The identification and analysis of students’ misconception in chemical equilibrium using computerized two-tier multiple-choice instrument

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Abstract. The concept of chemical equilibrium is fundamental for students to understand. This concept becomes a prerequisite knowledge for many of Chemistry topics such as acid and base, hydrolysis, buffer and solubility. The characteristics of chemical equilibrium topic that have abstract concept are difficult to understand. It drives students to misconceptions. The aim of this study was to investigate the students’ misconception of chemical equilibrium. Formative test using Computerized Two-Tier-Multiple-Choice (CTTMC) instrument had been conducted. The participants of this study were 158 students from three different schools. The CTTMC instrument was developed in three indicators of chemical equilibrium consisting of 15 questions to identify and analyse students’ misconception. The students’ responses were marked in three levels of understanding (understand, not understand and misconception). From the study, it was found that the students adequately understood the chemical equilibrium, but still had misconception especially for explaining dynamic equilibrium and equilibrium shifting. The details of the students’ misconceptions were discussed. For the future research, the information of their misconception can be used as the basis to address the misconception in appropriate way.

1. Introduction
The concept of chemical equilibrium is fundamental for students to understand. This concept becomes a prerequisite knowledge for many of Chemistry topics such as acid and base, hydrolysis, buffer and solubility. The chemical equilibrium concept is a central and complex concept in Chemistry. It is considered as one of the most difficult topics in Chemistry education [1]. The characteristics of chemical equilibrium topic that have abstract concept are difficult to understand. It drives students to misconceptions. One of the reasons for a great number of the students’ misunderstandings is that chemical equilibrium is an abstract concept demanding the mastery of a large number of subordinate concepts [2].

Misconceptions can be interpreted as a misunderstanding of the phenomena that occur in the real world that is incompatible with the scientific explanation of the phenomenon [3]. This misconception usually has a negative impact on later Chemistry learning because it leads to a false concept that inhibits the further acquisition of a scientifically accepted concept and thus negatively impacts the learning process. It is beneficial to identify students’ conceptions so that appropriate strategies may be formulated.
to challenge their understandings in order to help them develop more scientifically acceptable views of science concepts [4].

There have been many ways to identify misconceptions including the use of concepts mapping [5], multiple-choice diagnostic instruments [6], or interview [7]. The focus of this study was to identify misconceptions using CTTMC instruments on chemical equilibrium materials. Many other materials have been studied, for example in inorganic chemistry [8], the concept of solution in chemistry [9], chemical reaction [4], and chemical equilibrium [10–12].

Two-Tier Multiple Choice (TTMC) is a more qualified question form of multiple choice questions. The first level resembles the traditional multiple choice, which is usually related to the state of knowledge. The second level resembles the format of the traditional multiple choice problem but aims to encourage higher thinking and reasoning skills [13]. TTMC is similar with the traditional multiple-choice question format but as the name suggests, TTMC contains two levels of interconnected questions. The purpose of this second tier is to encourage students to think in high-level and reasoning skills [14].

According to Tan [15] the items in a two-tier multiple choice diagnostic instrument are specifically designed to identify alternative conceptions and misconceptions in a limited and clear content area. The first part of each item consists of multiple choice questions usually content has two or three choices. The second part of each item contains four or five possible reasons for an answer from the first part, making the diagnostic instrument more robust and effective as it allows underlying the reason of the student's answer. The wrong reasons (distractors) are derived from alternative conceptions of students collected from literature, interviews and free response tests. In addition, Tan and Treagust [16] has been developed the Two-tier multiple choice in chemical bond material that can be used to identify alternative chemical concept in ionic bond. A two-tier-multiple-choice diagnostic instrument that has been reported in the science education research literature and shows that its development and use can make an important contribution to improve teaching and learning and to retain students’ interest in the science concepts involved with it [17–19].

The development of multiple-choice tests on students' misconceptions has the potential to make a valuable contribution, not only to the body of work in the area of misconceptions, but also to assist in the process of helping science teachers use the findings of research in this area [6]. TTMC can be used to detect high school students' conceptual understanding related to chemical equilibrium. The aim is to detect students' conceptual understanding in such topics as near equilibrium, equilibrium, equilibrium shifts, and the addition of inert gases and catalysts. Each test item is analysed to determine students' conceptual understanding and identify alternative conceptions of the chemical equilibrium concept [10].

