US-China Education Review B 1 (2011) 12-23
Earlier title: US-China Education Review, ISSN 1548-6613

Using Open-Ended Questions to Diagnose Students' Understanding of Inter- and Intramolecular Forces*

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The purpose of this study was to investigate Grade 10 Thai students about their understanding on inter- and intramolecular forces. Sixty four students were elicited by administered open-ended questions after finishing normal instruction on chemical bonding topics. The instrument was in a set of open-ended questions which contained a number of systematic elicited questions, but only six questions were reported here. It was found that the students had difficulty in understanding inter- and intramolecular forces. Even though they had learned these conceptions in chemistry class, the students were not able to distinguish between inter- and intramolecular forces. The implications of this research indicated that making students understand chemistry concepts and principles was not an easy task. There are numerous ways in which students can misconstruct concepts and principles largely due to failing of shifting between macroscopic and microscopic phenomena. Teachers must be aware of the various conceptions, otherwise, the alternative conceptions will be the obstacle to understand more complex conceptions on learning chemistry.

Keywords: chemical bonding, diagnostic test, intermolecular force, intramolecular force

Introduction

A major goal of science teaching is to help students understand natural phenomena, the scientific principles and theories that describe them. This goal is difficult to achieve, because many phenomena are difficult to perceive, and the scientific principles used to explain them are abstract and complex (Collette & Chiappetta, 1994). Chemistry is also regarded as a highly abstract and complex subject (Johnstone, 2000; Gabel, 1999). Chemistry is a difficult subject for middle school and college students (Nakhleh, 1992). No wonder why many students answered questions related to some chemical concepts correctly, but they completely lack of understanding in those concepts (Lythcott, 1990).

Chemical bonding is a central concept in chemistry (Nicoll, 2001; Taber & Coll, 2002; Levy-Nahum, Mamlok-Naaman, & Hofstein, 2007), because it concerns with a combination of particles and the nature of

* This paper was presented at "2010 NARST Annual International Conference" (Philadelphia, USA, March 21-24, 2010) organized by National Association for Research in Science Teaching, Virginia, USA 20190-3221.

Acknowledgement: We wish to thank the IPST (Institute for the Promotion of Teaching Science and Technology), Thailand, for providing the research fund.

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bonding between particles related to the chemical and the physical properties of the substance. Because the chemical bonding and related concepts are far from students' daily experiences, students cannot see an atom and its interactions, they may have difficulty in understanding the concepts, and as a result, alternative conceptions are easy to be formed (Tan & Treagust, 1999; Coll & Taylor, 2002; Taber & Coll, 2002; Unal, Calik, Ayas, & Coll, 2006; Gabel, 1999).

Nicoll (2001) reported that inter- and intramolecular bonding concept is difficult for students to understand. The students held many alternative concepts, such as "Covalent bond is not as strong as hydrogen bonding" (Nicoll, 2001, p. 712); "Covalent bonds are broken when a substance changes state" (Tan & Treagust, 1999, p. 79); "The bubbles in boiling water as water vapor are hydrogen, oxygen gas and air" (Mulford & Robinson, 2002, p. 74). Intermolecular forces were identified as the forces within a molecule, or even believed that molecular solids consist of molecules with weak covalent bonding between the molecules (Tan & Treagust, 1999, p. 76). Taagepera, Arasasignham, Potter, Soroudi, and Lam (2002) concluded that students displayed very little understanding of inter- and intramolecular interactions. In order to elicit and challenge students on alternative conceptions, several approaches were reported in the literature, such as using conceptual maps (Taber, 2002), interview (Barker & Millar, 2000; Boo, 1998; Coll & Taylor, 2002; Harrison & Treagust, 2000; Nicoll, 2001; Unal et al., 2006), two-tier format (Tan & Treagust, 1999) and open-ended question (Targan, 1987).

The results from previous studies and the alternative conceptions on chemical bonding with respect to inter- and intramolecular interaction inspired the researcher to study Thai students' understanding of those conceptions after finishing a normal instruction. The purpose of this study was to identify and describe Grade 10 students concerning their understanding in the inter- and intramolecular interactions when the change of state occurred.

