Factors contributing to students' misconception in learning covalent bonds

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Factors Contributing to Students' Misconceptions in Learning Covalent Bonds

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Abstract

This study aims to identify students' misconceptions regarding covalent bonds. Seventy-seven graduate students in the middle of Indonesia participated in the study. Data were collected in three stages. First, misconceptions were identified by using the Semi Open Diagnostic Test. Ten students who experienced the worst misconceptions were interviewed. Lastly, textbooks were reviewed. Content analysis was used to analyze the misconception data. We identified 8 primary misconceptions, namely: (1) a covalent bond is formed between two atoms with a pair of free electrons, (2) each atom in a stable molecule must follow the octet rules, (3) a covalent bond is polar if the electron affinity of two bonded atoms is different, (4) the form of the molecule depends on the number of atoms bonded to the central atom, (5) nonpolar molecules have a dipole moment $\mu > 0$, (6) all bonds in polar molecules are polar, while all bonds in non-polar molecules are non-polar, (7) the number of bonds depends on the electronegativity of the atoms, and (8) bond length depends on the type of bond. The main causes of student misconceptions are (1) incomplete information, (2) difficulty understanding basic concepts regarding covalent bonds, and (3) lack of effective communication between students and teachers. The results suggested the following implications for teaching: the teacher should identify misconceptions about prior knowledge or concepts prior to teaching the basics, identify reference book learning, and facilitate effective communication so that information received by the student is complete and correct.

Keywords: misconception, graduate student, covalent bonding, chemistry

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Introduction

Misconceptions are encountered in chemistry at all educational levels. Many misconceptions have been identified on a variety of topics (e.g., chemical bonds by Acar & Tarhan, 2008; Dhindsa & Treagust, 2014; Tan & Treagust, 1999; Ozmen, 2008; Pabuçcu & Geban 2012; Taber 1994; Peterson, Treagust, & Garnet, 1986, solutions by Devetak, Vogrine, & Glazar, 2007, chemical equilibrium by Cheung, Ma, & Yang, 2009, atomic structure by Griffith & Preston, 1992; Ibnu, 1989, oxidation and reduction by Barke, Hazari, & Yitback, 2009, and acid-base reactions by Cetingul & Geben, 2005).

Many chemical educators fear that misconceptions are difficult to change (Driver, 1989; Ibnu, 1989; Duit & Treagust, 1998), and they actively influence student learning of interrelated topics (Griffith & Preston, 1992; Özmen, 2004), and make it difficult to achieve scientific literacy (Bybee, 1997).

Research suggests that misconceptions in chemistry are caused by many factors, including prior knowledge (Taber, 2002), because basic concepts form the basis of student learning on a given topic (Griffith & Preston, 1992; Devetak, Vogrine, & Glazar, 2007), textbooks used by students and lack of information (Anderson, 1990; Garnet, Garnett, & Hackling, 1995; Pedrosa & Dias, 2000), the complexity of chemical concepts (Devetak, Vogrine, & Glazar, 2007; Johnstone, 1991; Meyer & Moreno, 2001; Wu, Krajcik, & Soloway, 2001), and ineffective communication (Gudyanga & Madambi, 2014; Ibnu, 1989; Tan & Treagust, 1999; Dhinsa & Treagust, 2014; Brandriet & Bretz, 2014; Johnstone, 2010; Nakiboghu, 2003). As a result, students develop new knowledge based on misconceptions (Tan & Treagust, 1999; Taber, 2011).

Many methods have been developed to address and prevent misconceptions (e.g., the use of various learning approaches by Krajcik, 1991, integration of laboratory activities in the classroom by Johnstone & Letton, 1990; Birk & Kurtz, 1999, and use of concrete models by Copolo & Hounshell, 1995, and technology as tools by Kozma, Russel, Jones, Marx, & Davis, 1996; Williamson & Abraham, 1995), however, misconceptions persist, primarily because of the various causes of misconceptions.

The earliest research on misconceptions in chemistry lessons in Indonesia is the study by Ibnu (1989), which identified misconceptions among Senior High School students on the matter of atomic structure. However, until now there has been no empirical study of the contributing factors for each identified misconception. Misconceptions in one basic topic, such as the atomic structure, can potentially lead to misconceptions in other related topics, such as chemical bonds. Therefore, the causes of such misconceptions need to be addressed, especially for students of chemical education department in universities, who may unwittingly transmit the misconceptions.