In the field of education, information technology is used to support administration, library, value processing, selection of new admissions, and learning activities. In addition, the development of information technology in the field of education also allows the existence of Computer-Based Test (CBT) to do evaluation. In addition, moving toward computerized tests is rooted in the advantages it provides compared to traditional methods with paper and pencil [20]. These advantages include cost efficiency, easier administration, more accurate and faster assessment and reporting, as well as more flexible scheduling and test locations. This study also shows that the students who are familiar with computers feel more comfortable in performing computer-based tests [21].

Most of two-tier-multiple-choice tests are provided by using paper and pencil, and the students' misconceptions were analysed manually. CTTMC is the modification of two-tier multiple choice and computer-based test. This application must be supported by internet network. The aim of this study was to investigate the students’ misconceptions of chemical equilibrium using CTTMC.

2. Method

The method used in this research is descriptive method. The participants of this research were 158 students from 3 different schools with high, medium, and low category. The schools’ categorization was based on the quality of the schools. The technique of collecting misconception data was using test. The instrument used in this test is a Computerized Two-Tier-Multiple-Choice (CTTMC) instrument developed based on chemical equilibrium learning indicators. This instrument consists of the first tier
used to recognize the students' knowledge of chemical equilibrium material, while the second tier is used to recognize the conception of the students. The making of this second tier is based on an alternative student conception that usually appears on chemical equilibrium material. The students' responses from CTTMC Instrument were analysed automatically and classified according to three categories; they are understand, not understand, and misconception. The example of CTTMC Instrument is presented in table 1 while the assessment method and the analysis of the students' conception levels are presented in table 2.

Table 1. The example of Computerized Two-Tier-Multiple-Choice test.

| No | Indicators | Question items |
|----|------------|----------------|
| 1  | Explain the dynamic equilibrium and equilibrium constants | 1. The equilibrium reaction between NO$_2$ to NO and O$_2$ follows the following chemical equations:  
   
   $2\text{NO}_2 (g) \rightleftharpoons 2 \text{NO} (g) + \text{O}_2 (g)$  
   
   Brown $\rightarrow$ Colourless  
   
   When a certain amount of nitrogen dioxide gas at 25 °C is introduced into the enclosed space, the brown gas will turn colourless, indicating the decomposition of NO$_2$ to NO and O$_2$. After a while, the colour does not change again. This indicates that the equilibrium has been achieved. The final product when the reaction has reached equilibrium is …
   
   a. NO$_2$ only with a certain amount  
   b. NO$_2$ and NO with the same amount  
   c. NO and O$_2$ with a certain amount  
   d. NO$_2$, NO and O$_2$ with the same amount  
   e. NO$_2$, NO and O$_2$ with a certain amount  
   
   The statement below which represents your answer above is
   
   1. when the equilibrium is reached, the reaction of the formation and decomposition of the reactants remains at the same rate  
   2. when the equilibrium is reached, all reactants react to form a product at a rapid rate  
   3. by the time the equilibrium is reached, the reaction keeps running to balance the amount of product and reactant  
   4. at the time the equilibrium is reached, the reaction of the formation and decomposition of the reactants has ceased |

Table 2. Scoring on CTTMC.

| Students' Answers | Scores | levels of understanding |
|-------------------|--------|-------------------------|
| True              | True   | 3                       | Understand              |
| True              | False  | 2                       | Misconception           |
| False             | True   | 1                       | Misconception           |
| False / No Answer | False / No Answer | 0                       | Not Understand          |
3. Result and discussion

3.1. Preliminary study

The formulation of the indicators of chemical equilibrium concept as the basis of the CTTMC questions is examined from several literatures, including [11,22]. Indicators in line with chemical equilibrium concepts are showed in table 3.

Table 3. The indicators of chemical equilibrium concept.

| Number | Indicators |
|--------|------------|
| 1.     | Explain the dynamic equilibrium and equilibrium constants |
| 2.     | Predict the direction of equilibrium shift by using Le Chatelier principles and explain the principles of chemical equilibrium in daily life |
| 3.     | Interpret the experimental results on the concentrations of the reactants and the reaction products in equilibrium and conclude the equilibrium constant |

The instrument of CTTMC consists of 15 questions that contain 3 indicators of chemical equilibrium concept. Each indicator consists of 5 questions. The instrument has been adapted from the indicators in literature review. The instrument of CTTMC was tested, and its feasibility was analysed. The instrument was tested to 158 students from high, medium and low categorized schools in Surakarta. The result of the test analysis can be seen in table 4.