Methodology

Sample

The sample was 64 Thai students at Grade 10 from a publish school where is far from Bangkok about 150 kilometers. Before taking the test, the students had already finished learning the chemical bonding topic in the first semester of B.E. 2552 academic year.

Research Procedure

A completed test version had been developed by the researcher to determine high-school students' conceptions on the chemical bonding conception, but merely the conception of inter- and intramolecular force was reported here. To align assessment questions with learning goal, the processes of the test development firstly determined the content areas of the chemical bonding conceptions. This content area was based on a list of propositional knowledge appeared in chemistry textbook volume 1 (Teacher handbook) of the IPST (Institute for the Promotion of Teaching Science and Technology), Thailand. The test items were systematically organized around the ideas that all student should learn to achieve the goal of science curriculum by the time they graduate from high school. To elicit students' ideas, a paper-and-pencil form of the test was adopted as an instrument. The instrument mostly resembled to a two-tier form which consists of two components: The first tier asked students to draw a picture or choose an answer and the second tier asked students to give reasons to support the answer of the first tier. The content validity of the instrument was verified by five experts consisted of two chemistry university professors, two chemistry high school teachers and one chemist. The instrument was administered to 64 Thai high school students after finishing normal instruction on the chemical bonding topic. The test was done within a normal class period. After finishing the examination, data were collected.

In general, the test items present the learning goals as lists of what students should know and be able to do. These test items were not simply disconnected facts about a scientific phenomenon; rather, they were key elements in a series of conceptual questions to elicit deeply conceptual understanding. The students' ideas were framed by introductory essays that summarized the conceptual story. The expectation was that students richly interconnected mental models of objects, events and processes in the natural phenomena that made them to explain related events.

Data Analysis

The open-ended questions were used as an instrument for revealing of and distinguishing among students' complete conception, incomplete conception, alternative conception, no conception and no response. Students' responses were analyzed based on the consistence between the first and the second part. The responses needed to be completed both parts: the first and the second tier, and the analysis were based on the consistence between them. Students' responses were evidence of students' conceptions. The study of Tan and Treagust (1999, p. 78) interpreted students' ideas as holding alternative conceptions were existed when there were at least 10% of the student samples. In this study, however, alternative conception was existed when there were at least 7% of the student samples.

A student's answer was considered as a "complete conception" if the student had selected the content choice and the reason for the first part correctly. If the student only had selected the first part correctly but without giving a reason for the answer, then it was considered as "incomplete conception". If the answer on the first part was incorrect and without answering the second part, then it was determined as "no conception". In addition, if the students had given an incorrect answer for the first part, and the second part's reason did not make any sense, it was also considered as "no conception". If the students had selected correctly on the first tier and given a reason showing alternative conception, this response was considered as an "alternative conception". In summary, complete conception means a student gives a right answer for both parts. Incomplete conception means a student gives a correct answer only one part but no answering for the other. Alternative conception means that a student's response holds alternative conceptions either on the first part or the second part or both. No conception means that a student's response shows unrelated to the question. No conception includes students who write "I don't know" or "I am not sure" or "I cannot remember". Finally, no response includes student who is not response or leave the question blank.

Results and Discussion

Examples of typical students' responses categorized as complete, incomplete, alternative and no conception which revealed respective examination questions are given as follows:

Question 1: Key idea intended to measure the understanding on intermolecular force. Firstly, students were asked to indicate "What the component of a water molecule is". Students should know that a molecule of water consists of one atom of oxygen and two atoms of hydrogen. A water molecule had been used as an example, because it is a simplistic substance that students are very familiar with. Students' responses on the first question are revealed in Table 1.

Table 1

Students' Responses on Question 1

Answer	Reason	Judgment	Percentage (%)
Two atoms of hydrogen and one atom of oxygen	Two atoms of hydrogen and one atom of oxygen	Complete conception	87.30
Hydrogen and oxygen	A water molecule composes of hydrogen and oxygen atom	Incomplete conception	3.17
One atom of hydrogen and two atoms of oxygen	No reasons	Alternative conception	0.00
Ice and water I do not know	No reasons	No conception	3.17

Note. No response is 6.36%.