This study has four focus questions, namely: (a) Do college students experience misconceptions regarding covalent bonding? (b) Is there a pattern in student misconceptions of covalent bonding material? (c) What factors cause college students to have misconceptions? (d) Are the misconceptions and causes of student misconceptions in covalent bonding different from the misconceptions that have been found to date? To answer these questions, a semi-open diagnostic test, Covalent Misconception Identification Semi-open Test (CMIST) will be used to identify student misconceptions. CMIST was selected because in the study by Treagust (1988), multiple choice conventional tests are not sufficient to evaluate student understanding and Teichert and Stacy (2002) reported that the best way to determine whether a student understands the material is by judging their ability to explain the concept to others. However, CMIST can only determine whether the student experiences misconceptions. Unlike previous studies, this study uses student participants from a specific learning environment. Hence, the identified misconceptions could be confirmed through interviews and analysis of textbooks. Textbooks will be reviewed to identify causes of misconceptions in terms of the presentation of basic concepts necessary to understand covalent bonds.

In Indonesian universities, the typical chemistry curriculum is oriented towards the mastery of knowledge (75%) with a minimum load of 144 credits, consisting of 140 credits (97%) on compulsory subjects and 4 credits (3%) on optional ones. There are approximately 70 subjects within a 4-year study period. Chemistry learning is generally teacher—centered, with classroom and laboratory activities determined by the lecturer. Therefore, the students spend most of their time listening and noting explanations of the lecturers. Students from the middle of Indonesia generally have difficulty understanding textbooks written in English. Meanwhile, universities-level textbooks written in or translated into the local languages are difficult to obtain. Consequently, old reference books, including textbooks at the Senior High School level, are still stored and used at universities.

Theoretical Background and Framework

The Nature of Misconceptions

Misconceptions are deemed to have occurred if the students' understanding of a concept differs from what is understood by the scientific community (Ibnu, 1989). Misconceptions are sturdy and resistant, so they are difficult to replace with new, true understandings; they consistently influence the effectiveness of further learning (Ibnu, 1989; Taber, 2009; Özmen, 2004). Misconceptions are easily recognizable and identifiable.

Misconceptions occur primarily because of four factors (the nature of instructional materials, teachers, students, and reference books, and the relationship between these factors). Learning materials contain abstract concepts and the relationships between the complex concepts are elusive (Rhodes & Schaible, 1989; Devetak, Vogrinc, & Glazar, 2007; Johnstone, 1991; Meyer & Moreno, 2001; Tan & Treagust, 1999; Dhinsa & Treagust, 2014).

Teachers contribute to ineffective learning owing to their own misconceptions or failure to appropriately communicate (Ibnu, 1989; Gudyanga & Madambi, 2014). The ability of students to think abstractly is limited (Herron, 1975; Shayer & Adey, 1993, Çepni, Özsevgec, & Cerrah, 2004) and students are highly dependent on sense-based learning (Wu, Krajcik, & Soloway, 2001) as well as prior knowledge, especially basic concepts (Griffith & Preston, 1992). Textbooks and handbooks do not always provide complete and correct information or explanations (Devetak, Vogrinc, & Glazar, 2007; Gudyanga & Madambi 2014).

Causes of Students' Misconceptions in Chemistry

Students experience misconceptions in chemistry due to four factors (the students, and the nature of the material, teachers, and textbooks). First, students have difficulty understanding chemical materials (Tan & Treagust, 1999; Dhinsa & Treagust, 2014; Taber, 1998; Brandriet & Bretz, 2014; Jhonstone, 2010). Herron (1975), Karplus (1977), and Martini and Author (2009) found a relationship between chemistry learning difficulties and abstract thinking ability. Many college students have limited abstract thinking skills (Herron, 1975; Martini & Author, 2009). Difficulties occur because of the students' inability to interpret the meaning of chemical representations (e.g., symbols and chemical formulas) (Krajcik, 1991; Kozma & Russel, 1997).

