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# High School Students' Mental Models on Chemical Equilibrium

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**Abstract:** Chemical equilibrium knowledge has many abstract concepts that often lead to alternative conceptions and misconceptions. One way that can be used to find out students' conceptions is to identify their mental models.The purpose of this study was to investigate students' mental models in understanding knowledge of chemical equilibrium. This study applied a survey research design. The subjects were 12$^{th}$grade high school students consisting of 181 students distributed into 5 classes. Data was collected through a written test using the Mental Models Test on Chemical Equilibrium (M2T-CE) consisting of 18 two-tier multiple choice items. Data analysis was performed by categorizing student' mental models into initial, synthetic and scientific mental models. The results showed that 51.60% of respondents had a scientific mental model, 23.52% of them had a synthetic mental model, and 24.88% of others had an initial mental model. Whereas the respondents' average score of chemical equilibrium mental models was 63.36 from a maximum score of 100. This score belongs to the good category.

**Key Words:** initial mental models, synthetic mental models, scientific mental models, chemical equilibrium

**Abstrak:** Pengetahuan kesetimbangan kimia memiliki banyak konsep abstrak yang sering mengarah pada konsepsi alternative dan kesalahpahaman. Salah satu cara yang dapat digunakan untuk mengetahui konsepsi siswa adalah untuk mengidentifikasi model mental mereka. Tujuan penelitian ini adalah untuk menyelidiki model mental siswa dalam memahami pengetahuan tentang kesetimbangan kimia. Penelitian menggunakan desain penelitian survei. Subjek penelitian adalah siswa SMA kelas 12 yang terdiri dari 181 siswa yang didistribusikan ke dalam 5 kelas. Data dikumpulkan melalui tes tertulis menggunakan Tes Model Mental pada Kesetimbangan Kimia (M2T-CE) yang terdiri dari 18 item pilihan ganda dua tingkat. Analisis data dilakukan dengan mengelompokkan model mental siswa ke dalam model mental awal, sintetis dan ilmiah. Hasil penelitian menunjukkan bahwa 51,60% responden memiliki model mental ilmiah, 23,52% dari mereka memiliki model mental sintetik, dan 24,88% lainnya memiliki model mental awal. Sedangkan skor rata-rata responden dari model mental kesetimbangan kimia adalah 63,36 dari skor maksimum 100. Skor ini termasuk dalam kategori baik.

**Kata kunci:** model mental awal, model mental sintetik, model mental ilmiah, kesetimbangan kimia

## INTRODUCTION

Chemical equilibrium is one of the main topics of chemistry subject matter. Knowledge of this topic underlies the understanding of other chemistry topics such as acid-base chemistry and solubility products. However, many students have difficulty understanding this knowledge and experience misconceptions (Ghirardi, Marchetti, Pettinari, Regis, & Roletto, 2015; Karpudewan, Treagust, Mocerino, & Chandrasegaran, 2016; Mensah & Morabe, 2018; Voska & Heikkinen, 2000). Students have difficulty understanding the concept of reversible reactions. A glance, the concept of a reversible reaction is contrary to the concept of the ended or one direction reaction that they had previously understood. They also have difficulty understanding the concept of dynamic equilibrium (Eilks & Gulacar, 2016).The dynamic equilibrium is a reversible reactions in which the rate of the forward reaction is equal to the rate of the reverse reaction. In dynamic equilibrium, macroscopically there is no reaction that can be observed but



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sub-microscopically the reactions take place in both directions (forward and reverse) at the same rate. In addition, learning chemical equilibrium knowledge also requires other knowledge as a prerequisite, namely knowledge of reduction oxidation and reaction rates.

Understanding the concept of chemical equilibrium needs to be linked to three levels of chemical representation (Treagust, Chittleborough, & Mamiala, 2003), macroscopic, submicroscopic, and symbolic representations. Macroscopic representations represent macroscopic phenomena of reaction mixtures in equilibrium. After the equilibrium point is reached, macroscopically the reaction mixture does not change in color, volume, pressure and amount of deposits, the reaction seems to stop. Sub-microscopic representations represent equilibrium at the level of particulates which describe the composition of molecules, ions, atoms and electrons in equilibrium. Symbolic representations represent the stoichiometry of an equilibrium reaction involving reaction symbols such as an equilibrium reaction sign, the reaction coefficient, the phase of the substance involved in the reaction, and the equilibrium constants $K_c$ and $K_p$.