Students who correctly identified elements and number of each element were 87.30%, whereas students who did not identify number of composed atoms in the molecule but identified the component elements of water correctly were 3.17%. Not surprising that almost all of the students answer the first question correctly and no one is justified as a holding alternative conception. But the interesting thing is that 3.17% of the students are considered as no conception with respect to their answer. Moreover, 6.36% leaves this test question blank.

Question 2: Key idea intended to further more challenge to gain a deep understanding on particular science ideas. The students were asked more apply conceptions through the second question in that "When ice becomes liquid water whether the component of water molecule is still the same". Students were expected to know that when a substance changes in state, their intermolecular force will be destroyed but not for the intramolecular force (or covalence bonding). According to scientific fact, at atmospheric pressure and at temperatures below 0 ˚C, water is in its solid state, known as ice. If heat is added to the ice, it melts and becomes liquid water. Because liquid water and ice have very different appearances, students may think that their composition between ice and liquid are different. Examples of students' responses on question 2 are illustrated in Table 2.

Table 2

Students' Responses on Question 2

Answer	Reason	Judgment	Percentage (%)
The same	The same because when water changes in state, its chemical bond in the molecule does not be destroyed	Complete conception	49.21
The same	The same because the component of water in all states (liquid, solid or gas) will be the same for it is stable	Incomplete conception	12.70
Either the same or difference	The same but the size of atom will be smaller Difference because liquid water change to hydrogen gas	Alternative conception	12.70
Difference	Different because water becomes a vapor when the temperature reach 100 ˚C Different because water molecule changes in state from solid to liquid	No conception	15.87

Note. No response is 9.52%.

Comparing to question 1, students' responses on question 2 which were considered as complete conception decrease. Only 49.21% of the responses confirmed that the component of water is still the same. Looking further to the reason, students stressed that its intramolecular force does not change but they did not explain further about how it relates to intermolecular force. Twelve point seven point of the responses considered that the component is unchanged, but they cannot give a scientific reason to support their thinking. Students' responses were justified as an alternative conception, because their responses show that scientific conception is distorted. For example, students believe that when water melts, water will change to hydrogen gas. This finding consistent to the previous study of Tan and Treagust (1999) in that students revealed that "Covalent bonds are broken when a substance changes state" (p. 79) or even believed that the bubbles in boiling water as water vapor are hydrogen gas and oxygen gas (Mulford & Robinson, 2002, p. 741). Up to 15.87% of students' responses were considered as no conception, because their response did not give any reason to support the answer. Rather, such answers just re-stress the question on the test item.

Question 3: Key idea intended to gain more students' understanding about the concepts of inter- and intramolecular forces. The question 3 challenged students "to draw a molecule of water when it is in the solid, liquid and gas state". Students were expected to know that when water changes in state, its component and shape must be exactly the same. Although the fact that the shape of a water molecule is bending, and the bond angle of water molecule is 104.5 due to the VSEPR (Valence Shell Electron Pair Repulsion) theory, if students' responses are consistent to one of these (see Figure 1), it is then considered as a right answer no matter what the shape of water molecule is. Examples of students' responses on question 3 are demonstrated in Table 3.

or or or

Figure 1. A molecular shape of water considered as a right answer.

Table 3

Students' Responses on Question 3

Answer (drawing)	Reason	Judgment	Percentage (%)
Student draw a shape of water molecule correctly in all states	Because, covalence bond in water molecule is stronger than hydrogen bond; as a result, water is still being in the same molecule Because, the distance between molecules of water may differ but the component and chemical formula of water will be the same	Complete conception	23.81
Student draw a shape of water molecule correctly in all states	Student gives no reason for the drawing	Incomplete conceptions	7.94
The answer shows evidences of holding alternative conceptions. For example,	Because ice is denser than liquid water and gas, so oxygen atom and hydrogen atom will separate when it reaches the gas state (see Appendix B student 1) Because, when water stay in solid or liquid state, it will state loosely, water in gas state hydrogen and oxygen atoms won't have interaction to each other and become free (see Appendix B student 2)	Alternative conceptions	46.03
No answer	Students do not drawing and write unrelated reason, e.g., boiling of water is 100 ˚C	No conception	1.59

Note. No response is 20.63%.