Second, chemical reference materials contain complex concepts and abstract information (Rhodes & Schaible, 1989; Devetak, Vogrinc, & Glazar, 2007; Jhonstone, 1991; Meyer & Moreno, 2001), such as covalent bonds (Karplus, 1977; Good, Kromhout, & Mellon, 1979; Pedrosa & Dias, 2000; Taber, 2011). Reference materials use chemical models to present chemical phenomena and are generally metaphorical and the language is not everyday language (Gudyanga & Madambi, 2014). Students require ample time to adapt to chemical language that is used in many reference materials (Taber, 2001). Chemical materials can be classified into four viewpoints: (a) macroscopic (that which can be directly observed through practical activities in the laboratory), such as combustion reactions, (b) microscopic (atomic or subatomic details which cannot be seen directly), such as particles of atoms and electrons, (c) symbolic language chemical, and (d) mathematical models, such as: Lewis formula (Johnstone, 1991; Gabel, 1998; Robinson, 2003). According to Wu, Krajcik, & Soloway (2001), many students have difficulties adapting to the symbolic and molecular representations that are used throughout chemistry.

Teachers also propagate misconceptions because of their inability to communicate effectively with students (Gudyanga & Madambi, 2014). Robinson (2003) highlighted the importance of being able to change chemical symbols into meaningful information. Teachers could also be the cause of students' misconceptions owing to discrepancies and inadequacies in the implementation of various approaches (e.g., inconsistency displays essential aspects of concepts, or using terms or symbols that are unfamiliar to students) (Taber, 2003; Gudyanga & Madambi, 2014), and failure to connect various concepts (Ibnu, 1989). Moreover, teachers contribute to misconceptions by failing to identify preconceptions and misconceptions of students before determining the teaching method that will be used (Pekmez, 2010; Palmer, 2001; Al-Balushi, Ambusaidi, Al-Shuaili, & Taylor, 2014) and not knowing how to determine students' misconceptions (Calik & Ayas, 2005). Furthermore, teachers often fail to appropriately present abstract concepts, either by visualization or analogy to help students understand the material (Treagust, Chittleborough, & Mamiala, 2003). Visualization can help students improve their spatial thinking skills (Hurst, 2002; Barnea & Dori, 1999). Brandriet & Bretz (2014) stated that lack of understanding chemical representations submitted by teachers/lecturers can be a potential source of students' misconceptions. Finally, teachers also have misconceptions (Gudyanga & Madambi, 2014) and thus their students receive inadequate information. Teachers have some misconceptions regarding reaction rate, from the definition of reaction rate to the relationship between reaction rate and activation energy;

organic chemical materials were also identified as frequent misconceptions in teachers (Sendur, 2012; Kolomuc & Tekin, 2011).

Textbooks may also serve as a cause of misconceptions (Devetak, Vogrinc, & Glazar, 2007; Gudyanga & Madambi, 2014; Chiappetta & Fillmann, 2007) primarily due to six factors. The first factor is the use of confusing language (Devetak, Vogrinc, & Glazar, 2007). Science presentation as a collection of facts in the form of generalizations and mathematical formulas also contributes to misconceptions (Gudyanga & Madambi, 2014). The third factor is the presentation of oversimplified material and misleading information (Yifrach, 1999; Gilbert, 2003). Moreover, the presentation of information or ideas that are too difficult for entry level students (Gilbert, 2003; Taber, 2003) can lead to misconceptions. Furthermore, the use of symbols that are difficult to interpret may contribute to students' misconceptions (Nyachwaya & Wood, 2014). Finally, the use of terms that are unfamiliar to students (Taber, 2003) may contribute to students' misconceptions. Text or symbol-based language are seen as a system of interpretation that is very important to build and to develop understanding (Sutton, 1992). According to Nyachwaya and Wood (2014), approximately 85% of textbooks present chemical information in symbols, which are difficult to understand (Gabel, 1998).

