Analysis of students’ difficulties in chemical bonding based on computerized two-tier multiple choice (CTTMC) test

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Abstract. Student learning difficulties occurred from two factors those are internal and external factors. To detect learning difficulties in student’s one of them by using diagnostic tests. The aims of this study are to identify students' learning difficulties and map the student profile categories. The formative assessment post-test was administrated to 166 student’s grade 11th using CTTMC instrument to find out their learning difficulties. The instrument contained 20 items computerized two-tier multiple-choice (CCTMC). The results showed that learning difficulties experienced by students in high, medium and low-grade schools were the metal bond, the molecular shape, and the covalent bond portion, while the easiest part of the chemical bond was the stability of electron, the Lewis structure, an ionic bond. One of the factors causes students' learning difficulties that chemistry contains three levels of understanding that are macroscopic, sub-microscopic and symbolic. Most Students find it difficult to connect the three. For the future research, students' learning difficulties can be used as for the teachers to know good steps in overcoming students' learning difficulties.

1. Introduction
Students’ learning difficulties in the process learning to understand scientific models have been one of the major concerns in chemistry education research [1]. To determine students’ learning difficulties and to deal with such issues need a good understanding and knowledge [2]. As previous research has identified students’ learning difficulties in understanding of chemical bonds by using interviews in grade 12, the findings that most grade 12 do not understand the bonds that occur in electron transfer of sodium chloride from sodium to chloride, many of which cannot understand and ionic bonds [3].

Another finding in learning difficulties in chemistry learning is the students’ inability to understand the three levels of representative chemical phenomena [4]. This level is the macroscopic, sub-microscopic and symbolic level [5].

In order to help students develop a conceptual understanding of chemical representation, several studies have been conducted over the last few decades state that students have difficulty in understanding sub-microscopic and symbolic representations because these representations are abstract and cannot be experienced, whereas student thinking, is strongly influenced by the sensory information they can experience [6, 7]. In addition, students sometimes cannot translate one representation given to another because of their limited conceptual knowledge and poor visual-spatial skills [8]. Many high school teachers do not integrate the three representations in their teaching but move between representational levels without highlighting their inter-connectedness [9, 8]. Thus, students cannot see the linkage...
between the three levels of chemical representation, although they may already know about the three levels of chemical representation. For students, it is important to look at the relationship between the three levels of chemical representation, so that students can have a better conceptual understanding [9]. One way to learn the students' ability to use different levels of representation when explaining and explaining chemical phenomena involves the use of two-tier multiple choice diagnostic instruments.

The two-tier multiple choice diagnostic test question is a test of two-tier items. The first tier of being a between multiple choice question related to a propositional statement and it is part of the concept map as well. The second tier of each item consists of a multiple choice set of reasons for the answer related to the first tier item [10, 11, 12] Most of the two-tier diagnostic tests are using paper and pencil, but on TTMC instrument is already using the computer. This is done in order to train students in using the computer during the test because in the national exam is based on CBT (Computer Based Test). One study stated that a two-tiered diagnostic test instrument is effective in diagnosing students' understanding and this computer-based study [13].

2. Method
The methodology used is quantitative method. The purpose of this research was to identify students learning difficulties and map the students profile category in learning chemistry.

2.1. Participants
The research participant consisted of three high schools in Surakarta, Central Java, Indonesia, which consisted of high, medium, and low categories based on the school rank. Participants in the study were 166 students in grade 10th consisted of 63, 60, and 43 students from high, medium and low rank respectively.

2.2. Instrument Computerized Two-Tier Multiple Choice (CTTM C)
The CTTMC was developed to diagnose students' difficulties learning-based computer. The CTTMC developed with 20 items with this CTTMC instrument has been validated by 9 experts consisting of six experienced chemistry teachers and three lecturers in chemistry. The reliability of the instrument measured by the Alpha Cronbach formula with the coefficient of reliability from first tier and second tier are 0.79 and 0.7 as high category items.

