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University Students' Understanding of Intermolecular Forces: A Comparison of First & Third-Year Students

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Abstract: The study aims to analyze chemistry education students' understanding of intermolecular forces more deeply in 2021 (third-year) and 2023 (first-year). This type of research is descriptive research, and the technique used to collect data is a test and interview. Students encountered difficulties connecting types of Intermolecular Forces (IMFs) and molecular examples. Students' understanding of hydrogen bonding is higher than that of dipole-dipole, induced dipole, and London (dispersion) forces. This study implies that third-year chemistry education students demonstrated superior mastery of intermolecular forces than first-year students.
Keywords: Comparison of students' understanding, chemistry teaching, chemistry teaching

INTRODUCTION

Intermolecular forces (IMFs) comprise atoms, ions, and molecules that interact, and there are representations of phenomena at the macroscopic, symbolic, and microscopic levels (Johnstone, 1991). Intermolecular interaction is the most crucial concept for chemistry education students, particularly those taking general chemistry (Baldock et al., 2021), to understand and even predict the physical properties of macroscopic systems. The difference in boiling point and melting point of substances results from this difference. The path that connects the molecular structure to the properties of a substance requires a long chain of inferences. Ideally, a student should be able to construct and then use the structure (by understanding that the shape and distribution of electrons in the molecule determine the molecule's polarity) to make inferences about the interactions between molecules (intermolecular forces) that govern physical and chemical properties (Cooper et al., 2015) to intermolecular forces encompass concepts involving representative phenomena at macroscopic, symbolic, and microscopic levels. A comprehensive understanding of any chemical topic relies on students' ability to integrate these three interconnected levels, which can be illustrated in the form of a triangle.

Understanding chemical concepts is part of the results of the chemistry learning process. In addition, as the center of science, concepts in chemistry are the basis for the development of science, technology, and industry. Based on previous research, misconceptions experienced by students occur in several chemical concepts, including the concept of forces between molecules. Cooper et al. (2015) found that the first and second years of general chemistry showed surprising results; namely, 55% of students stated that intermolecular forces occur within molecules. Only 10-30% of students understand that intermolecular forces occur between molecules. Even more surprising is that 59% of students must consistently state that intermolecular forces are within or between forces. Another study also found the same misconception that intermolecular forces occur within molecules. Students assume hydrogen bonds involve hydrogen atoms, occurring when a C atom binds to an H atom in the molecule.

Misconceptions about intermolecular forces also occurred among chemistry education students at one of the universities in Malang in 2021 (third-year) and 2023 (first-year). This is evidenced by the question regarding the comparison between two compounds that have the highest boiling point, where students are asked to explain the differences in the factors that affect the boiling point, such as the functional group factor (Hydrogen Bond), Molar mass factor (Van der Waals Dispersion Force), steric factor (Van der Waals Dispersion Force), polarity factor (Van der Waals Dipole-Dipole Force), atomic size factor (Van der Waals Dispersion Force). From the results of interviews, some students still have difficulty understanding the concept of intermolecular forces. From these problems, the topic of chemistry education students' understanding of intermolecular forces in 2021 (third-year) and 2023 (first-year) needs to be analyzed more deeply. Through this research, it is hoped that it can be known to what extent chemistry education students understand the concept of intermolecular forces.

This study aimed to determine the levels of understanding and misconception experienced by chemistry education students about intermolecular forces. Most students still did not have a coherent and stable understanding of intermolecular forces as interactions between molecules. The same thing was also reported by Schmidt et al. (2009), who concluded that misconceptions often occurred about intermolecular forces and that students' understanding of intermolecular forces was insufficient. Taagepera & Noori (2000) also noted students' misconceptions about the physical properties of organic compounds topic. From such reality, it is possible that the prospective chemistry teachers also face difficulty and even experience misconceptions about the concept, even though the concept has been delivered during Senior High School and in Basic Chemistry courses.

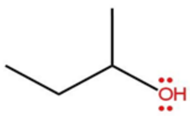
METHOD

This descriptive research aims to describe the ability of first-year (2021) and third-year (2023) students to understand and solve problems with intermolecular forces. This study used short-answer and multiple-choice questions and interview techniques to collect data. It involved 20 Chemistry Education students at a public university in East Java, with 10 students for each cohort. The test is used to determine chemistry students' understanding of intermolecular forces, while interviews validate the answers written by students on the answer sheet. The interview results confirmed students' knowledge of the intermolecular forces from the written test.

Instrument

The questions in the test are divided into two parts, part A and part B. The inquiries in part A were created separately, while part B was adopted from Musawwa et al. (2018). Questions 1-5 in part A required students to identify boiling points from the molecules' examples. In part B, students were asked to determine the type of IMFs from the examples of the molecules.

Table 1. Question in part A

No.	Questions
1.	Which compound has the highest boiling point? A.  B. 
2.	Which compound has the highest boiling point? A.  B. 
3.	Which compound has the highest boiling point? A.  B. 
4.	Which compound has the highest boiling point? A. CH_4 B. $CHCl_3$
5.	Which compound has the highest boiling point? A. Br_2 B. I_2

Students group answers based on the answer choices for each question number. After grouping, the total number of answers for each question is calculated for each question with a variety of answer choices. Analysis of a combination of students' correct answers will show students' understanding of intermolecular forces. Meanwhile, analysis of a combination of wrong answers will provide data about where students made mistakes in understanding the material on intermolecular forces. A multiple-choice test was applied to determine the levels of understanding and misconception of prospective chemistry teachers related to the concept of intermolecular forces.