Framework

Students' responses to the CMIST will be divided into three sections (correct answer for the right reasons, correct answer for the wrong reason or for no reason, or incorrect answer for the wrong reason). Judging from the development of classical theory, students who have misconceptions are basically able to differentiate and integrate understanding, but the understanding is immature as it not adapted to empirical reality (Navarro, 2014). During the conceptualization process, the brain uses limited information from perceptual experience to construct concepts, because of received incomplete information or misconceptions (both from the lecturer and reference books/textbooks). Immature students will answer the CMIST with a certain understanding that are retained (consistent) because they believe the answer. Students whose answer is wrong but inconsistent because it is not sure of the answer are not classified as misconceptions (see Figure S1). To address the consistency of students' answers and the underlying reasons, CMIST provides a main question and two or more additional questions for each aspect of the understanding of covalent bonds.

Methods

Herein, we used a cross-sectional survey design (Creswell, 2008) using three approaches (semi-open diagnostic tests, interviews, and textbook review) (Osborne & Gilbert, 1980; Peterson & Treagust, 1989) to examine the students' misconceptions regarding covalent bonds. Misconceptions identified from CMIST were further assessed through interview of students who have these misconceptions, and the corresponding reference books were also reviewed. Misconception data and causes were analyzed descriptively using content analysis. The semi-open diagnostic test was used to identify misconceptions by assessing the students' ability to explain a concept to others (Teichert & Stacy, 2002).

Participants

This research was conducted in the University at The Middle of Indonesia. A total of 77 students in their fifth semester in the Chemical Education Department at the University who had just participated in a course in chemical bonding were included as participants. They were able to learn the covalent bond materials that contain many abstract concepts, demonstrating their abilities of abstract thinking in terms of Piaget's theory (Piaget, 1972). Covalent bonding is taught in high schools' curriculum in Indonesia, so university students have prior knowledge of covalent bonds, and high school chemistry books are used in college.

Based on the found misconceptions, we interviewed 10 respondents selected by purposive sampling. The students who showed the most misconceptions refer to both the number of misconception and aspects of covalent bonding were chosen for interview, in order to obtain as much information as possible about the sources of their misconceptions. Thus, these 10 interviewees do not necessarily represent all the students who have these misconceptions.

Instruments

We used a form of the semi-open test called covalent misconceptions identification semi open test (CMIST). The CMIST consists of 42 multiple choice questions with four possible answers (1, 2, 3, and 4) equipped with 4 options grounds (A, B, C, and D). One alternative answers (answer 4) and one alternative reasons (reasons D) left empty were to be selected if students wanted to give their own response (Table S1). This form of the test was selected in accordance with the opinion of Treagust (1988) and Teichert and Stacy (2002), who suggested that conventional multiple choice tests are not suitable to assess student understanding.

The CMIST contains eight aspects of covalent bonds (covalent bond concept, octet rule, bond polarity, molecular shape, dipole moment, molecule polarity, amount of bonds, and bond length) in accordance with the applicable curriculum at the University and high school. In the bachelor's degree curriculum of chemistry education at the university, covalent bonds are studied in the course of chemical bonds, with the weight of 2 credits in fifth semester. The topics include the concept of covalent bonding using octet rule and Lewis structure, the simple of covalent bonds of diatomic (the number, length, and the polarity of the bonds), and the geometry of covalent bonding (molecular shape, bond angles, bond lengths, number of bonds, polar molecules, bond strength, and stability of the molecules) that is explained by the distribution of electron pairs around the central atom, overlapping atomic orbitals, and hybridization. At the Senior High School level, the corresponding curriculum includes: the octet rule and its application to explain the stability of noble gases, covalent bonding and coordinate covalent bonding, the amount of bonds, polar covalent bonds, and the properties of covalent compounds. Because misconceptions are consistent and resistant (Driver, 1989; Ibnu, 1989; Taber, 2009; Duit &Treagust, 1998), every aspect was assessed by more than one question (e.g., one main question and two or more additional questions) depending on the complexity of the topic. Additional questions aimed at determining the nature--the consistency of students' responses or not, of the answer of main question. This was done to discriminate between misconceptions and lack of understanding, according to reports by Brandriet and Bretz (2014), Dunning (2011), and Chi and Roscoe (2002).

CMIST validity was determined by content validation by 3 chemistry professors from the State University of Malang. Once the consideration process was complete, the CMIST was revised until all the test items were declared valid. Its reliability was 0.65, as determined by the moment product correlation analysis (Arikunto, 1998) after it trying it out on 40 equivalent background students from the department of Chemical Education with the test-retest method. Thus, it is valid and consistent enough to identify the same misconceptions in a student when used at different time.

