The Effects of Using Multiple Representations on Prospective Teacher’s Conceptual Understanding of Intermolecular Forces

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Abstract. Intermolecular force is one of study material in Organic Chemistry I course, which involves numerous representations. This study aimed to find out the effects of using multiple representations on prospective teacher’s conceptual understanding of intermolecular forces. The research method used in this study was a quasi-experiment. The research subjects were 56 second-semester chemistry education students batch 2017-2018 in Universitas Negeri Malang which enrolled in Organic Chemistry I course. The research subjects are grouped into two classes including experimental and control classes with 28 students each. The experimental class was taught with the multiple representations-based learning, while the control class was taught using an expository learning. The measuring instrument included 6 question items with three-tier test question type and a reliability of 0.639. The research result showed there was a positive effect on the use of multiple representations-based learning. This can be seen from the existence of a difference in experimental and control classes’ conceptual understanding. The conceptual understanding of intermolecular forces in the experimental class (mean 55.93) was higher compared to the control class (mean 36.96).

1. Introduction
Organic Chemistry I course is one of the required course in the department of chemistry of Universitas Negeri Malang. The material in Organic Chemistry I course prepares the students with a fundamental knowledge on basic concepts in organic chemistry, including organic compound structure, conjugation and resonance, intermolecular force, physical and chemical properties of the organic compound, isomeric, reactions of the organic compound [1]. From the field study, information was obtained that there were students who have difficulties, and even encountered misconception in the Organic Chemistry I course, specifically in the materials of resonance, intermolecular force, space isomerism, and organic reactions. This was also stated by [2] that was still be found students who have difficulties and misconception in the Organic Chemistry I course, particularly on the materials of resonance and intermolecular forces. Therefore, there needs to be a learning innovation which can increase the students’ understanding of the learning organic chemistry materials.

One of the learning innovations which can be applied in the Organic Chemistry I course specifically intermolecular force is by using multiple representations. Chemistry material has 3 levels of representations including macroscopic, symbolic, and sub-microscopic. According to [3] a macroscopic
level is a level which describes the real phenomena which can be observed by five senses, while sub-microscopic is the level which describes a particular level of a material which cannot be observed using senses such as the atom, molecule, and ion. Meanwhile, the symbolic representation consists of diverse representations with figures which cover all kinds of signs and symbols which are used to explain the chemistry concepts. The three levels of representation need to be comprehended by the students so the students could have a thorough knowledge of chemistry, particularly on intermolecular forces material.

The intermolecular force is a part of Organic Chemistry I material. There are three types of intermolecular forces which are Van der Waals force (London), dipole-dipole interactions and hydrogen bond. Van der Waals force occurs due to a temporary dipole in a molecule. The forces exist on all compounds both nonpolar and polar. The dipole-dipole interactions occur in the compounds which has a permanent dipole. The hydrogen dipole occurs in the compound which has hydrogen bound to the nitrogen/oxygen/fluorine atom. Being seen from its material, the intermolecular force has many characteristics, involving intermolecular interactions in the organic compound. From the material characteristic of intermolecular force, media is needed to make it easy to understand, for instance by using multiple representations which covers macroscopic, sub-microscopic, and symbolic to reveal phenomena clearly.

The use of multiple representations such as in the intermolecular forces material is very important. This is based on the statement of when the chemical phenomenon is only explained through a lecture on the macroscopic level without an explanation on the molecular level (sub-microscopic), and it will be hard to comprehend. The importance of multiple representations established in the chemistry learning has been reported by researchers. [4] reported that multiple representations give a positive effect on students’ ability to construct arguments in the laboratory class though science writing heuristic strategy. In addition, [5] stated that the use of multiple representations supports the writing-to-learn assignment as a pedagogical tool in improving chemistry learning at schools. Multiple representations also help the students in problem-solving on the chemistry concept about spectroscopy NMR [6]. The use of other representations has also been performed to increase the students’ understanding such as the transformation representation of macroscopic, submacroscopic, and symbolic [7] external multiple representations [8] and virtual and concrete model [9]. There is a difference between instruction with Multiple Representations (IMR) and Instruction with Verbal Representations (IVR), where the students’ scientific understanding taught by using multiple representations is better than students taught by using verbal representations [10].