Table 4. The percentage of chemical equilibrium conceptual understanding.

| Levels of Understanding Categories | Percentage of Each School |
|-----------------------------------|---------------------------|
|                                   | High | Medium | Low |
| 1. Understand                    | 53.8 | 43.2   | 20.1 |
| Misconception                    | 24   | 29.5   | 32.1 |
| 3. Not Understand                | 22.2 | 27.3   | 47.4 |
| Total                            | 100  | 100    | 100 |

Table 4 shows that the average percentage of the level of chemical equilibrium conceptual understanding of high, medium and low categorized school. Based on data of table 3, it can be seen that the average level of chemical equilibrium concept understanding is various on each school. The highest percentage of understanding is at high categorized school. The highest misconception is at low categorized school. The difference of misconception among the three schools is not quite significant.

3.2. The analysis of the students' misconception

The analysis of the students' misconception was done by looking at the pattern of students' answer distribution on the first and second tier. The answer patterns on the second tier, which are the reasons of the students' answers can be used as the basis to determine the students' alternative conception. The students' alternative conception data are presented in table 5.
Table 5. The percentage of the students’ level of understanding and their alternative conception.

| Indicators                                                                 | Levels of understanding categories (%) | Students’ alternative conceptions                                                                 |
|---------------------------------------------------------------------------|----------------------------------------|----------------------------------------------------------------------------------------------------|
| Explain the dynamic equilibrium and equilibrium constants                  | 1. 35.1                                | 1. Once the equilibrium is reached, the reaction of the formation and decomposition of the reactants has ceased |
|                                                                            | 2. 34.8                                | 2. At the heterogeneous equilibrium, the gas pressure is assumed to be fixed                       |
|                                                                            | 3. 30.1                                |                                                                                                                                              |
| Predict the direction of equilibrium shift by using Le Chatelier principles | 1. 53.8                                | 1. When the temperature is fixed, and the volume is reduced, the equilibrium will shift in the direction of the number of moles or the small coefficient, and the value of K becomes smaller |
| and explain the principles of chemical equilibrium in daily life          | 2. 10.7                                | 2. The number of catalysts can multiply the product so that the reaction will shift on the right side |
|                                                                            | 3. 35.5                                |                                                                                                                                              |
| Interpret the experimental results on the concentrations of the reactants and the reaction products in equilibrium and conclude the equilibrium constant | 1. 28.8                                | 1. In the state of the equilibrium, the number of moles of all substance is equal                   |
|                                                                            | 2. 40.0                                | 2. In a state of equilibrium, the number of moles of substance in the reactants and products is the same |
|                                                                            | 3. 31.7                                |                                                                                                                                              |

Table 5 shows that indicator interpreting the experimental results on the concentrations of the reactants and the reaction products in equilibrium and concluding that the equilibrium constant is the most causing misconception of all. The indicator predicts the direction of equilibrium shift by using Le Chatelier principles and explains the principles of chemical equilibrium in daily life as the highest achievement in the level of understanding. This misconception is due to an over emphasis of the ‘change-then-minimize’ logic of Le Châtelier’s principle in the school Chemistry curriculum and textbooks [23].

Table 5 shows the students’ alternative conception from three indicators. In fact, students come to the classroom brimming with ideas about a great many issues and events in the natural world. People are constantly building mental models to make sense of the world around them. Unfortunately, a substantial number of these models are erroneous from the scientific point of view [24]. The students’ bias alternative conception is due to their experience, interpretation of their ideas, culture and language [25]. Other factors can be caused by textbooks used by them [26]. The results of the research can be used as an input for teachers in order to develop a reliable and valid conception test instrument and employ learning methods that are able to develop the concept of students [26].

Two-tier multiple choice instrument can be used for various purposes [4], [8], [27–29]. The two-tier diagnostic test provides a structured method to diagnose the student misconception more precisely, and it is suitable for a large amount of survey [30]. Paper-and-pencil test can collect lots of data but lack of students’ explanations for their responses. Conducting individual interview can obtain students’ thinking process. However, it is a time consuming, and it may not be useful for a large scale study to detect a large number of students' misconceptions [31].

The advantages of computer-based test are quick and objective results and the ease of comparing results with others which make this method very popular [32]. These advantages include cost efficiency, easier administration, more accurate and faster assessment and reporting, as well as more flexible
scheduling and test locations. This study also shows that students who are familiar with computers feel more comfortable in performing computer-based tests [21].

4. Conclusion
Students adequately understood the chemical equilibrium, but still had misconception especially for explaining dynamic equilibrium and equilibrium shifting. CTTMC is useful for detecting student misconceptions. With CTTMC, students can get instant feedback once the exam ends. This quick feedback allows them to review on which part they have misconceptions. This can help teachers and students to revise the wrong concept. For the future research, the information of their misconception can be used as the basis to address the misconception in appropriate way.

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