Student’s mental model, misconceptions, troublesome knowledge, and threshold concept on thermochemistry with DToM-POE

W Wiji* and S Mulyani
Chemical Education Department, Universitas Pendidikan Indonesia, Bandung, Indonesia

*Corresponding author’s e-mail: maswiji@upi.edu

Abstract. The purpose of this study is to obtain a profile of students’ mental models, misconceptions, troublesome knowledge, and threshold concept on thermochemistry. The subjects in this study were 35 students. The method used in this research was descriptive method with instruments Diagnostic Test of Mental Model - Prediction, Observation, and Explanation (DToM-POE). The results showed that the students’ ability to predict, observe, and explain ΔH of neutralization reaction of NaOH with HCl was still lacking. Most students tended to memorize chemical concepts related to symbolic level and they did not understand the meaning of the symbols used. Furthermore, most students were unable to connect the results of observations at the macroscopic level with the symbolic level to determine ΔH of neutralization reaction of NaOH with HCl. Then, most students tended to give an explanation by a net ionic equation or a chemical reaction equation at the symbolic level when explaining ΔH of neutralization reaction at the submicroscopic level. In addition, there are seven misconceptions, three troublesome knowledges, and three threshold concepts held by students on thermochemistry.

1. Introduction

The characteristics of the chemistry demonstrated by the three levels of the chemical representations are macroscopic, submicroscopic and symbolic level [1]. Mental model is an internal representation of the ideas as the process of student cognitive thinking goes [2]. Students use their mental models to give reasons, describe, explain, and predict a phenomenon based on the knowledge they have. If the students can link the three levels of representation, they will understand the concept as a whole [3].

Mental models profiles provide information on the composition or the conceptual framework that students owned. By knowing the profile of mental models of students, the lecturers are able to know misconceptions, troublesome knowledge, and the threshold concept that the students experienced. This is useful in determining the appropriate learning strategies to avoid mismatch. Misconception is a different concept from the generally accepted scientific concept or concepts that cannot be accepted as true by science [4]. Troublesome student knowledge is a difficult or problematic concept for students who become the main obstacle for them to learn. Threshold concept can be regarded as a concept similar to a gate, opening a new way of thinking about a subject previously inaccessible [5].

Student mental models can be explored by using Diagnostic Test of Mental Model - Prediction, Observation, and Explanation (DToM-POE) [6]. DToM-POE is developed by integrating the process of predicting, observing, and explained. Prediction further enable students to use the knowledge they have.
In providing answers rather than to cultivate knowledge of textbooks without thinking [2]. In addition, the students are trained to communicate the relationship between predictions and observations. Thus the mental models profile revealed an actual understanding possessed by the student about a phenomenon or concept and they not only rely on logic or memorization. One important concept in chemistry is thermochemical that is the study of energy accompanying chemical reaction. Thermochemical is a chemical material which is considered the most difficult by students [7].

Based on this background, the formulation of research problems in general is "What is the profile of mental models the students on thermochemistry using DToM-POE?" In particular, the formulation of the problem in this study is expressed in the form of questions as follows: (1) What is the profile of student mental models in predicting $\Delta H$ solution neutralization reaction of NaOH with HCl based on thermochemistry equations and data standard enthalpy of formation? (2) What is the profile of student mental models in determining $\Delta H$ neutralization reaction of NaOH with HCl based on measurements calorimeter? (3) What is the profile of students mental models in explaining the neutralization reaction NaOH with HCl in the sub-microscopic level? (4) What are the misconceptions, troublesome knowledge, and the threshold concept on thermochemistry?

2. Methods
This study was conducted in one of the Education Institutions in Indonesia which organizes Chemistry Education. The data for the research was retrieved at the beginning of the new academic year. The subjects were the magister students of Chemistry Education. The method used in this research is descriptive method.

The instrument used in this study is the DToM-POE in the form of essay test on the thermochemistry, especially the determination of $\Delta H$ neutralization reaction NaOH with HCl based on thermochemical equation, the data standard enthalpy of formation, $\Delta H$ measurements using calorimeter. In the process of predicting, students were required to give reasons based on the knowledge they have. Furthermore, they were facilitated to prove predictions by observing the trial. The students could compare the suitability of predictions with observations. In the final stage, they reconstructed their thinking and provided an explanation in three levels of representation. The answers are grouped into four profiles mental model that is scientifically correct, partially correct, incorrect answers, and no response. Then the answers were analyzed further to determine misconceptions, troublesome knowledge, and the threshold concept.