The research on student’s difficulties in learning organic chemistry material has been conducted by [11] which the result stated that the students experienced difficulties in comprehending the alkyl halide reaction such as categorizing a compound as base and nucleophile, determining the strength of base and nucleophile of a compound, describing the mechanism stages of alkyl halide reaction, and determining the reactive intermediate form in the alkyl halide reaction. The same incidence also occurs in America in Organic Chemistry course, where the resonance is one of the concepts in the organic chemistry courses which is considered difficult by the students [12].

[13] conducted a research related to intermolecular forces on the students’ thinking on the intermolecular force material (hydrogen bond, dipole-dipole interaction, and the strength of London dispersion), by assigning the chemistry student to illustrate the comprehension written and its representations. The research results showed that most of the students did not have a coherent and stable understanding of the intermolecular force as the intermolecular interactions. Students’ representation on the intermolecular force varied. The students’ written description on the strength between molecules is commonly rather ambiguous, whether the students have understood the intermolecular force as a bond or interaction. In this case, spatial information is very essential. The illustrated representation is the free form is likely to give more meaningful knowledge to the students’ thinking.

A similar study has also been reported by [14], related to intermolecular forces material, which also reported the same matter occurred to high school students in Germany, where the 11 to 13-grade students encountered difficulties to predict the boiling point of the organic compounds. A common misconception is the breakdown of covalent bonds that cause boiling organic compounds, hydrogen
bonds are only formed if organic molecules contain hydrogen and oxygen atoms, and polar molecules can form hydrogen bonds. These results indicate that students' understanding of intermolecular forces is inadequate. [15] have conducted learning innovations on intermolecular style material with problem-based learning (PBL). The results of his research show that PBL is effective against student achievement can overcome the formation of alternative conceptions and also improve social skills. One of the learning innovations that can also improve problem-solving abilities is Problem-Solving. Research on the application of problem-solving by using representation in first semester students at Purdue University who take Organic Chemistry courses has been carried out by [16]. Students are given questions to write systematic names (IUPAC system) for compounds with different structural formula. Generally, the students are able to write correct names in the form of straight chain structure but cannot write the names in the form of cyclical structures.

Based on several research findings above, organic chemistry is a hard concept to be understood by the students. The occurrence of misconceptions will affect students in understanding the concept of advanced organic chemistry. From these studies, it can be seen that learning using multiple representations can improve understanding of chemical concepts in the classroom or in the laboratory. Similarly, there is a relationship between the symbol system presented by the teacher and the representation that is built when solving chemical problems. With regard to the matter of intermolecular forces which involves more interactions of dipole-dipole forces, type of bond, type of force, strength of force, and description of dipole-dipole interactions, then there is a need to use multiple representation (submicroscopic, macroscopic, and symbolic).

2. Research Method
The research method used is a quasi-experimental method. The research subjects were 56 second-semester chemistry education students batch 2017-2018 Universitas Negeri Malang who enrolled in Organic Chemistry I course. The research subjects were divided into two classes, namely the experimental class and the control class of 28 people each. The experimental class was taught with multiple representations-based learning, providing problems that must be solved in the student worksheet. The control class was taught using expository lectures. The instrument consists of a syllabus, semester lecture plans, student worksheets, and questions. The instruments to identify the conceptual understanding are six question items of three-tier test question type with a reliability of 0.639. The instrument was in the form of three-tier test, which was multiple choice test with open-ended questions and Certainty of Response Index (CRI) scale technique developed by [17] and have been modified by [18] and [19]. The three-tier test instruments can be seen in the appendix.

