Caballes et al., 2020). These misconceptions can have a significant impact on student outcomes, with factors such as self-confidence, previous educational experiences, and instructional methods playing a role (Swoope, 2020). One of the main obstacles is the lack of spatial ability to understand the new material they learn (Akkuzu & Uyulgan, 2016). Which material in this course contains multiple representations. (Gilbert & Treagust, 2009) and (Sirhan, 2007) stated that connecting macroscopic, microscopic and, symbolic representations will greatly help improve the mastery of chemical concepts. Chemical misconceptions may occur because students cannot connect the three chemical

representations (Akkuzu & Uyulgan, 2016). If they cannot learn basic chemistry concepts properly or have misconceptions, they will have an impact on understanding more advanced chemistry topics (Nakhleh, 1992).

Misconceptions in general chemistry courses are prevalent among students and teachers, often stemming from a variety of sources such as textbooks, electronic media, teachers and cultural influences (Chu & Hong, 2010; Abenes, 2020). These misconceptions are particularly challenging to address due to the abstract nature of chemistry concepts (Zoller, 1990). The alternative conceptions stay with students and impede their conceptual understanding of chemistry concepts (Salame & Casino, 2021). Learning new science concepts is influenced by alternative conceptions and is viewed by it (Duit & Treagust, 1995; Taber, 2014). Students ranging from middle school to doctoral level can possess alternative conceptions about chemistry (Bodner, 1991). Researchers have found that alternative conceptions or misconceptions are resistant to extinction with instruction (Cracolice & Busby, 2015).

In recent five years, research on the topic of misconceptions in general chemistry which include electrolysis (Iter, 2023), phase changes, scales and size of atoms, redox reactions (Salame & Casino, 2021), equilibria in acid base solutions (Gültepe, 2021), colligative properties (Türk & Seyhan, 2021), chemical equilibrium (Andriani et al., 2021), valence and valency (Sindhu, 2021), reduction-oxidation reaction (Hadinugrahaningsih et al., 2022), coordination number and the oxidation number in coordination compounds (Turan-Oluk, 2023), redox reaction (Soeharto & Csapó, 2021), and covalent bonding (Vladusic et al., 2023). There is no specific research on intermolecular forces topic.

Students achievement in learning chemistry based on their prior knowledge (Seery, 2009), mathematics fluency, as measured by the math-up skills test, and performance on common questions have been identified as important predictors of success in first-semester general chemistry (Willis et al., 2022) and attitude towards the subject matter which can also have an effect on performance and achievement (Bauer, 2008). The three factors can be influenced by teaching method and strategy.

Intermolecular forces (IMFs) are a foundational concept for understanding phases, the reactivity of functional groups, and organic chemistry courses (Lee & Beggs, 2021). A variety of teaching techniques and laboratory experiments have been developed in order to make concepts will easier to understand. However, there are still many students who experience misconceptions as obtained in (Lee & Beggs, 2021) the first introduced to intermolecular forces (IMFs) either in a lecture or in an activity, a student may form misconceptions based on prior knowledge or their perceptions of the macroscopic world.

Misconception can be analyzed by interviews, open-ended questions, and two-tier diagnostic tests. Particularly in recent years, there have been a number of researchers in the literature who develop two-tier tests (Şekerci & Erdem, 2022; Uyulgan et al., 2014). Various studies have proposed different methods for identifying misconceptions in chemistry concepts. Mulyani et al., (2021) suggests using distractor analysis in multiple-choice questions, while Damsi & Suyanto, (2023) emphasizes the use of multiple-tier diagnostic instruments, particularly the three-tier multiple-choice. (Putri et al., (2021) introduces the certainty of response index (CRI) as a tool for identifying misconceptions, and Üce & Ceyhan (2019) highlights the importance of addressing misconceptions in abstract chemistry concepts through constructivist learning theory. These studies collectively underscore the need for a range of assessment tools and teaching strategies to effectively identify and address misconceptions in chemistry education.

This study aims to analyze student misconceptions on the material of intermolecular forces considering the importance of this basic material to be well mastered by students

so that it does not have an impact on other related material in subsequent courses. Misconception analysis is done by giving a two-tier question test.