3. Results and Discussion

3.1. The student mental models
The profile of the student mental models in predicting the $\Delta H$ of neutralization reaction NaOH with HCl based on thermochemical equation can be seen in Table 1. A total of 60%, 17%, 20%, and 3% of the students are, in sequence, in the mental model profile of scientifically correct, partially correct, incorrect answers and no response. On the mental model profile partially correct, the students can manipulate thermochemical equations to obtain the correctly thermochemical equation but without the ability to manipulate value any enthalpy change or incorrect in the mathematical operation. In the mental model profiles incorrect answers, students are not able to manipulate thermochemical equations and value enthalpy changes given to obtain the desired equation.
Table 1. The profile of the student mental models in predicting the ΔH of neutralization reaction NaOH with HCl based on thermochemical equation

| Percentage (%) | Description |
|----------------|-------------|
| Scientifically Correct | 60 | Students are able to manipulate thermochemical equations and value enthalpy changes given to obtain the desired equation, and can calculate enthalpy changes correctly |
| Partially Correct | 17 | Students can manipulate thermochemical equations to obtain the correctly thermochemical equation but without the ability to manipulate value any enthalpy change or incorrect in the mathematical operation |
| Incorrect Answers | 20 | Students are not able to manipulate thermochemical equations and value enthalpy changes given to obtain the desired equation |
| No Response | 3 | No answer or rewrite the thermochemical equations has been given in the question |

Table 2 presents the profile of mental models in predicting the standard enthalpies of neutralization reaction NaOH with HCl based on data standard enthalpies of formation. A total of 57%, 26%, 14%, and 3% of the students are in the scientifically correct profile of mental model, partially correct, incorrect answers, and no response, respectively. In the profile of mental models is partially correct, the students know that the enthalpy change of the reaction can be obtained from value enthalpy changes of formation of the products minus reactants, but are not able to determine the enthalpy change of formation of the substances involved in the reaction, do not pay attention to the sign (-) and (+) on value enthalpy changes of formation or incorrect in the mathematical operation. In the incorrect answers mental model profiles, the students do not know that the reaction enthalpy change can be obtained from value enthalpy changes of formation of products minus reactants.

Table 2. The profile of mental models in predicting the standard enthalpies of neutralization reaction NaOH with HCl based on data standard enthalpies of formation

| Percentage (%) | Description |
|----------------|-------------|
| Scientifically Correct | 57 | Students know that the enthalpy change of the reaction can be obtained from value enthalpy changes of formation of the products minus reactants, and can determine the enthalpy change correctly |
| Partially Correct | 26 | Students know that the enthalpy change of the reaction can be obtained from value enthalpy changes of formation of the products minus reactants, but are not able to determine the enthalpy change of formation of the substances involved in the reaction, do not pay attention to the sign (-) and (+) on value enthalpy changes of formation or incorrect in the mathematical operation |
| Incorrect Answers | 14 | Students do not know that the reaction enthalpy change can be obtained from value enthalpy changes of formation of products minus reactants |
| No Response | 3 | No answer or rewrite the thermochemical equations has been given in the question |

Table 3 presents the profile of mental models in determining standard enthalpies of neutralization reaction based calorimeter measurement. A total of 11%, 20%, 66%, and 3% of the students are in the mental model of scientific correct profile, partially correct, specific misconception, and no response, respectively. On the partially correct mental model profile, the students understand the working
principles of the calorimeter but do not pay attention to the amount of substances that react in determining the reaction enthalpy change or wrong in mathematical operations.

**Table 3. The profile of mental models in determining standard enthalpies of neutralization reaction based calorimeter measurement**

| Percentage (%) | Description                                                                 |
|----------------|-----------------------------------------------------------------------------|
| Scientifically Correct 11 | Students understand the working principles of the calorimeter and can determine the enthalpy change correctly |
| Partially Correct 20 | Students understand the working principles of the calorimeter but do not pay attention to the amount of substances that react in determining the reaction enthalpy change or wrong in mathematical operations |
| Incorrect Answers 66 | Students not understand the working principles of the calorimeter |
| No Response 3 | No answer or rewrite the thermochemical equations has been given in the question |

Table 4 shows the profile of mental models in explaining standard enthalpies of neutralization reaction at the submicroscopic level. Most students are not able to explain the neutralization reaction at sub-microscopic level. Only 6% of the students who have a mental model that is able to explain the whole particles (atoms, molecules, ions) which are actually involved in the neutralization reaction and explain the involvement of the energy (enthalpy change) in a chemical reaction.