The question 3 asked students to draw the molecular structure of a water molecule in three states: solid, liquid and gas; and explain the reason why the structures of water molecules appeared in that manner. Even though students had learned about inter- and intramolecular force, but only 23.81% had a complete conception. No matter what the shape of water looks like, if students' answers maintained a constant on shape and component of water, the justification was considered as a complete conception. The results revealed that most students (46.03%) were considered as holding alternative conception, because some students believed that when water is in gas state, its atomic component would break apart and became free, or even believe that the hydrogen gas (H_2) was formed during changing in state. Seven point nine four percent of students' responses are incomplete conception, because many of them draw a water molecule correctly but without giving any reasons. However, up to 20.63% of the students did not respond on this question.

The other examples of typical students' responses on questions 4 to 6 which are categorized as complete, incomplete, alternative and no conceptions, and were revealed respective examination questions, are discussed as follows:

Question 4: Key idea was to find out if students understand the concepts of attraction between molecules. Students were expected to know that intermolecular force can hold identical particles together. Due to both of them containing hydrogen atom and having similar molecular mass, ammonia and methane were used as an example to elicit students' idea. The forth question asked students "to choose between 'intramolecular force' and 'intermolecular force' that affects the process of changing state of the chosen substances". Students' responses on this question are clarified in Table 4.

Table 4

Students' Responses on Question 4

Answer	Reason	Judgment	Percentage (%)
Intermolecular force	Because NH_3 is a covalence substance. If it changes state, it will break down forces between molecules which differ from ionic substance	Complete conception	12.70
Intermolecular force	Students give no reasons	Incomplete conception	33.33
Intramolecular force	Because the bond between N and H atom is destroyed Because it was an ionic substance	Alternative conception	11.11
Intramolecular force	Because NH_3 contains a single covalent bond Because both of them are gases	No conception	20.64

Note. No response is 22.22%.

Twelve point seven percent of the students answered correctly that intermolecular force affected that process of state changing and gave reasons which referred to the destruction of intermolecular force, but not for covalent bond. Most students (33.33%) selected the right answer without giving any reasons. Eleven point one one percent of the students were considered as holding alternative conceptions, because they had chosen "intramolecular force" and given reasons which "referred to the destruction of covalent bond between molecules and referred to other chemical bonds". For example, the bond between nitrogen atom and hydrogen atom in ammonia molecule was breaking during the changing state, or even stress that ammonia (NH_3) is an ionic substance. Students who were considered as no conception dramatically increase (20.64%). Moreover, 22.22% of the students did not respond to the question. This may be the signal that even finishing a normal instruction, most students cannot distinguish the difference between intermolecular and intramolecular forces and how they relate to the process of changing state of substances.

Question 5: Key idea asked further about "Whether the force which had already answered to the question 4 has particular name". Students' responses on question 5 are revealed in Table 5.

The general fact that attractive forces hold particles together in ionic, covalent and metallic bonds are called intramolecular forces, but it does not account for all attractions between particles. In covalence substance, there are forces of attraction called intermolecular force. The intermolecular forces contain three different kinds which are dispersion force, dipole-dipole force and hydrogen bond. Dispersion force or London force is weak forces that result from temporary shifts in the density of electrons and exist between all particles, but they play a significant role as long as no stronger force acts on particles. Dipole-dipole force is attraction between oppositely charged regions of polar molecules. Finally, hydrogen bond is a dipole-dipole attraction that occurs between molecules containing a hydrogen atom bonded to a small and highly electronegative atom. Nitrogen atom is considered as a small and highly electronegative atom; therefore, it forms a hydrogen bond as an intermolecular force. In this analysis, if students' answers on the question 4 were "intermolecular force" and the answer on question 5 contained at least a hydrogen bond, the answer then was justified as a complete conception. Only 11.11% of students' responses were a complete conception, because students had chosen "intermolecular force" and given specific name on question 5 which referred to one of these forces (London force, intermolecular force or Van der Waals force) and hydrogen bond. Most of them (30.16%), who's answer on question 4 was "intermolecular force", answered either London force or Van der Waals force. Fourteen point two nine percent of the responses were justified as no conceptions, because they had given unrelated answers (e.g., because it is a chemical bonding). Not surprisingly, students with holding alternative conception referred to covalence bond as an intermolecular force, or even believed that no force related to the process of changing state. Clearly, some of them cannot distinguish between inter- and intermolecular forces. Percentage of alternative conception students was merely 7.94%, but it does not mean the total number of students who held alternative conception decrease, because a number of students (36.50%) did not respond on this question.