Various studies show that in understanding the chemical equilibrium concepts high school students experience many alternative conceptions and misconceptions (Ghirardi et al., 2015; Mensah & Morabe, 2018; Russell & Kozma, 1994; Van Driel, De Vos, Verloop, & Dekkers, 1998), the students' conceptions that are different from those accepted by the scientific community. Table 1 shows various alternative conceptions and misconceptions on chemical equilibrium concepts that occur in students.

## Mental Models and Students' Conception

Mental model is the cognitive representation of a person towards a phenomenon (Greca & Moreira, 2000). A cognitive representation can be in the form of descriptive, procedural, and conceptual knowledge (Korhasa et al., 2016). The mental model that a student has is unique and describes personal understanding, concepts or ideas. Students' understanding of macroscopic, submicroscopic, and symbolic levels is an external representation obtained through the learning process. These three levels of representation then form internal representations in the forms of mental models. Mental models of students can be expressed in the form of oral, written or picture. A representation facilitates access only to selected aspects of a phenomenon and, therefore, contribute incrementally to the formation and elaboration of mental models of the phenomenon (Buckley & Boulter, 2000).

**Table 1. Alternative Conceptions and Misconceptions of High School Students on Chemical Equilibrium**

| Subtopic | Students' Alternative Conceptions, Misconceptions or Learning Difficulties |
|---|---|
| Dynamic Equilibrium | • Students have difficulty understanding reversible reactions (Juliao et al., 2018)<br>• Students assume that after the reaction is complete the reactants disappear forever (Van Driel et al., 1998)<br>• Students find it difficult to distinguish between endness and reversible reactions, they believe that the decomposition reaction can only take place if the formation reaction has been completed (Al-Bhalushi et al., 2012).<br>• Students have an understanding that in equilibrium the forward and reverse reactions take place separately and alternately (Ghirardi et al., 2015)<br>• Students have an understanding that the reaction rate of forward is greater than the reaction rate of backward, and when a state of equilibrium has been reached, the reaction stops (García, Calatayud, & Hernández, 2014; Russell & Kozma, 1994) |
| Predict the direction of the equilibrium shift based on the principle of Le Chatelier | • Students have difficulty in using the Le Chatelier principle to explain the effect of changing a variable on the equilibrium system (Mensah & Morabe, 2018)<br>• Students have difficulty in predicting the direction of the equilibrium shift if the equilibrium is subjected to an interference (Ghirardi et al., 2015)<br>• Students believe that the catalyst only accelerates the rate of forward reaction but does not accelerate the rate of backward reaction (García et al., 2014) |
| Determine the equilibrium constant. | • Students have difficulty in setting up correct $K_c$ expressions, manipulating mathematical equations involving $K_c$ to determine the concentration of a reactant, and interpreting $K_c$ values correctly (Mensah & Morabe, 2018)<br>• Students have an understanding that the stoichiometric coefficient in the equilibrium equation reflects the concentration of substances involved in equilibrium (García et al., 2014). |

Mental models are very important in science instruction, including chemistry instruction. Students represent their understanding of macroscopic phenomena in the form of mental models. Therefore the study of mental models is important to explain the theoretical construction of how internal representations are formed from macroscopic phenomena (Greca & Moreira, 2000). If it is expected that science learning does not merely present knowledge content, the learning process needs to involve mental models so that the formation of students' mental models representations from macroscopic phenomena can be well explained (Borges & Gilbert, 1999; Lajium, 2013).

Students' mental models are classified into three levels, namely initial, synthetic and scientific mental models (Panagiotaki, Nobes, & Potton, 2009). Initial Mental Model held by students before they acquire the scientific view. Students construct naïve theory that enable them to explain phenomena. During their conceptual development, their mental model change from initial to synthetic. Synthetic mental model are developed by combination of students' intuition and beliefs with scientific concept. Scientific mental model is in accordance with concept of scientist.

## Mental Models and Three Levels of Representation

Bent mentioned that identify mental model is a complex work (Coll, 2006). Expressing students' mental model accurately must use the three levels of representation. The three levels of chemistry are macroscopic, symbolic and microscopic representations. If students understand the role of each level of representations, they can transform knowledge from one level to another. They are able to generate relational understanding and reducing alternative conceptions (Jansoon, Coll, & Somsook, 2009). Figure 1 shows the relation between mental model and the three levels of representation where mental model is the slice that can explain students understanding of phenomena using three level of representations. The three levels are linked and reflected in their personal mental model (Halim, Ali, Yahaya, & Said, 2013).