CMIST can only determine students experiencing misconceptions or not, but it does not provide information on the cause of misconceptions and sources. Interviews using a guide of questions to determine preconceptions about essential basic concepts (e.g., electron configuration, octet rule, valence electron, etc.) were used to understand the covalent bond. To identify the cause of the misconceptions, interviews were conducted following set guidelines. The set interview guidelines consists of two packages of open-ended questions. The first package consists of 12 similar questions (Table S2) for 8 types of molecules in which the central atom does or does not satisfy the octet rule (e.g. F_2, O_2, and CCl_4 for the former, PCl_5 and SF_6 for the latter). These questions can reveal how the students understand the basic concepts associated with covalent bonds, including the consistency of the answer that triggered misconceptions. The second package consists of two questions about the reference books used in the covalent study and the student writes during class. All items in the interview guides were validated by three experts on chemical education.

Data Collection

Data collection was carried out in three stages. First, student misconceptions were identified using the CMIST. Second, the level of student misconceptions was determined based on the number and pattern of misconceptions; 10 participants who experienced the most misconceptions owing to a lack of understanding of basic concepts and aspects of covalent bonding were identified for subsequent interview. They were not chosen to represent all students with misconceptions, but for the purpose of identifying the sources of these misconceptions. Before the interview, meetings were conducted with the prospective interviewees to obtain permission for the interview and to process the permit (access) of the University authorities (i.e., head of the study program and dean). The students were asked to bring relevant documents, namely; all reference books used in the study of covalent bonds (college textbooks, Senior High School textbooks, and the notes the student wrote during class). The time and place of the interview and the time to return the documents were also determined. The interview focused on basic concepts required to understand covalent bonds, using the first package of questions. Then the second package of questions were asked about the reference books used by student and the notes he/she took during class. Finally, reference materials or textbooks including lecture notes of student learning were reviewed to study how covalent and related topics were presented.

Data Analysis

Data obtained from the CMIST was processed using content analysis, through three stages, namely: 1) determination of students' conceptions status at every aspect of covalent bonds (misconception or not), 2) determination of the patterns of misconceptions at every

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aspect of covalent bonds, and 3) calculation of percentage of students with misconceptions. Misconceptions were determined by checking the answers and reasons provided by the students and by analyzing the consistency of answers and reasons, which were confirmed in the interviews (Ibnu, 1989). The patterns of misconceptions were determined by analyzing the answers and reasons given by the students. The percentage of students with misconceptions was calculated by comparing the number of students with misconceptions to the total number of participants for each pattern. Answers and reasons that were not consistent were not considered to be misconceptions (naïve idea or incorrect answer) (Dunning, 2011; Chi & Roescoe, 2002) and were not processed further. The data analysis procedure is schematically illustrated in Table 1.

Table 1

Determination of misconception status using content analysis (submitted as separate file)

Interviews were carried out to obtain information about students' conceptions of covalent bonds and related topics. Content analysis was used to analyze each subtopic covalent bonds and related topic (essential basic concepts) presentation in the textbook/handbooks of students learning. The results of interviews and textbooks review were used to address causes of misconceptions.

Results

In this section, three main results of the research questions will be discussed. First, the students' misconceptions at each subtopic covalent bonds and the students' percentage at each misconception. Second, the list of essential basic concepts required to learn about covalent bonds and the percentage of students who have trouble understanding each basic concept. Finally, the textbook source of misconceptions.

Students' Misconceptions of Covalent Bonds

Based on the analysis of the answers and reasons provided by the students on the CMIST, students have misconceptions regarding all aspects of covalent bonds. Most misconceptions were related to the octet rule and molecule shape, with 77% of students experience misconceptions related to these topics, while only 36% of students had misconceptions related to molecular dipole moment (see Figure 1).

Figure 1. Student percentage experience misconception in each subtopics of covalent bonding (submitted as a separate file)

Students' misconception statements in every subtopic regarding covalent bonding are shown in Table 2.

Table 2

Students' misconceptions of various topics related to covalent bonds (submitted as separate file)

Students with misconceptions gave consistent answers and reasons on the CMIST.