Table 5

Students' Responses on Question 5

Reason	Judgment	Percentage (%)
London force and hydrogen bond Hydrogen bond and Van der Waals force	Complete conception	11.11
Student referred to either London force or Van der Waals force	Incomplete conception	30.16
Covalence bond because both N and H atom are nonmetallic substance Covalence and Van der Waals force No force related to this change	Alternative conception	7.94
Student gave unrelated answer. For example, Because it is single bond Because it is a chemical bonding	No conception	14.29

Note. No response is 36.50%.

Question 6: Key idea of question 6 was to know further on a particular attractive force affecting the boiling point of substances. The question asked students "to choose specific name for intermolecular force that causes the boiling point of ammonia (M.W. 17) to be higher than methane (M.W. 16)". Examples of students' responses on the question are illustrated in Table 6.

Even the molecular mass of methane and ammonia is closed to each other, but in this case, nitrogen has an electronagativity higher than carbon atom in methane; as a result, methane molecule has only London force as an intermolecular force and leads to a low melting and boiling point. On the other hand, hydrogen bond occurs with hydrogen atom and nitrogen atom between ammonia molecules and leads to a high melting and boiling point. The results of the study revealed that only 6.35% of the students had chosen a hydrogen bond and given the correct explanation. Twenty-three point eight one percent of students held alternative conceptions, because they had referred to the difference of boiling point depending on the number of hydrogen atom in a molecule. Besides that, some students who were justified as a holding alternative conception referred to covalent bond as an intermolecular force. Examples of students' responses were justified as that holding alternative conceptions which were the boiling point of ammonia is higher than methane because of the different number of a hydrogen bond, and methane and ammonia have hydrogen bond because both of them have hydrogen in their molecules. Nevertheless, a number of students who did not respond on the question 6 are up to 26.98%, which is very high. All in all, the students' responses on the questions were concluded as in Table 7.

Table 6

Students' Responses on Question 6

Answer	Reason	Judgment	Percentage (%)
Hydrogen bond	Because molecules of H-F, H-O, H-N can perform hydrogen bond as an intermolecular force and substance with hydrogen bond will have higher boiling point Because CH_4 has London force as an intermolecular force, but NH_3 has hydrogen bond so it has high boiling point	Complete conception	6.35
Hydrogen bond	Because they have very different boiling points	Incomplete conception	20.64
Hydrogen bond	Because CH_4 have one more hydrogen atom so NH_3 has higher boiling point than methane Because both of them contain hydrogen atom	Alternative conception	23.81
Covalent bond	Because substance with covalent will have the highest boiling point when compared to other substances Because it has H in their chemical formula Both of them are covalent substances but they have different number of a hydrogen atom, so their boiling point will different Because CH_4 is a covalent substance		
Covalent bond	Because the boiling are highly different	No conception	22.22

Note. No response is 26.98%.

Table 7

Percentage of Students' Responses to the Six Questions (N = 64)

Questions	Complete conception	Incomplete conception	Alternative conception	No conception	No response
1	87.30	3.17	0.00	3.17	6.36
2	49.21	12.70	12.70	15.87	9.52
3	23.81	7.94	46.03	1.59	20.63
4	12.70	33.33	11.11	20.64	22.22
5	11.11	30.16	7.94	14.29	36.50
6	6.35	20.64	23.81	22.22	26.98

A conclusion on a percentage of students' responses on the test items classified as complete conception, incomplete conception, alternative conception, no conception and no response is illustrated in Figure 2.

Overall, questions 1 to 3 asked students to explain a component of water and its shape after being changed state by using a familiar example, a water molecule. A number of right answers considered as completed conception prone to dramatically decrease, but the trends of alternative conception, no conception and no response were likely to increase. Questions 4 to 6 used ammonia and methane as an example, but asked more challenge questions and gained more deep understanding of inter- and intramolecular forces. Compared to questions 1 to 3, a complete conception of questions 4 to 6 was very low, whereas the incomplete conception was quite high. The trend of the complete conception for total six questions was gradually decreased, whereas the trend of alternative conception and no conception grew to increase. Besides, no conception and no response were very high. One possible reason to explain the large difference of the complete conception on the first three questions and the last three questions is the adopted examples. Water was adopted to elicit student conceptions on the first three questions, whereas ammonia and methane were used on the last three questions. Students seem comfortable with applying scientific conception to familiar substance such as water, but they may be unfamiliar with ammonia and methane; as a result, it may cause the students difficult to apply their knowledge.