3. Research Results and Discussion
This research aimed to find out the effect of using multiple representations on the conceptual understanding of intermolecular forces and also to find out the understanding, not understanding, and misconception between experimental and control class students.

How the effect of the use of multiple representations is in the chemistry prospective teacher students’ conceptual understanding of intermolecular forces material (experimental class) compared to the students with expository class (control class). With any learning, each chemistry prospective teacher student has a different comprehension of the concept learned in the class, thus the level of comprehension of a concept is also different. This is in line with what has been conducted by [13], who reported that many students have not a coherent and stable understanding of intermolecular forces as intermolecular interactions. The similar matter also stated by [14], which concludes that misconception often occurs in the matter of intermolecular forces and students' understanding of intermolecular force is inadequate. This reality does not rule out the possibility of chemistry prospective teachers also having difficulty even experiencing misconceptions on the concept of intermolecular force, although the concept of intermolecular force has been given during high school and in the Basic Chemistry course.

From the results of the three-tier test data analysis on the intermolecular forces material obtained information on the chemistry prospective teacher students related to understanding of the concept, not
understanding, and misconceptions on the intermolecular material between the experimental class and the control class conducted multiple choice tests with open reasons and CRI (three-tier test). The percentage distribution of chemistry prospective teachers’ understanding of the concept, not understanding, and misconceptions, based on each question items on intermolecular forces material from both classes can be seen in Table 1. Meanwhile, the existence of differences in learning outcomes between the experimental class and the control class can be seen in Table 2.

### Table 1. Percentage Recapitulation of Conceptual Understanding, Not Understanding, and having Misconception on Chemistry Prospective Teacher Students on the Intermolecular Forces Material in the Experimental and Control Classes

| Question number | Number of Pre-Service Chemistry Teachers’ Conceptions | Understand | Not Understand | Have Misconception |
|-----------------|---------------------------------------------------|------------|----------------|-------------------|
|                 |                                                   | Experiment | Control        | Experiment        | Control        |
| 1               | 23                                                | 5          | 1              | 12               | 4              |
| 2               | 15                                                | 8          | 5              | 3                | 8              |
| 3               | 16                                                | 14         | 6              | 8                | 6              |
| 4               | 17                                                | 13         | 6              | 9                | 5              |
| 5               | 15                                                | 15         | 9              | 6                | 4              |
| 6               | 9                                                 | 2          | 9              | 8                | 10             |

Percentage 56.00% 33.92% 22.00% 27.38% 22.00% 38.70%

### Table 2. The Statistical Calculation Results of Experimental and Control Classes’ Scores

| Group         | Average  | Standard Deviation | t-Test (α = 0.05) | Identification           |
|---------------|----------|--------------------|-------------------|-------------------------|
| Experimental  | 55.93    | 16.80              | 0.007             | Null hypothesis is rejected |
| Control       | 36.96    | 13.70              |                   |                         |

Table 1 showed that the percentage of experimental class’ conceptual understanding (56.00%) is higher compared to control class (33.92%). This shows that the learning using representation control is very helpful in students’ comprehension in learning intermolecular force in Control Chemistry I course which has abstract and complex characteristics. These characteristics include much intermolecular force material involving illustrations/depictions related to dipole-dipole interactions, several types of chemical bonds, and strength of forces, in which to study requires clear depiction. This is in accordance with [10] which states that there is a difference between Instruction with Multiple Representations (IMR) and Instruction with Verbal Representations (IVR), where students' scientific understanding is taught with better representation control than students taught with verbal representations.