For example:

Question 1: the bonds contained in the molecules H_2, Cl_2, and HF are…

Answer 1: covalent bonds

Argument 1: bonded atoms use existing free electron pairs

Student answers and arguments on question 1 on the understanding of covalent bonds were consistent with those of question 17 on the definition of coordinate covalent bonds ("The bond between the B and N atoms in $BF_3.NH_3$ is ...") and questions 18, 19, and 20 on bond number ("The number of bonds between Br atoms in Br_2 molecule is ...", "The number of bonds between O atoms in O_2 molecule is ...", and "The amount of the bond between N atom in the molecule N_2, is ..."). Students give the right answer to the wrong reasons because it involves a free electron. The concept of free electrons is also used in the question 17 (because the N atom provides a pair of free electrons), and Questions 18, 19 and 20 (for Br atom using a pair of free electrons, O atoms using two pairs of free electrons, and N atoms using 3 pairs of free electrons, respectively). Through the interview (question 7) students failed to correctly count the number of free electron pairs and the number of electrons in the bond in the 8 molecules provided. All respondents indicated that the lecturer never explained the pairs of bonding electron and pairs of free electron, but only describes electron pair. Students could not distinguish free and bonding electrons pairs because textbooks and lecturers do not provide adequate information of free and bonding electron pairs; the materials only state that there are pairs of electrons.

Essential Basic Concepts that are Difficult to Understand

Based on student misconceptions data, a number of basic concepts that are essential for understanding covalent bonds were identified. An understanding of basic concepts is gained by students in high school. The interview results clarified misconceptions that occur in college students based on the inability to understand basic concepts (please see Table 3 and Table 4).

Table 3

Essential basic concepts required to understand covalent bonding (submitted as separate file)

Students with misconceptions can write the electron configurations of simple and complex molecules. Only about 20% of students had difficulty writing electron configurations. However, almost all of the students had trouble writing the octet rule or Lewis formulas.

Table 4

The percentage of students who have difficulty understanding basic concepts, from diatomic to six bonding pairs molecules (submitted as separate file). Such essential basic concepts generally have been studied in Senior High School and some have learned in the basic chemistry college in the first semester at universities in accordance chemistry curriculum in Indonesia.

The textbooks sources of misconceptions

Misconceptions occur when students are could construct concepts, but the information they receive in the classroom or from textbooks/reference books is not perfect or contains other misconceptions (Navarro, 2014). Four textbooks (see Table 5) are used by students in the university to learn covalent bonds: (a) Balai Pustaka Department of Education, Chemistry for Senior High School by Harry Firman and Liliasari (BP), (b) PT. Remaja Rosdakarya, Chemistry for Senior High School by Poppy K.D., Rismiati, Farida, Sunarya, Mapati S., and Tati Setiawati (RR), (c) PT. Tiga Serangkai, Chemistry for Senior High School by Radjijanti (TS), and (d) PT. Pabelan, Chemistry for Senior High School by Sajimanto (PB). All these four are reference books intended for Senior High School students, and are still used by the respondents to study chemistry at the University. None of the respondents indicated using a university--level chemistry book during the interviews. Their reasons for using Senior High School books are that the materials studied in college is almost the same, and there is no available university books written in Indonesian. Indeed, all university-level general chemistry textbooks in the library are written in English, which is difficult for the students to understand.

Table 5

Textbooks as sources of student misconceptions regarding covalent bonding (submitted as a separate file)

Misconception 1

A covalent bond is formed when two atoms share one or more pairs of free electrons.

BP, RR, and TS books explain that a covalent bonding is formed when two atoms share electrons. PB book explains that a covalent bond is a bond between atoms with unpaired electrons. The explanations in BP, RR, and TS books are not complete because it does not show the bonding electrons and free electrons. Similarly, PB book uses the term bonding electron force between atoms without an explanation.