Table 2. Question in part B

No.	Questions
1.	Which interactions might occur between two chloromethanes? [A] London dispersion force [B] Dipole-induced dipole [C] Momentary dipole-induced dipole [D] Dipole-dipole [E] Hydrogen bond
2.	Which interactions might occur between I_2 and other polar molecules? [A] London dispersion force [B] Momentary dipole-induced dipole. [C] Dipole – dipole [D] Hydrogen bond. [E] A and B correct
3.	Which interactions might occur between dichloromethane and chloromethane? [A] London dispersion force [B] Dipole-induced dipole [C] Dipole – dipole [D] Hydrogen bond [E] A and B correct
4.	What interactions occur between molecules (F_2) composed of atoms with high electronegativity (F)? [A] London dispersion force [B] Dipole-induced dipole [C] Dipole – dipole [D] Hydrogen bond [E] Covalent bond
5.	What interactions occur when Cl_2 has dissolved in chloromethane solution? [A] London dispersion force [B] Dipole-induced dipole [C] Dipole – dipole [D] Hydrogen bond [E] Covalent bond
6.	Which interactions might occur between H_2O and HF? [A] London dispersion force [B] Dipole-induced dipole [C] Dipole – dipole [D] Hydrogen bond [E] Covalent bond
7.	What interactions occur between methane containing H atoms [A] London dispersion force [B] Dipole-induced dipole [C] Dipole-dipole [D] Hydrogen bond [E] Covalent bond
8.	In which of the following compound(s) is hydrogen bonding likely to occur between the same molecules? [A] CH_4 [B] $CHCl_3$ [C] CH_3F [D] CH_3OH [E] H_2
9.	Which hydrogen bond is the strongest? [A] H_2O – HF [B] H_2O – H_2O [C] HCl – HBr [D] HF – HCl [E] H_2 – H_2O
10.	Which molecular forces below are the strongest? [A] CH_3Cl – I_2 [B] F_2 – F_2 [C] $CHCl_3$ – CF_4 [D] CH_4 – H_2O [E] CH_3OH – H_2O

RESULTS AND DISCUSSION

The purpose of question 1 is to determine the understanding of chemistry education first-year and third-year students regarding the influence of functional groups on boiling points. It was found that third-year students could understand the problems better than first-year students. This is proven by 100% of third-year students who answered correctly, while only 50% of first-year students answered correctly. Some first-year students seem unaware that a functional group can affect a molecule's boiling point. Different functional groups with the same carbon atoms will have different boiling points. The correct concept is that "the boiling point of alcohol is higher than ether due to the presence of hydrogen bonds, which results in the strength of the force between alcohol molecules higher than ether, which only has a dipole-dipole force and London force."

The purpose of question number 2 is to determine students' understanding of the effect of carbon chain length on boiling point. Again, 100% of third-year students answered correctly, with only 50% for first-year students. Several first-year students assume that the most volatile compounds are the compounds with the highest boiling points and molar masses. They incorrectly believed that the higher the hydrocarbon compound's molar mass, the lower its boiling point was due to the weaker the bonds between hydrocarbon molecules compounds and their nonpolar character. They failed to recognize that the van der Waals forces exist in non-polar molecules. The knowledge of third-year students for the first two questions is classified as very high, while first-year students are classified as intermediate.

The aim of question number 3 is to determine the student's understanding of the influence of steric effects/number of branches on carbon chains with the same functional group on boiling point. 70% of third-year students answered the question correctly, while only 20% of first-year students. In this question, the level of understanding of third-year students is relatively high, while that of first-year students is relatively low. They failed to realize that the size of the iodine atom is greater than the bromine atom, so the valence electron in the iodine atom is weakly bound by the nucleus more than the bromine atom. Hence, iodine atoms are more easily polarized.

Question 4's purpose is to determine the students' understanding of the effect of molecular weight on boiling point. Eighty percent of third-year students answered the question correctly, while 40 percent of first-year students were relatively intermediate. Question number 5 shows a dipole-induced dipole interaction between the polar molecule chloromethane and the nonpolar molecule Cl_2. The percentage of correct answers is 20% from the first year, which shows the level of student understanding at the low level, and 50% from the third year, which shows the level of student understanding at the intermediate level. In number 6, the interaction formed between H_2O and HF is hydrogen interaction. The electronegative atoms and the visible H atoms in both molecules indicate the two molecules' propensity to form hydrogen bonds. A hydrogen interaction or bond is a primary attraction between hydrogen (H) atoms that bond covalently to a more electronegative atom or group (DeFever et al., 2015). The student understanding of this problem reached 70% from the first year, which means their understanding was high, and a score of 100% or perfect from the third year, which means their understanding was very high. In question number 7, the interaction between the methane molecules is London dispersion forces because methane is a nonpolar molecule. The correctness of the answer in number 7 is quite low, 20% from first-year students and intermediate, 50% from third-year students.

Another type of question (part B) that emphasizes students to predict molecular examples of the IMFs is correctly demonstrated by 63.33% of third-year students and 33.33% of first-year students. The elevated percentage of successful third-year students responding to the questions is unsurprising, given the number of courses they have completed. The result of this study also implies the necessity to consider how we represent chemical phenomena to students. The representations provided to pupils influence the characteristics highlighted to them and the probability that they will make accurate predictions about chemical properties (Farheen & Lewis, 2021; Nelsen et al., 2024).

CONCLUSIONS

This study found that third-year chemistry education students demonstrated a better mastery of intermolecular forces than first-year students. This phenomenon is understandable because they have completed more chemistry courses. Further studies to deeply uncover students' understanding of intermolecular forces should be carried out from another perspective published by previous researchers, such as tactile models (Bromfield Lee & Beggs, 2021), visual representations (Patron et al., 2021) and other forms of instruments.

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