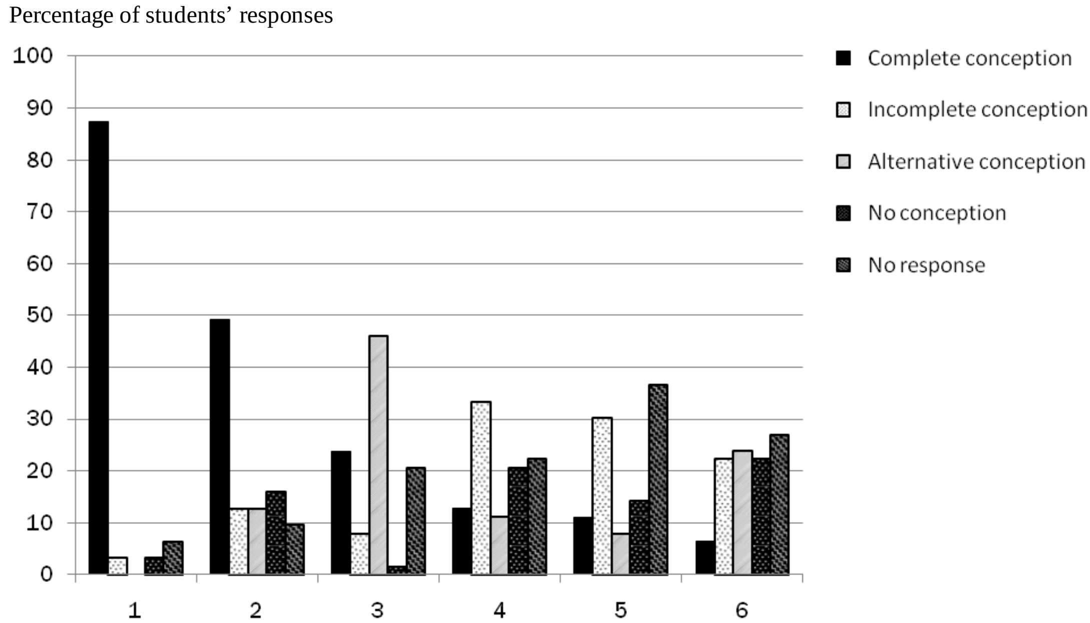

Figure 2. Students' responses on the test items.

Conclusions

This study was to identify and describe Grade 10 students' understanding about inter- and intramolecular interactions when the state of matter is changed by using water and ammonia as the example molecules or substances. The data from this study supported the previous research on students' alternative conceptions of chemical bonding. The study found that there is a number of students held alternative conceptions on inter- and intramolecular forces related to the change of state. Overall, at the macroscopic level, students seem comfortable with the idea that something changes, but they are less certain about what happens to the molecules of those substances. For example, the students believed that water molecule would break apart into a single atom when liquid changes to gas. Some believed that water will change to hydrogen and oxygen gas when the state changed. This result was consistent with the research finding by Mulford and Robinson (2002). Of course, the finding has already been known for years, but this may confirm in the way that even students had experienced with a normal instruction, they may hold alternative conceptions. This study, nevertheless, uses a series of questions to gain the whole ideas of students' understanding on particular conception. If each question was considered individually, it may not effectively provide useful information. Rather, if one consider further to the overall of the questions (e.g., questions 1-3 and questions 4-6), it will provide more advantageous data of students' mental model on chemistry conceptions.