Misconception 2

Each atom in a stable molecule meets the octet rule, especially the central atom. Four reference books (BP, RR, TS, and PB) explained that the octet configuration of outer shell electrons of an atom is required to become stable. The books did not disclose that some of the atoms can be stabilized by their outer electron configurations less than octet (e.g., Be in $BeCl_2$), and more than octet (e.g., P in PCl_5, and S in SF_6). It seems that students take the explanation in the books as a true statement and apply it to all molecules. In Senior High School chemistry curriculum in Indonesia, the octet rule and Lewis structures are subtopics of chemical bonding used to explain the stability of atoms forming a covalent bond, especially with regard to the central atom, the number of covalent bonds can be formed, and the properties of covalent compounds. Universities in the middle of Indonesia also use the octet rule and Lewis structures in explaining the covalent bonds and aspects of covalent bonding, even though this topic overlaps with the atomic structure of matter. If the lecturer and the author of the reference books are not careful when explaining the use of the octet rule in the process of forming a covalent bond, student misconceptions may ensue. .

Misconception 3

Polar covalent bonds form if the atoms have different electron affinities. Four reference books (BP, RR, TS, and PB) explained the concept of electron affinity and electronegativity clearly, and also explained that the shared electron pair is closer to the more electronegative atom. However, in some examples of Lewis molecular formulas, the shared electron pairs lay in the middle between the two atoms (BP, RR, and PB), and the bonding pair is placed closer to the more electropositive atoms (TS). Some explanations with images were out of sync with each other or even showed conflicting information. In

Indonesian chemistry curriculum, the polarity of the bond is one of the aspects of chemical bonds that are used to describe the properties of covalent compounds, particularly polar molecules.

Misconception 4

Molecular shape depends on the number of atoms bonded to the central atom.

BP explained that repulsion between electrons can be used to predict the molecular structure based on the number of electrons in the outer shell of the central atom, which gives the impression that the number of atoms bonded to the central atom determines the shape of the molecule because it is associated with the number of bonding electron pairs. Covalent molecular shape is used to describe the geometry of covalent bonds and properties of covalent molecules (molecular polarity).

Misconception 5

Nonpolar molecules have dipole moment $\mu > 0$ because the positive and negative charges are separated by a certain distance, while polar molecules have a dipole moment $\mu = 0$ when the positive and negative charges are not separated.

BP, RR, and TS explain the dipole moment as the product of the distance (d) separating charges of equal magnitude and opposite sign and the magnitude of the charge (q), the greater price of the dipole moment, the more polar the molecule. The explanation was mathematically inclined and less practical, so students understand the moment dipole of payload and distance. Dipole moment was not described in PB. Dipole moment is used to explain the properties of covalent molecules.

Misconception 6:

All bonds in polar molecules are polarized and all bonds in nonpolar molecules are not polarized.

Polar molecules in BP are discussed along with bond polarity before molecule shape is described, while TS describes the polarity of molecules in terms of bond polarity and dipole moment. In PB, molecular polarity is described in terms of the differences between atoms. The above explanation gives the impression that the polarity of the molecules is only dependent on the polarity of the bond. Bond polarity is used to explain the properties of covalent molecule (molecular polarity).

Misconception 7:

The number of bonds depends on the electronegativity of the atoms involved in the bond. If the atoms have the same electronegativity, double bonds occur. Conversely, if atoms have different electronegativity, a single bond will occur.

All textbooks clearly explained the concept of bond number. The misconception was caused by a lack of understanding free and bonding electron pairs, Lewis structures, and the octet rule. The number of bonds is used to explain the properties of covalent molecules.

Misconception 8:

Bond length depends on the bonding type of molecule.

All books and reference materials, including teacher explanations in students' notebooks, did not explain the concept of bond length. The lack of understanding of basic concepts, such as free electron pairs, bonding electron pairs, Lewis structures, and molecule shape led to misconceptions regarding bond length. Bond length is used to explain the geometry of covalent molecules.

Misconceptions experienced by students are generally related to the basic concepts (e.g. pairs of free electrons, the distribution of electron pairs around the central atom in terms of the octet rule, electronegativity of atoms that form the bond) that are used to understand the concept of covalent bonds and properties of covalent compounds. In Senior High Schools in Indonesia, the stability of the molecule and the properties of covalent compounds are still explained in terms of the octet rule. They are not discussed using the theory of distributing pairs of electrons around the central atom, atomic orbital overlap, and hybridization; all of which are widely used in university books to explain the geometry of covalent bonds (molecular shape, bond angles, strength of covalent bonding, molecular polarity, the amount of the bond, the bond length, and the stability of the molecule).