2.3. Data collection and analysis
2.3.1. The data were collected using CTTMC diagnostic test. The instrument CTTMC included twenty questions. Data were analysed using Graded Response Model (GRM) method. Scoring on CTTMC using the Graded Response Model [14]. Scoring is showed in table 1.

| Answer | Score |
|--------|-------|
| First Tier | Second Tier | |
| True     | True      | 3  |
| True     | False     | 2  |
| False    | True      | 1  |
| False/ not answering | False/ not answering | 0  |

3. Results and discussion
The results of the students 'learning difficulties test are shown in percentage of the average score of students' answers from each indicator on three categories of schools. The percentage of students' learning difficulties is presented in Table 2. Table 2 shows that in the same category of problems in each school have different results. Questions involving the application of concepts seem to cause many problems. Student learning difficulties are seen from the percentage of students under 70%.
The difficulty of learning in high rank school only has difficulty in: (1) determining the molecular shape and the nature of the compound (question 9); (2) determining the covalent bond (question 8); (3) determining the polarity of the compound from the electronegativity data (question 14); (4) analysing the image of covalent bonding (question 9) and detect the properties of the compound of several compounds. The easiest question according to the students in this school is to determine the stability of an element (question 2) and determine the ion bond question 5) that has 97% mastery percentage.

Table 2. The percentage of the average student's answer on Chemical Bond.

| Number | Student competence indicator in the topic of chemical bond | Percentage (%) of the Average Student's Answer |
|--------|-----------------------------------------------------------|-----------------------------------------------|
|        |                                                            | High   | Medium | Low    |
| 1      | Determine the noble gas configuration of some elements    | 89     | 73     | 43     |
| 2      | Analyze an element's tendency to achieve stability by binding to other elements. | 97     | 78     | 60     |
| 3      | Analyze the arrangement of valence electrons of noble gases (duplet and octets) of some elements with the electrons that surround. | 92     | 76     | 55     |
| 4      | Understand the formation of ionic bonds from one element. | 87     | 72     | 28     |
| 5      | Determine the formation of ionic bonds from some element with its atomic number. | 97     | 78     | 43     |
| 6      | Detect ionic bonds of some compounds                       | 74     | 49     | 39     |
| 7      | Express the properties of ionic compounds of the NaCl.    | 72     | 28     | 33     |
| 8      | Determine the formation of covalent bonds                 | 51     | 23     | 15     |
| 9      | Analyze the formation of covalent bonds from an illustration of the formation of bonds between F atoms and F atoms. | 68     | 61     | 45     |
| 10     | Classify single, double covalent bonds of the structure formula of Lewis CH₃COOH. | 77     | 84     | 30     |
| 11     | Determine the coordination from the illustration of the Lewis structure of the H₃PO₄ compound. | 79     | 45     | 36     |
| 12     | Analyze polar covalent bonds of an illustration of the polar HF covalent bond. | 78     | 72     | 42     |
| 13     | Determine the properties of non-polar covalent compounds of some properties of the compound | 74     | 51     | 40     |
| 14     | Determine to distinguish the polarity of a compound attributed to the electronegativity of the bonding elements | 51     | 50     | 29     |
| 15     | Detect the properties of the compound                      | 69     | 42     | 58     |
| 16     | Establish a metal bond from the illustration of the metal bond image | 79     | 17     | 28     |
| 17     | Identify the properties of metal bonds                     | 77     | 46     | 38     |
| 18     | Predict the shape of molecules based on electron domain theory. | 80     | 56     | 22     |
| 19     | Predicts the molecular shape and physical properties of a compound of two elements | 40     | 30     | 26     |
| 20     | Predict hybridization based on the hybridization theory of a compound | 82     | 55     | 29     |

The similar issue, in schools with the category, is showing different difficulties. In medium category, schools have more difficulty level than high school category. Student difficulties start the difficulties students experience begins with determining the metal bond (question 16). Students still find it difficult
to determine the formation of covalent bonds (question 8). Such as research from thirty-three per cent of students in grade 11 and twenty-three per cent of students in grade 12 held a misconception relating to the bond polarity that indicated confusion regarding the unequal sharing and position of the electron pair in many covalent bonds [15]. Other difficulties students experience in determining the nature of the ionic compound (question 7), predicting the molecular shape (question 19), differentiating the properties of some compounds (question 15), students still find it difficult to determine single covalent bonds and double covalent bonds (question 11), determine the nature of the metal compound (question 17), students found it difficult to determine the ion bond (question 6). Several reasons chemistry students’ understanding of ionic bonding: overemphasizes the process of electron transfer, explicitly or tacitly uses the notion of ion-pairs as molecules; is restrained by an inappropriate consideration of valence, pays heed to an irrelevant electron history [16]. Another difficulty is that students still find it difficult to determine the polarity of the compound from the electronegativity data (question14), determining the polar covalent bond (question 13), predict hybridization based on the hybridization theory of a compound (question 20), predict the shape of molecules based on electron domain theory (question 18), and the last one the students found difficult Analyse the formation of covalent bonds (question 19). The easiest thing to do according to the students in this school is in determining the single covalent bond and the double covalent bonds (question 10), which has a percentage of 84%. While in the low category schools all students still find it difficult from all chemical bonding concepts, this school still has a low level of student understanding. So that student answers are still below 70%.