## The Purposes of The Research

The purpose of this study is to analyze students' mental models on chemical equilibrium. Mental model describes student's conception in depth so that teacher can uncover student's alternative conceptions and misconceptions. By knowing student's mental model, the teacher can design, plan, implement, and evaluate instruction that is more in line with the subject matter, instructional media, and student conditions.

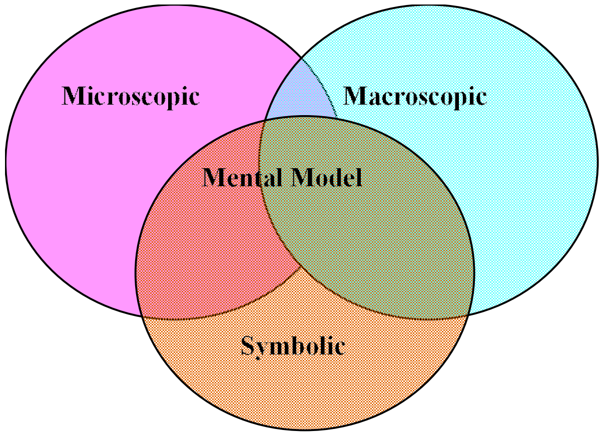


**Figure 1. Interconnections of Mental Model and Three Levels Representation**

## METHOD

This research applied a survey research design in which investigators administer a survey to the entire population to describe their characteristics (Creswell, 2012), in this case the student's mental model on chemical equilibrium. The subjects of this study were 12th grade high school students of the Mathematics and Natural Sciences program who had studied chemical equilibrium which included knowledge, skills and attitudes domains. The research subjects consisted of 181 students who were distributed into five classes. The research instrument was the Mental Models Test on Chemical Equilibrium (M2T-CE) (Ulinnaja, Subandi, & Muntholib, in press). This test consists of 18 valid two-tier multiple choice items with reliability of 0.715. This test is intended to reveal students' mental models on chemical equilibrium in terms of macroscopic, submicroscopic, and symbolic representations.The distribution of M2T-CE items in chemical equilibriumsub-topics is provided in Table 2.

Data was collected by giving M2T-CE instruments to 181 high school students of 12th grade. Student responses were coded based on the criteria as provided in Table 3 (Kurnaz & Eksi, 2015).

Students' responses to the M2T-CE items were analyzed and classified into one of three levels of mental models, namely initial mental models, synthetic mental models and scientific mental models. The score of each level was calculated using the equation:

**Table 2. The Distribution of M2T-CE Items in Chemical Equilibrium Sub-topics**

| Chemical equilibrium sub-topics | No. of M2T-CE Items |
|---|---|
| Dynamic equilibrium | 1, 2, 3, 4, 5, 6 |
| Low of mass action | 7, 8, 9 11, 12, 13, 15 |
| Le Chatalier Principe | 9, 10, 11, 12, 13, 14, 16, 17, 18 |

**Table 3. Criteria for Initial, Synthetic and Scientific Mental Models**

| Asnwer | Mental Model Category | |
|---|---|---|
| | Description | Score |
| Correct answer and correct reason | Scientific mental model: perception is accordance with scientific knowledge | 2 |
| Wrong answer but correct reason or correct answer but wrong reason | Synthetic mental model: perception are partly compatible and partly not with scientific knowledge | 1 |
| Wrong answer and wrong reason | Initial mental model: perception does not match with scientific knowledge | 0 |

$$\text{Score of mental model level} = \frac{\textit{the number of respondents asnwering level}}{\textit{the number of respondents involved in this survey}} \text{ X } 100\%$$

While the average score of students' mental models was calculated using the equation:

$$\text{Average score of students' mental models} = \frac{(2\ x\ \textit{scientific mental models score}) + (\textit{synthetic mental models score})}{2\ x\ \textit{highest mental models}}$$

The qualification of the average scores of students' mental models was determined using the criteria provided in Table 4 (Heng, Surif, & Seng, 2014, 2015).

## RESULTS

The analysis of students' mental model results of each item of M2T-CE is given in Figure 2. The figure shows us that 51.61% students already have scientific mental model. As many as 23.52% students have synthetic mental model and as many as 24.88% have initial mental model.