Methods

The project used a convenience sample of 88 students (76 Female and 12 Male) Chemistry Education program that studied IMFs. IMFs concepts were taught in the first year in general chemistry courses. These students were voluntary and were picked from different levels of achievement. In most recent studies, a misconception has been identified by a two-tier test (Şekerci & Erdem, 2022; Uyulgan et al., 2014). Two-tier test instrument has validity and reliability. The IMFs concepts tested in the two-tier question are definition, the strength of IMFs and their effect on boiling point, London forces, strength of London force, dipole-dipole force, hydrogen bonding, and strength of hydrogen bonding covered in 20 questions. Tests are conducted through quizzes. In these cases, students must answer and write the reason for the answer chosen. Open-ended reasoning will better explore students' understanding and possible misconceptions.

In order to know misconception in IMFs, evaluate the levels of conceptual understanding of students will help to present data in an organized manner, the reason from the answer of quizzizs were analyzed according to 5 categories: SU: sound understanding, PU: partial understanding, SM: specific misconceptions, NU: no understanding, and NR: no response. Similar categorization processes for determining students' levels of understanding are frequently encountered (Abraham et al., 1994; Çalık & Ktü, 2005; Ünal et al., 2010; Akkuzu & Uyulgan, 2016).

Table 1. Categories used in the analysis of the reason acquired from the quizziz and their coding criteria.

Categories	Coding criteria
No Response (NR)	Blank or no reason
No Understanding (NU)	Repeats part or all of the question and uncodable responses
Spesific Misconception (SM)	Responses that include descriptive, incorrect or illogical information
Partial Understanding (PU)	Responses that include at least one of the components of the acceptable response
Sound Understanding (SU)	Responses that include all components of the acceptable responses

Results and Discussion

The diagnostic test instrument that has been validated and tested for validity and reliability is then used to determine the misconceptions experienced by students on the material of IMFs. The questions are given through a quizziz with an essay format so that students can write the reasons for the answers to the answer choices that have been chosen. The weakness of using quizziz is that it cannot be ensured that the answers

obtained by students are the result of their independent understanding. To minimize this, each question is given a time limit. The diagnostic test question grid can be seen in Tabel 2. Diagnostic test results were analyzed based on the concept understanding category modified from (Abraham et al., 1994) which can be seen in Table 2.

Table 2. Analysis of the reasons for the answer in quizziz.

Q	Concept	f _R	NR		NU		SM		PU		SU	
			f	%	f	%	f	%	f	%	f	%
1	IMFs Definition	30	58	65.91	10	33.33	4	13.33	0	0	16	53.33
2	Dipole-dipole definition	27	62	70.45	12	44.44	<u>14</u> 1	<u>51.85</u> 3.70	0	0	0	0
3	Dipole-dipole definition	24	64	72.73	8	33.33	3	12.5	0	0	13	54.17
4	Examples and definitions of dispersion	28	60	68.18	19	67.85	3	10.71	0	0	6	21.42
5	Examples and definitions of dispersion	27	61	69.32	7	25.93	1	3.70	1	3.70	18	66.67
6	Hydrogen bond strength	33	55	62.50	16	48.48	<u>13</u> 3	<u>39.39</u> 9.09	0	0	1	3.03
7	Hydrogen bond strength	24	64	72.73	9	37.5	1	4.17	<u>1</u> 2	50	2	8.33
8	Formation of hydrogen bond	28	60	68.18	7	25	20	71.42	0	0	1	3.57
9	Formation of hydrogen bond	26	62	70.45	7	26.92	17	65.38	0	0	2	7.69
10	Comparis on of london forces and dipole-dipole	28	60	68.18	13	46.43	<u>10</u> 2	<u>35.71</u> 7.14	0	0	3	10.71
11	Examples and definitions	25	63	71.59	4	16	<u>1</u> 3 4	<u>4</u> 12 16	1	4	11	44