Based on the above results, students in high, medium and low-grade schools have similar difficulties in determining the molecular form (question 19), determining covalent bonds (question 8), determining the polarity of a compound from the electronegative data (question 14), still find it difficult to analyse images of covalent bonds (question 9) and the differentiating properties of some compounds (question 15).

Significant differences between schools with high, medium and low ability experienced by students are caused by several factors including by the high level of abstraction of concepts contained in the chemical bonding material, besides the students must have mastered the material before studying chemical bonds, such as atomic structure has many abstract [17]. Another cause is that chemistry contains three levels of understanding that are macroscopic, sub-microscopic and symbolic. Sometimes students find it difficult to connect the three levels [18]. In many studies on students’ conceptions, authors frequently referred to generic factors drawn from educational psychology (and especially from constructivism) such as learners’ prior knowledge, daily life experiences, confusion of scientific and everyday terminology, and incorrect representations in textbooks as the possible sources of misconceptions in chemistry [19, 20]. Another factor that was the way of teaching teachers at high, medium and low school is very different. Schools with high and low category have high ability and experience. Whereas in School with a low category of teachers who teach have difficulty in delivering material that is abstract. Chemistry teacher should have the ability to change the content of the material that is felt difficult, but presented easily so that students are easier to receive the material [21].

Table 3. Percentage of students' answers to the average student's learning difficulties level of chemical bonding substances.

| Sub material in Chemical Bonding | Percentage (%) of the Average Student's Answer learning difficulties |
|---------------------------------|---------------------------------------------------------------|
|                                 | High  | Medium | Low   | Average |
| Electron stability             | 93    | 76     | 52    | 74      |
| Lewis theory                   | 92    | 76     | 55    | 74      |
| Ion bond                       | 73    | 55     | 37    | 55      |
| Covalent bond                  | 68    | 55     | 34    | 52      |
| Molecular from                 | 67    | 47     | 26    | 47      |
| Metal bond                     | 78    | 32     | 33    | 48      |
Table 3 shows that students learning difficulties in 3 schools with high, medium and low school categories. Student’s learning difficulties from metal bonding, molecular form, covalent bonding, and ionic bonding. Based on the analysis of 166 students who has been the successful completeness of students’ in answering the CTTMC instrument to diagnose students’ learning difficulties by 46 %. In Schools with high category completeness reached 40 % from 60 students, medium school category 4 % from 63 students and low school category only 2 % from 43 students.

Table 4. Three example determining the Students Profile from CTTMC Test.

| Students Code | Student Profile |
|---------------|-----------------|
| A-1           | It has not been able to determine the noble gas electron configuration, has not been able to establish a coordination bond, has not been able to resolve the properties of non-polar covalent compounds, and has not been able to identify the properties of metal bonds. |
| R-1           | Not able to determine the shape of the molecule, yet can differentiate determine the ionic bond, cannot establish a metal bond. |
| N-1           | Unable to confirm molecular form based on hybridization theory, it has not been able to determine single and double covalent bonds. |

Table 4 shows an example of a student profile generated after a CTTMC test is applied, in which the student will know what indicators are still experiencing difficulties. Based on the results of research using CTTMC instrument can be used in diagnosing students' learning difficulties. Studies using CTTMC, as a means of evaluation accompanied by a chemical representation stated that the effectiveness of diagnostic instruments contributed significantly in evaluating the ability of chemical reactions [22]. Another study stated to find out the results of the TTMC student learning test can be used as an alternative to traditional tests because, in addition, the CTTMC test can help teachers in the assessment process [23]. Another result shows a two-tier test helps teachers in the assessment process so that students learn better [24].

CTTMC question on these instruments using the computer, things that make it easier for students’ in the process of work. In additions, process learning student claimed in a national exam already based CBT. As the study developed a two-tier instrument with computer aided the result is that the two-tier instrument multiple choice mental train students by analyzing the problem to obtain the correct concept so put aside misconceptions students [13, 24]. Another study that developed the two-tiered diagnostic evaluation using CB (Computer Based) can improve students' understanding. In this study, researchers said that the two-tier instrument can enhance the understanding of students of CB and can stimulate feedback and confidence of students against the instructions in his assessment of prior knowledge [25].