**Table 4. Mental Models Determination Scale Used in this Research**

| Average Score (%) | Qualification |
|---|---|
| 80.00–100.00 | Excellent |
| 60.00–79.99 | Good |
| 40.00–59.99 | Moderate |
| 20.00–39.99 | Weak |

## DISCUSSION

Figure 2 shows us that 51.61% students already have scientific mental model. This means students already have scientific conceptions. Students understand

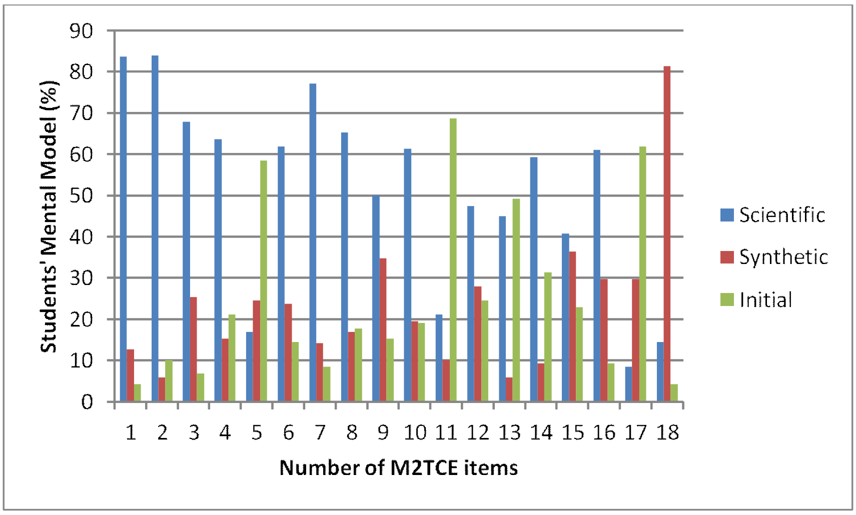


**Figure 2. Distribution of Students' Mental Model on The Topic of Chemical Equilibrium**

chemical equilibrium topic deeply and can transform their knowledge from one representation to another. As many as 23.52% students have synthetic mental model. It means that students do not fully understanding chemical equilibrium topic. Their knowledge is not reach microscopic level. And as many as 24.88% have initial mental model. It means that students held naïve theory to explain the phenomena.

Research regarding understanding of chemical equilibrium concept has been widely carried out. Previous research revealed that chemical equilibrium is a difficult topic to learn. Demircloglu et al. (2013) said that chemical equilibrium concept is considering to be a difficult concept in chemistry cause it need other prerequisite concepts such as the rate reactions, oxidation and reduction and require understanding of the three levels representation.

Nevertheless, this research reveals the opposite. Students who held scientific mental model is 51.60%, higher than synthetic and initial category which were 23.52% and 24.88%. The researcher conducted personal communication with the chemistry teacher in order to explore further about this achievement. The interview revealed that the learning was carried out using video-assisted lecture methods that represent submicroscopic representations.

The teacher said that this is very helpful for students to understand chemical equilibrium topic cause it provides microscopic visualizations for them so they can understand the abstract concept of chemical equilibrium more easily. Furthermore, students were more enthusiastic because of the pleasant learning process.

> "Yes (students were more enthusiastic). I gave 4 vidios. First about the dynamic equilibrium then about the calculation (law of mass) and two vidios about the equilibrium shift using Le Chatalier Principe. It was effective. They (students) got high score in their test. Even I enjoyed it (using the video). I only need to emphasize major concept."

The result of video analysis that provide by the teacher are shown in Table 5.

The table shown that using video on learning process could improve students' scientific mental model on subtopic of chemical equilibrium which are dynamic equilibrium, equilibrium constants and Le Chatalier Principle. However on subtopic the effect of catalyst, the video doesn't have contribution to construct students' scientific mental model because the fourth video do not explain deeply about the effect of catalyst.