	of dispersion						1	4				
12	Examples and definitions of dispersion	22	66	75.00	7	31.82	1	4.54	7	31.82	6	27.27
							1	4.54				
13	Examples and definitions of dispersion	22	66	75.00	6	27.27	2	9.09				
							3	13.64				
							1	4.54	8	36.36	0	0
							2	9.09				
14	-	-	-	-	-	-	-	-	-	-	-	-
15	Hydrogen bond definition	26	62	70.45	5	19.23	11	42.30				
							4	15.38	1	3.84	0	0
							4	15.38				
							1	3.84				
16	London forces strength	27	61	69.32	10	37.03	2	7.41	1	3.70	14	51.85
17	IMFs strength and the effect on boiling point	29	59	67.05	16	55.17	1	3.45	3	10.35	2	6.90
							7	24.14				
18	Examples of hydrogen bond formation	24	64	72.73	4	16.67	16	66.67	0	0	4	16.67
19	Examples of hydrogen bond formation	29	64	72.73	6	20.69	2	6.90	5	17.24	5	17.24
							11	37.93				
							1	3.45				
							2	6.90				
20	Examples and definitions of dispersion	26	62	70.45	5	19.23	1	3.84	0	0	20	76.92

The results of the test analysis were then tabulated in order to know exactly the number of participants who fell into the predetermined categories. The total number of questions given was 20 questions with 88 students participating. However, the results obtained show that only a few students gave reasons for each problem. For questions number 12 and 13, the number of students who did not provide reasons reached 75% of

the total participants. For the SU, PU, SM and NU categories, the divisor number used is the number of students who give reasons for each problem. The results of the documentation analysis also found that students who gave reasons tended to be consistent in several questions, so there were no questions that reached 100% of the reasons given. This is a challenge for further research so that students can follow the instructions for working on problems and it is indicated that if students do not provide reasons, then students do not understand the concept in depth. To ensure this, it is necessary to conduct an interview. However, it has not been done in this study. Misconceptions in IMFs in all concepts can be seen in Table 3.

Table 3. Misconception in all concept of IMFs.

Concept		Misconception
IMFs	Definition	1. Intermolecular forces are forces that occur between atoms to form molecules or compound
	The strength of IMFs and their effect on boiling point	2. It takes a high boiling point to break the bonds in a liquid phase. 3. The greater the boiling point, the more difficult it is for the forces between the molecules of the compound to be broken so that the forces between the molecules are stronger
London Force	Definition	4. London forces are forces that occur between nonpolar molecules and dipole permanent. 5. London forces occur in ethanol i.e. between ethyl and OH 6. London forces occur in CH ₄ due to the tetrahedral shape of the CH ₄ molecule 6. 7. London force is a nonpolar force 8. London force occurs between positive and negative ions on a molecule 9. The London force is a force of attraction that occurs between atoms 10. Nonpolar molecules can undergo permanent dipoles
	The strength of IMFs and their effect on boiling point	11. The bond in the compounds CH ₄ and O ₂ is a weak bond 12. Students think that the low boiling point is due to the London force which is indeed very weak and is not related to the number of electrons
Dipole-dipole forces	Definition	13. HCI molecules are polar molecules, so the interaction between HCI molecules is a polar intermolecular force 14. H atoms as positive atoms and Cl as negative atoms produce attractive forces 15. This polar molecule has a positive dipole and negative dipole in the polar region 16. Polar molecules have permanent dipoles so that positive dipoles will bind to negative dipoles.
	Definition	17. Hydrogen bonds are formed due to shared electron usage 18. Hydrogen bonds occur between N and H atoms 19. Hydrogen bonds uses PEB fot bonding

The strength of Hydrogen Bonding	20. Students define that hydrogen bonds occur between atoms in a molecule, not intermolecular
	21. Students assume that the difference in electronegativity of covalent compounds affects the boiling point.
	22. The strength of the hydrogen bond is affected by the difference in electronegativity between H and the elements N, O, and F.
	23. Hydrogen bond strength is affected by PEB
	24. The strength of hydrogen bonds is related to the acidity of the substance
Hydrogen Bond Formation	25. Students assume that hydrogen bonding occurs at the H atom with one of the F, O, and, N atoms.
	26. Hydrogen bonding occurs between O and H atoms in ether molecules
	27. The bond between the elements H and O in the alcohol molecule is a hydrogen bond
	28. Hydrogen bonding is present in the OH group of polar molecules
	29. Hydrogen bonding occurs in methane (C and H atoms)

As can be seen from table 3, students cannot distinguish between intermolecular forces and intramolecular forces, this is obtained from the question of the definition of intermolecular forces. As mentioned in the literature review that indicating each IMFs an interaction within a molecule and confusion between intramolecular forces and intramolecular forces (Cooper et al., 2015; Lee & Beggs, 2021; Othman, et al., 2008; Sukib & Mutiah, 2020). They cannot identify the characteristics and differences between intermolecular forces and intermolecular forces (Fahmi & Irhasyuarna, 2017) students assume that intermolecular forces are forces that exist within molecules. (Rahayu & Fitriza, 2021). The second concept talks about the strength of IMFs. Students define in reverse the concept of the relationship between IMFs and boiling points. They cannot to breakdown how the effect of intermolecular forces within molecules to boiling point. This finding was also reported by (Islami et al., 2019).