**Table 4. The profile of mental models in explaining standard enthalpies of neutralization reaction at the submicroscopic level**

| Percentage (%) | Description                                                                 |
|----------------|-----------------------------------------------------------------------------|
| Scientifically Correct 6 | Students are able to explain the whole particles (atoms, molecules, ions) which are actually involved in the neutralization reaction and explain the involvement of the energy (enthalpy change) in a chemical reaction |
| Partially Correct 6 | Students are able to explain the whole particles (atoms, molecules, ions) which are actually involved in the neutralization reaction but not explain the involvement of the energy (enthalpy change) in a chemical reaction |
| Incorrect Answers 43 | Student are not able to explain the whole particles (atoms, molecules, ions) which are actually involved in the neutralization reaction |
| No Response 46 | No answer or rewrite the thermochemical equations has been given in the question |

Based on the obtained profiles mental models, most of the students were able to determine the reaction enthalpy change based on thermochemical equations and data standard enthalpy of formation but only a few were able to calculate the enthalpy of reaction based calorimeter measurement results. In addition, students also have difficulty in explaining the process of neutralization reaction at the level of particles and energy involved. This shows that in thermochemistry, the student knowledge only on a symbolic level and look hard at the macroscopic and submicroscopic level. This is in line with the opinion of [2] which states that most students used to solve the problems of chemicals at a symbolic level, but do not understand the meaning of the symbols used. Submicroscopic level is a level that is real but can not be observed directly, so the students have difficulty in understanding it. In addition, the lack of ability of visualization (imagination) students to the phenomenon that occurs also cause students have difficulty understanding regards submicroscopic level [2].
3.2. Misconceptions, Troublesome Knowledge, and Threshold Concept
Further Analysis from the mental model profile shows misconceptions, the troublesome knowledge, and threshold concept. The research found nine misconceptions students based on partially correct and incorrect answer: (a) enthalpy change not depend on phase reactants and products; (b) sign (+) and (-) not affecting the calculation and value enthalpy change; (c) standard enthalpies change same with enthalpies change; (d) \( \Delta H \) reaction = \( \Delta H_f \) reactants – \( \Delta H_f \) products; (e) \( \Delta H \) reaction = \( \Delta H_f \) reactants + \( \Delta H_f \) products; (f) \( \Delta H \) reaction is not depend on number of substances that reacts; (g) \( \Delta H \) reaction obtained will be different if using different ways. Further, there are four troublesome knowledge such as: (a) manipulate equation thermochemical reaction to predict standard enthalpies of neutralization reaction; (b) determine the system and the environment in the context calorimeter; (c) explaining standard enthalpies of neutralization reaction at the submicroscopic level. Then, there are three found threshold concept, namely; (a) the standards state; (b) the enthalpy change function as a state; (c) the enthalpy change magnitude as extensive properties.

4. Conclusion
Based on the discussion of the data discovery research which has been done, it can be concluded that: (1) Profile mental model student in predicting \( \Delta H \) of neutralization reaction of NaOH with HCl solution based on thermochemical equations data and standard enthalpy of formation is dominated the scientifically correct answers (2) Profile student mental models in determining \( \Delta H \) of neutralization reaction of NaOH with HCl solution based calorimeter measurement result is dominated by incorrect answer profile (3) the profile of student mental models to explain the neutralization reaction of NaOH with HCl solution in the sub-microscopic level is dominated by the incorrect answer (4) Based on the analysis of student mental models profile, it is found 7 misconceptions, 3 troublesome knowledge, and 3 threshold concept on thermochemistry.

5. References
[1] Johnstone A H 1991 Why is science difficult to learn? Things are seldom what they seem Journal of Computer Assisted Learning 7 2 75-83
[2] Wang C Y 2007 The role of mental-modeling ability, content knowledge, and mental models in general chemistry students’ understanding about molecular polarity (Columbia: University of Missouri)
[3] Treagust D F, Chittleborough G, and Mamiala T L 2003 The role of submicroscopic and symbolic representations in chemical explanations International Journal of Science Education 25 11 1353-1368
[4] Sendur G and Toprak M 2013 The role of conceptual change texts to improve students’ understanding of alkenes Chemistry Education Research and Practice 14 4 431-449
[5] Meyer J and Land R 2003 Threshold concepts and troublesome knowledge: Linkages to ways of thinking and practising within the disciplines (Edinburgh: University of Edinburgh)
[6] Liew C W and Treagust D F 1998 The Effectiveness of Predict-Observe-Explain Tasks in Diagnosing Students’ Understanding of Science and in Identifying Their Levels of Achievement (Australia: Curtin University of Technology)
[7] Ayyildiz Y and Tarhan L 2012 The Effective on Students’ Understanding of Chemical Reactions and Energy H U Journal of Education 42 42