Discussion

Students in college have eight primary misconceptions in almost all subtopics related to covalent bonds (Table 3). The eighth of student's misconceptions patterns have different in both pattern and causes with students' misconceptions that are often identified by chemistry education researchers in various countries. Misconceptions regarding the octet rule, polar bonding, molecular shape, and molecular polarity were described by Özmen (2004) based on a survey of literature, but different patterns were observed. Specifically, the polarity of bonds was thought to be affected by the valence electrons (Özmen, 2004), whereas in this study, bond polarity was thought to depend on the electron affinity of bonded atoms. Differences in the pattern of these misconceptions show that misconceptions can vary between students from different locations.

The main cause of misconceptions in students is incomplete information from three sources (textbooks, students, lecture). First, textbooks are used in high school contain incomplete information. Clearly, some reference books (see Table 5) contain incomplete information and are likely to confuse students (Devetak, Vogrinc, & Glazar, 2007). In CMIST, students can distinguish covalent bonds from others types of bonds, including coordinate covalent bonding, in terms of shared of electron pairs donated by the bonded atoms. However, they believe that the electron pair shared by the bonded atoms consists of two free electrons (Misconceptions 1). The reference books used by the students for learning do not contain information about free electron pair and bonding electron pair. Consequently, students built their own alternative concept by integrating the concept of a covalent bond with a pair of free electrons due to the limited information. In addition, unclear language makes basic concepts difficult to access by beginners (Gilbert, 2003; Taber, 2003), and some images are difficult to interpret (Nyahchwaya & Wood, 2014). Thus, explanations in reference books contribute to misconceptions in students.

Based on the interviews, students generally have trouble understanding basic concepts needed to comprehend covalent bonding material. Misconceptions found in this study are generally associated with the basic concepts acquired by the students during Senior High School, and Senior High School textbooks are still used at the university. The process of conceptualization in the cognitive structure of the students to establish the concept involves only limited information from both from Senior High School textbooks and Lecturer's explanation.

Misconceptions regarding covalent bonds can be caused by difficulties in understanding or misconceptions of essential basic concepts (Krishnan & Howe, 1994; Gudyanga & Madambi, 2014; Calik & Ayas, 2005). According to Griffith and Preston (1992), an understanding of basic concepts is the foundation for understanding related concepts. Incomplete information from reference books and lectures can cause misconceptions (Peterson & Treagust, 1989). According to Navarro (2014), adaptations to the real experience are necessary to finalize the constructed concept, in order to minimize the uncertainty of these concepts and achieve the level of consciousness. This did not happen to the students studied here, because they were still using the Senior High School textbooks from which they learned these concepts, and the University lectures tend to only explain the aspects of the topic that are identical to what they already learned.

Lastly, based on the review of the students' notes, faculty do not provide complete information through effective communication about covalent bonds and related concepts.

Lecture explanations in student notebooks do not overcome the confusion and college students tend to follow the information in their reference book. Consequently, student receive good information on covalent bonding while their understanding of basic concepts is incomplete and they create their own understanding of the misconceptions.

The results of this study showed that college students have misconceptions because of their reference materials and ineffective communication. The students' statements about their sources during the interview were validated through analysis of the books and notes. Their learning environment contained no sources apart from the reference books and lectures. Lecturers should first identify preconceptions regarding the material to be studied as well as supporting materials or basic concepts. In the case of covalent bonding, teachers must first identify student preconceptions about the electron structure of atoms, molecules, electronegativity, electron affinity, and other related basic concepts. In addition, teachers need to identify the textbooks that were used previously by students to evaluate students' understanding of covalent bonds. If potential misconceptions are identified in reference books, the teacher needs to correct the misconceptions. Some strategies that have been developed by chemistry education researchers include using concrete models, using teaching with analogy (TWA), and the use of technology, such as the software to visualize covalent bonds.

Factors that cause college students to have misconceptions were assessed using reference books with a main focus on the presentation of basic concepts and covalent bonding. Teachers as the cause of misconceptions were only evaluated in terms of lecture notes from 10 students without conducting interviews with the lecturers themselves. The abstract thinking ability of students with misconceptions was not determined. Further work is required to gain more complete factors that cause college students to have misconception.

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