On the other hand, without understanding the concept experienced by chemistry prospective teacher, where the percentage of not understanding of the concept of students taught by multiple representations is lower (22.00%) than the class without using multiple representations (27.38%). Some of the reasons given by chemistry prospective teacher students in the experimental class that correspond to the theory in each problem number are described as follows. The students of experimental class on the question number 1 related to the determination of the van der Waals force, 23 out of 118 chemistry prospective teacher students understood the concept. Through the multiple representations-based learning with problem-solving strategy in the student worksheets, most of the chemistry prospective teacher students have answered correctly. The students who understood the concept with high confidence answered E, with a correct reason which is,
The mass of iodine molecule is bigger than bromine molecule; therefore it is easy to be protonated

The reason for the answer is in accordance with the concept that the electronegativity of an element is related to the ease in polarizing other elements. This is also in accordance with the van der Waals force theory, that van der Waals forces are influenced by the surface of the molecular touch, thus affecting the strength of the dipole-dipole attraction [20]. In other words, the more surface area of a molecule, the stronger the van der Waals force.

Experimental class students in problem number 2 are related to determining organic molecules that have dipole-dipole style if the molecular formula is known, as many as 15 students are chemistry prospective teachers who understand the concept by answering correctly, namely C. Examples of true reasons given by students are as follows (Figure 1).

![Figure 1. Examples of True Reasons Given The Question Number 2](image1)

On the \((\text{CH}_3)_2\text{C}=\text{C}(\text{CH}_3)_2\) compound, the difference of the electronegativity in atom H and C is very small thus both C-C and C-H bond are nonpolar bonds. Therefore, \((\text{CH}_3)_2\text{C}=\text{C}(\text{CH}_3)_2\) molecule is nonpolar molecule and only has van der Waals bond.

The CHCl₃ molecule does not contain atom F, O, and N which can form a hydrogen bond with water.

The students who have understood the concept gave an appropriate reason according to the theory. According to [20], hydrogen bond occurs in the hydrogen with free electron pair on atom N/O/F in other molecules.
The questions number 5 and 6 are related to the intermolecular force. In the experimental class, respectively there were 15 and 9 chemistry prospective teacher students understood the concept. The question number 5 is about predicting the type of intermolecular force occurs in the organic molecule. The students were given several questions relating to the intermolecular force and asked to choose the right statement. 15 students answered with a proper reason which is B.

The example of reason from the student who has a conceptual understanding is shown in the following (Figure 3).

\[ \text{CH}_3(\text{CH}_2)_2\text{COOH} \text{ molecule is a polar compound, therefore, it has van der Waals force and dipole–dipole forces. Besides, there is hydrogen atom bond directly with an oxygen atom in the molecule which can create hydrogen bond within the molecules.} \]

Figure 3. Examples of True Reasons Given The Question Number 5

The answer reason given by the students indicates that the student already understands the types of intermolecular forces. In which Molecule CH\textsubscript{3}(CH\textsubscript{2})\textsubscript{2}COOH is a polar compound which has van der Waals force and dipole-dipole force. In addition, there are hydrogen atoms that are attached directly to the oxygen atom in the molecule so that they can form an intermolecular hydrogen bond. In molecular compounds, there are bonds in molecules and intermolecular forces. This is consistent with [20] that intermolecular forces connect one molecule to another.

In the question number 6, the chemistry prospective teachers were asked to arrange the strength of the intermolecular forces by giving a statement related to the strength on intermolecular forces of several compounds. There were 9 chemistry prospective teacher students who answered with a correct reason. The example of the correct reason is as follow (Figure 4).

This molecule can form two intermolecular hydrogen bonds, therefore, the intermolecular forces are the strongest.
A different condition occurred to the chemistry prospective teachers who encountered misconception. In Table 1 it looks good on classes that use learning by using multiple representations (experimental class) or not using multiple representations (control class), both of them still see students experiencing misconceptions. These findings indicate that misconception is very difficult to completely eliminate (zero misconception). This is in accordance with the results of [20] research that misconceptions cannot be removed at all, especially related to concepts involving submicroscopic and symbolic representations. Whereas [21] suggests that the characteristics of misconceptions are durable, and firmly embedded in one's mind. Although the misconceptions cannot be completely lost from Table 1, it can be seen that the misconception in the experimental class (22.00%) is smaller than the control class (38.70%). This shows that there is an effect on the use of multiple representations on the learning process of intermolecular force material.