Normally, chemistry is taught at three levels: symbolic, macroscopic and microscopic. If students are not able to appropriately understand the relationships among these levels, they may not find the topics relevant or even meaningful. The literature review suggested that students failed to shift between the macroscopic and molecular levels (Taber & Coll, 2002; Unal et al., 2006). Consistent with the finding of this study, students easily perceived the change in state of water from liquid to gas when it is boiling, but they could not explain what happen to water molecules. Moreover, the result revealed that the students did not clearly understand why the boiling point of two substances, ammonia and methane, could be very different because of intermolecular force between molecules. In light of this evidence, it appears that some reformations may be necessary in the chemistry curriculum at all levels to facilitate students' conceptual understanding of bonding topics with respect to inter- and intramolecular forces. More time spent on these topics combined with more conceptual exercise is needed. If the test questions which can be used to elicit students' mental model as a whole, they will provide an advantages data for a teacher and students themselves to use that information to improve the learning process. Moreover, rigorously applying a set of conceptual questions aligned with learning goals will provide useful information on students' ideas. Teachers should see those obscure students' ideas as a key to improve students' learning and make the learning more meaningful learning. Also, they should emphasize the transitions between the symbolic, macroscopic and microscopic representation so that students will develop their own mental models of bonding at these three levels. It is necessary for chemistry students to firmly grasp these topics before moving on the more advanced ones.

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Appendix A: Questions Used to Elicit Students' Conception

1. What are the elements in a water molecule? And how many atoms of each element?

Answer………
……………………………………………………………………………………

2. When ice becomes liquid water or gas. Do the compositions of water molecule differ? Explain why?
(mark X in the blanket and give reason support your answer)

Answer [ ] the same [ ] difference

Reason………
……………………………………………………………………………………

3. Use following symbol, draw a shape of water when it is in solid, liquid, and gas. And explain why?

◯ Represent an oxygen atom ● Represent a hydrogen atom

------ Represent chemical bond between atoms

Solid	Liquid	Gas

Reason………
……………………………………………………………………………………

Use following information to answer questions 4-6 below.

NH_3 has molecular weight 17 with melting point -78 °C
and boiling point -33.5 °C at 1 atmosphere

4. If we want NH_3 to change its state. Which force is related to the changed state?
(mark X in the blank and give your reason)

Answer [ ] intramolecular force [ ] intermolecular force

Reason………
…………………………………………………………………………………… .

5. No matter what your answer is (intramolecular or intermolecular force), can you indentify specific name for that forces?

Answer………
……………………………………………………………………………………….

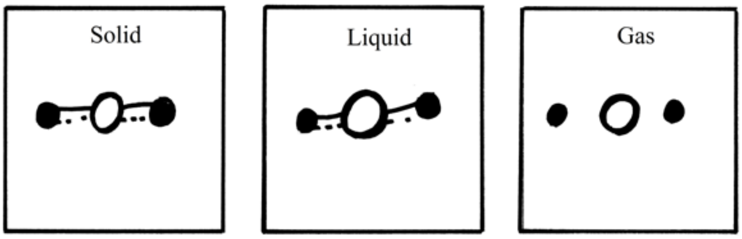
6. Methane (CH_4) has molecular weight 16 with melting point -182.5 °C and boiling point -161.6 °C whereas ammonia (NH_3) has molecular weight 17. Even though both substances have similar molecular weight but ammonia (NH_3) has higher boiling point than methane. What is the phenomenon depending on? (mark X in the blank and give your reason)

Answer [ ] hydrogen bond [ ] covalence bond

Reason………
……………………………………………………………………………………

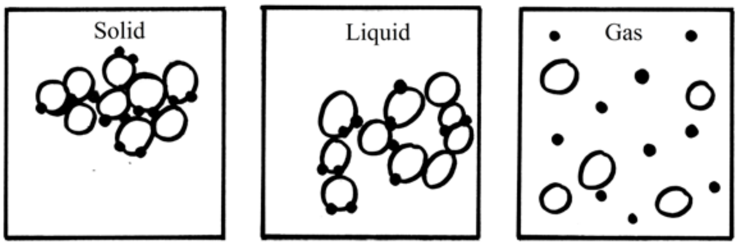
Appendix B: Examples of Students' Response Are Considered as Alternative Conceptions

Student 1:



Reason: Because ice is denser than liquid water and gas, so oxygen atom and hydrogen atom will separate when it reaches the gas state.

Student 2:



Reason: When water stay in solid or liquid state, it will state loosely, water in gas state hydrogen and oxygen atoms won't have interaction to each other and become free.