The London force is the weakest of the IMFs. However, this is used as a basis for students to assume that this is the result of the interaction of nonpolar molecules and nonpolar molecules regardless of other factors such as the number of electrons as can be seen in tabel 3. This has been found in previous research that students who state that the London force has a low attractive force is because the London force is generated from nonpolar molecules with non-polar molecules (Sukib & Mutiah, 2020) and that the London force is influenced by the polarity of a molecule not by the size of the molecule, structure, and distance between molecules (Sukib & Mutiah, 2020).

Students only assume that dipole-dipole forces occur due to the polarity of a molecule without being able to explain the interactions that occur between polar molecules. Students cannot (incorrectly define) identify the molecules involved in the dipole-dipole force of attraction. This was also found in previous research that compounds that experience dipole-dipole forces of attraction are compounds that have no hydrogen bonds

and are not bound to halogens (Widarti et al., 2019) It was also found in another study that the inter-molecular force in polar compounds is called dipole-dipole force because the affixation causes the separation of the center of positive charge with negative charge (Warsito et al., 2020).

The most common misconceptions found in this study were about the concept of hydrogen bonding. Starting from the definition of hydrogen bonds, the strength of hydrogen bonds and the formation of hydrogen bonds. This misconception occurs partly due to students' confusion in distinguishing intramolecular and intermolecular bonds. They did not seem to be aware of the general difference in magnitude that exists between the strength of a covalent bond and the strength of an intermolecular force (Nakhleh, 1992). For example, in misconceptions in numbers 18, 20, 25, 26 and 27. This was also found in previous research, namely confusing chemical bonds and intermolecular forces, thinking as if intermolecular forces were chemical bonds or as if they were the types of covalent bonding (Ünal et al., 2010). Creating a cognitive structure of a complex body of knowledge such as chemistry is not easy, and it is a small wonder that students find the subject difficult. Students don't know how to approach the material in a suitable manner (Nakhleh, 1992).

Understanding non-covalent interactions and intermolecular forces allow students to predict and explain observable phenomena including phase changes and solubility. Students confuse non-covalent and covalent interactions, often misunderstanding intermolecular forces such as hydrogen bonding to be interactions between atoms in a bond, rather than interactions between molecules (Cooper et al., 2015; Nakhleh, 1992; Peterson & Treagust, 1989). This will have an impact on learning in organic chemistry courses related to the concept of intermolecular forces that one of contributing factors and resultant difficulties in teaching and learning organic chemistry (O'Dwyer, 2012).

Finally, teachers should use models such as concrete models, analogical models, theoretical models and simulations to make more concrete the abstract concepts or facts for their students (Ünal et al., 2010), and use constructivist approach are exemplified as follows: conceptual change approach, analogy, concept cartoons, modeling, computed-assisted teaching, narratives and chemistry education and finally problem-based learning method (Üce & Ceyhan, 2019). Moreover, teachers should emphasize the transitions from the macroscopic properties of a matter or event to the sub-microscopic properties of those. These are the ways to improve students' understanding about the covalent bonding at both macroscopic and submicroscopic levels and to make students have fewer misconceptions. Moreover, learning environments based on teaching strategies or techniques for conceptual change such as concept mapping, conceptual change texts, and computer aided instruction should be designed to remediate students' misconceptions related to covalent bonding and its effectiveness should be investigated with extensive studies conducted by chemistry educators or researchers.

Conclusion

Misconceptions found in the material of forces between molecules are divided into 4 important concepts which include 29 misconceptions. This needs to be a special concern for lecturers of basic chemistry courses in order to evaluate the learning process that has been carried out. Students' misconceptions in basic chemistry courses will have an impact on organic chemistry courses, because the concept of intermolecular forces will be studied in depth in organic chemistry courses. The success of students in organic chemistry courses is highly dependent on the initial knowledge of students, especially in basic chemistry courses.

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