In the experimental class, the biggest not understanding the concept and misconception occurred in the question number 6. On the question number 6, the chemistry prospective teachers still have the difficulties in arranging the strength of the intermolecular forces. This can be seen from the few students who understand the concept were 9 people, which is comparable to students who did not understand and experienced misconceptions. This condition is due to the inability of students to describe the structures of the organic compounds and the poor understanding of concepts related to intermolecular forces. Therefore, many students found difficulties and misconception. The students also still considered that the strength of the intermolecular forces was affected by the electronegativity only.

Related to the strength of the intermolecular force, it will be easier to draw the structures of each compound, so that the type of force can be known and can compare the strength of the intermolecular forces. The strength of the intermolecular forces can be seen from the type of bond and the characteristics of the compound, whether the molecule has a momentary or permanent dipole, has an N-H, O-H, F-H bond, or the compound is an ionic bond. These characteristics will be easily seen if the chemistry prospective teacher understands the concept well and is able to describe its structure. This is in accordance with the results of [13] research on intermolecular forces which show that in understanding the intermolecular forces, spatial information is very important related to the structural representation of compounds that are described as being more able to provide meaningful insights into students' thinking. Therefore, the use of representation in the learning of intermolecular force material is indeed required.
The use of multiple representations gives effects on the conceptual mastery of chemistry prospective teacher students on the intermolecular force material. This gives impact on the difference of conceptual mastery of intermolecular force material between experimental and control classes. The difference between both classes is strengthened by the significance test (t-test) in Table 2 that there is a significant difference between the experimental and control classes. Where the mean of the experimental class (55.93) is bigger than the mean score of the control class (36.96).

The use of multiple representations in research is supported by problem-solving learning strategies. Desired expectations are problem-solving by providing problems and representations related to the intermolecular style material on student worksheets which can motivate students to study literature and try to gather information from other sources which will then help students solve problems and understand concepts which are in accordance with that is implemented in lectures. [16] also reported that the use of multiple representations helped students solve problems in the concept of organic chemistry.

The research results showed that the use of multiple representations helps the students in understanding the concepts of intermolecular forces which are abstract and needs a real depiction. Besides that, the use of multiple representations can also increase the mastery of intermolecular force material. This can be seen from the result of students’ conceptual mastery in the treatment class with multiple representations-based learning (experimental class) and the class without using multiple representations-based learning (control class).

4. Conclusion
Based on the research findings, it is obtained a conclusion that the use of multiple representations in the Organic Chemistry I course on the intermolecular forces material has a positive effect and helps the students in achieving a better conceptual understanding. This can be seen by the mean of conceptual understanding of intermolecular force in the experimental course (55.93) is higher compared to the control class (36.96). There is a difference in the conceptual understanding between the students taught using multiple representations-based learning (experimental class) and the class without using multiple representations-based learning (control class).

5. Suggestions
Based on the research finding, the learning strategy of organic chemistry particularly the intermolecular forces material needs an improvement, which puts emphasis on the optimization of the use of multiple representations. The application of multiple representations can be used to clearly show the structure of a compound, the formation of the hydrogen bond, and other types of intermolecular forces. Besides that, time is more calculated mainly in the group work doing the student worksheets. The most important thing is to give the opportunity to the chemistry prospective teacher students to practice drawing the molecular structure with the known chemical formula and to predict the strength of intermolecular force from the compound structure which has been made.