4. Conclusion
Based on the results of this study it can be concluded that a CTTMC can be used to diagnose students' learning difficulties. In high, medium and low schools have the same difficulty in determining the shape of molecules, determining covalent bonds, determining the polarity of compounds based on electronegativity, analyzing the formation of covalent bonds and determining the properties of the compound. The difficulties of the indicator because of the material that is considered difficult to be abstract, more to the application of concepts such as the form of the molecule, covalent bonds and the properties of compounds, in addition, students must also understand the prerequisite material before learning chemical bonds. Should the teacher teach this chemical bonding material should be able to present the material with the best possible, students are invited in the learning process as in the form of molecules should students be taught to make a molecular shape with the existing material. For more material to the application of the concept should students be invited to establish material in the form of prerequisite material. So when it comes to new concepts students do not experience difficulties.
Acknowledgments
The authors would like to thank to Institute of Research and Community Service (LPPM) Universitas Sebelas Maret Surakarta Indonesia for providing funding for the research through The Postgraduate Grant 2017 and 2018.

References
[1] Teo W T, Goh M T and Yeo L 2014 J. Chem. Educ. Res. Pract. 0, 1–3 p. 1–20
[2] Tumay H 2016 Emergence Learning Difficulties and Misconceptions in Chemistry Undergraduate Students Conceptualizations of Acid Strength Springer
[3] Buttsand B and Smith R 1987 J. Res. Sci. Educ. 17 p. 192–201
[4] Onwu G O M and Randall E 2006 J. Chem. Educ. Res. 7, 1978 p. 226–239
[5] Johnstone A H 1993 J. Chem. Educ. 70, 9
[6] Ben-zvi R Eylon B and Silbemein J 1986 J. Chem. Educ. 63 No. 1 p. 64–66
[7] Kozma R B and Russell J 1997 Multimedia and Understanding: Expert and Novice Responses to Different Representations of Chemical Phenomena 34, 9 p. 949–968
[8] Keig P F and Rubba P A 1993 J. Res. Sci. Teach. 30, 80 p. 883–903
[9] Gabel D 1999 J. Chem. Educ. 76, 4 p. 548–554
[10] Treagust D F 1988 Int. J. Sci. Educ. 10, 2 p. 159–169
[11] Peterson R F, Treagust D F, and Garnett P 1989 J. Res. Sci. Teach. 26, 4 p. 301–314
[12] Haslam F and Treagust D F 1987 J. Biol. Educ. 21, 3 p. 203–211
[13] Lai A 2007 The Development of Computerized Two-tier Diagnostic Test and Remedial Learning System for Elementary Science Learning Icalit
[14] Yamtinah S, Haryono Saputro S, Mulyani B, and Utomo S B 2016 Item discrimination of two tier test in hydrolysis of salt in ICERE (International Conference On Educational Research And Evaluation) p. 360–365
[15] Peterson R F and David F 1989 J. Chem. Educ. 66, 6 p. 12–13
[16] Taber K S 2017 Student Understanding of Ionic Bonding: Molecular versus Electrostatic Framework? Student understanding of ionic bonding: molecular versus electrostatic thinking? 78 No. 285, January 1997 p. 85–89
[17] Zephrinus C and Phoebe I 2015 Resolving Nigerian Secondary School Students’ Learning Difficulties in Nuclear Chemistry Using Computer Animation Solutions Procedia - Soc. Behav. Sci. 176 p. 1034–1040
[18] Johnstone A H 1991 J. Comput. Assist. Learn. 7 p. 75–83
[19] Sanger M J and Greenbowe T J 1999 J. Chem. Educ. 76, 6 p. 853–860
[20] Fatih K T U Faculty E and Education S S 2005 J. Chem. Educ. Res. Pract. 6, 1 p. 36–51
[21] Geddis A N, Onslow B and Beynon C, 1993 J. Sci. Educ. 77, 6 p. 575–591
[22] Chandrasegaran a. L, Treagust D F, and Mocerino M 2007 J. Chem. Educ. Res. Pract. 8, 3 p. 293
[23] Tüysüz C 2009 J. Sci. Res. Essay 4, 6 p. 626–631
[24] Tsai C C and Chou C 2002 J. Comput. Assist. Learn. 18, 2 p. 157–165
[25] Lin J W, 2016 J. Sci. Educ. Technol. 25, 3 p. 497–511