Previous research revealed similar result. Kozma and Ruzzel (1994) explained that media assisted learning can give contributions to students who have difficulty understanding chemical concept and principles. Nakhleh (1992) suggest for using multimedia to explain difficult concept such as chemical equilibrium concept. However, research of the impact of using multimedia

**Table 5. Analysis of Learning Video on Chemical Equilibrium Topic**

| No. | Vidio | Concepts of Chemical Equilibrium | Impact on Students' Mental Model |
|---|---|---|---|
| 1. | Video 1 | Irreversible and reversible reactions<br>Dynamic equilibrium<br>Chemical and physical equilibrium<br>Dynamic nature of chemical equilibrium<br>Write the equations of equilibrium constant<br>Homogenous and heterogeneous equilibrium<br>Chemical equilibrium graphs | Video 1 can construct students' scientific mental model primarily on the dynamic nature of chemical equilibrium. On the subtopic of dynamic equilibrium, students who have scientific mental model are relatively high. |
| 2. | Video 2 | Irreversible and reversible reactions<br>• Complete the equilibrium calculation using ICE BOX<br>• Understand the law of mass action<br>• Understand Qc<br>• Complete the calculation of Qc dan Kc | Video 2 can construct students' scientific mental model primarily on the Law of mass action. |
| 3. | Video 3 | • Le Chatalier Principe<br>• Effect of concentration on chemical equilibrium<br>• Effect of volume on chemical equilibrium<br>• Effect of temperature on chemical equilibrium | Video 3 can construct students' scientific mental model primarily on the Le Chatalier Principal. |
| 4. | Video 4 | • Le Chatalier Principe<br>• Experiment of adding HCl(aq) and $H_2O$(aq) to the equilibrium system<br>• Experiment of the effect of temperature to the equilibrium system. | Video 4 can construct students' scientific mental model primarily on the Le Chatalier Principe. |

and video-assisted learning for construct students' scientific mental model still have to be proved so it can be appointed to be a topic for further research.

## CONCLUSION

The scores of students' initial mental model level, synthetic mental model level, and scientific mental model level were 24.88%, 23.52% and 51.60% respectively. While the students' average score of chemical equilibrium mental models was 63.36 from maximum score of 100 with good criteria. Personal communication with the chemistry teacher shows that the instruction was carried out using video-assisted lecture methods that represent submicroscopic representations. These results need to be confirmed through experimental research before becoming a scientific recommendation.

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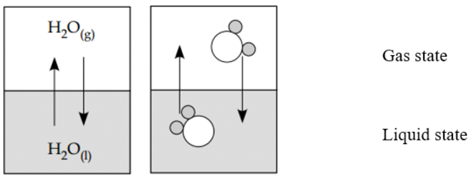
**Appendix A: Example of Test Items**

1. The following diagram illustrates the physical equilibrium of water ($H_2O_{(l)}$) with its vapour ($H_2O_{(g)}$)




At the particulate level, for every one molecule of water ($H_2O_{(l)}$) that evaporates, another water vapor molecule ($H_2O_{(g)}$) condenses to the liquid state. In the equilibrium state, the rate of product formation is same as the rate of decompositions of product. Consider the statement bellow.

| Macroscopic representation | Microscopic representation | Symbolic representation |
|---|---|---|
| 1. Occurs in isolated and closed system<br>2. Occurs in closed and open system<br>3. Occurs in all system | 1. The rate of forward reaction is faster than backward reaction<br>2. Backward reaction starts after all reactants turn into products<br>3. Forward reaction occurs simultaneously with backward reaction at the same speed | 1. The⇌ sign indicates that the reaction is irreversibel<br>2. The⇌ sign indicates that the reaction isreversibel<br>3. The⇌sign indicates that the reaction takes place twice. Once forward reaction and once backward reaction |

The right combination is….

A. 1, 1, 2 C. 1, 2, 3
B. 1, 3, 2 D. 3, 1, 1

Reason….

A. Equilibrium can occur in open and closed systems. The forward reaction is faster than backward reaction because it's a formation reaction while the ⇌ sign indicates that reaction is reversible
B. Equilibrium only occurs in closed system so that no matter or energy could release from the system. Forward reaction runs first until It is finished then the backward reaction begins while the ⇌ sign indicates that reaction occurs twice then ends
C. Equilibrium only occurs in closed system so that no matter or energy could release from the system. The rate of forward reaction same as the rate of backward reaction and takes place simultaneously while the ⇌ sign indicates that reaction takes place both directions dynamically
D. Equilibrium only occurs in closed system so that no matter or energy could release from the system. The rate of forward reaction faster than backward reaction while the ⇌ sign indicates that reaction takes place both directions dynamically