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### Distribution of intermolecular force questions

| No | Questions |
|----|-----------|
| 1  | Determining the strength of van der Waals force |
| A. | The CORRECT statement about the strength of van der Waals force is …. |
| B. | A. The strength of van der Waals force increases correlatively with the increase of molecular symmetry. |
| C. | B. The strength of van der Waals force of CH₃C(CH₃)₂CH₂CH₃ > CH₃CH₂CH(CH₃)CH₂CH₃ > CH₃(CH₂)₄CH₃ molecule due to the influence of polarizability. |
| D. | C. The strength of van der Waals force of CCl₄ < CF₄ molecule since the chlorine atom was easier to be polarized that atom F. |
| E. | D. Pentane (CH₃(CH₂)₃CH₃) and neopentane (C(CH₃)₄) molecules have the same molecular mass, however, the strength of van der Waals force of pentane molecule is smaller than neopentane. |
| F. | E. The strength of van der Waals force of CH₃Br < CH₃I molecule since the iodine atom is easier to be polarized than bromine atom. |

| No | Questions |
|----|-----------|
| 2  | Determining the organic molecule which has dipole-dipole forces if the molecular force is known |
| A. | The molecules below which does not have the dipole-dipole force is … |
| B. | A. CH₃CH₂CH=CHCH₂Cl |
| C. | B. (C₂H₅)₂O |
| D. | C. (CH₃)₂C=C(CH₃)₂ |
| E. | D. (CH₃CH₂)₃N |
| F. | E. CH₃(CH₂)₃OH |

| No | Questions |
|----|-----------|
| 3  | Determining the organic molecule which can form an intermolecular hydrogen bond if the molecular formula is known |
| A. | The organic molecules below CAN form an intermolecular hydrogen bond is … |
| B. | A. CH₃(CH₂)₃COCH(CH₃)₂ |
| C. | B. CH₃CH(CH₃)CH₂COOCH₂CH₃ |
| D. | C. (C₃H₇)₂O |
| E. | D. (C₃H₇)₂NH |
| F. | E. CH₃(CH₂)₃CHO |

| No | Questions |
|----|-----------|
| 4  | Determining the organic molecule which can create a hydrogen bond with water if the molecular formula is known |
| A. | The organic molecule below which CANNOT form a hydrogen bond with water is … |
| B. | A. (C₃H₇)₃N |
| C. | B. CH₃CH(OH)CH₂CH(OH)CH₃ |
| D. | C. C₂H₅OCH₃ |
### Predicting the type of molecular forces occurred in the organic molecular

| D. | CH₃F                                      |
|----|------------------------------------------|
| E. | CHCl₃                                    |
| Reason: | CRI:                                      |

The **CORRECT** statement is …

A. The CH₂Cl₂ molecule only has van der Waals force.
B. The CH₃(CH₂)₂COOH molecule has van der Waals force, dipole–dipole forces and intermolecular hydrogen bond.
C. The (CH₃)₃N molecule has van der Waals forces, dipole–dipole forces and intermolecular hydrogen bond.
D. CH₃CH₂CH=CHCH₂F molecule has dipole–dipole forces and intermolecular hydrogen bond.
E. The CH₃COCH₂CH₃ molecule has dipole-dipole force.

### Arranging the strength of molecular forces in an organic molecule

| 6 | The **CORRECT** statement is … |
|---|--------------------------------|
| A. | The strength of intermolecular forces CH₃(CH₂)₄I > CH₃(CH₂)₄Cl > CH₃(CH₂)₄Br |
| B. | The strength of intermolecular forces (CH₃)₃N > (CH₃)₃NH > CH₃CH₂CH₂OH |
| C. | The strength of intermolecular forces CH₂CH(OH)(CH₂)₂CH(OH)CH₃ > CH(CH₃)₂(CH₂)₂CH₂(OH) > CH(CH₃)₂CH₂CH₂(OH)CH₃ |
| D. | The strength of intermolecular forces CH₃(CH₂)₂CHO < CH₃(CH₂)₂COOH < CH₃CH₂COOCH₃ |
| E. | The strength of intermolecular forces (CH₃)₃CCH₂COCH₃ > (CH₃)₃CCH₂CH₂(OH)CH₃ > CH₃(CH₂)₁₀CH₂ |
| Reason: | CRI:                                      |