Misconceptions and troublesome knowledge on chemical equilibrium

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Abstract. This research aims to find out misconceptions and troublesome knowledge on chemical equilibrium. The qualitative method used in this study is conducting a semi-structured interview with prospective chemistry teachers. The interview consists of investigating the prospective chemistry teachers’ understanding using CaCO₃ equilibrium system, NO₂-N₂O₄ equilibrium system, and FeSCN²⁺ equilibrium system and asking about concepts that are considered troublesome according to their learning experiences. The common misconceptions on chemical equilibrium revealed by this study are about the dynamic nature of chemical equilibrium, the constancy of equilibrium constant, and the shift of equilibrium. Meanwhile, the dynamic equilibrium, the equilibrium constant, and Le Chatelier’s principle are considered troublesome knowledge because they can be alien, conceptually difficult, and troublesome language.

1. Introduction
Chemical equilibrium is one of the important concepts in learning chemistry because it is basic to understand other chemical concepts such as acid-base, oxidation-reduction reactions (in electrochemistry equilibrium), and solubility. Mastery of the equilibrium concept helps the mastery of these other chemical concepts [1]. Unfortunately, chemical equilibrium is considered a difficult concept by students. The concept is complex because it includes defined concepts, abstract concepts, mathematical calculations, and graphs. Furthermore, to understand chemical equilibrium concepts, students should understand several other related concepts such as concepts of concentration, stoichiometry, gas, and mole [2]. Consequently, student could construct concept that different from scientific concept which is called misconceptions [3,4].

A misconception is an idea or conception that is mistaken and not grounded in scientific understanding [5]. Other terms of misconceptions that used in the literature include misunderstandings, naive conceptions, alternative conceptions, naive beliefs, erroneous ideas, etc. [4]. Misconceptions are personal, incoherent, stable, and embedded in students as alternative beliefs that are difficult to change [6]. It greatly affects how students build new scientific knowledge and can inhibit their learnings [3].

Besides misconceptions, there is another idea that can inhibit a student’s ability to develop a complete understanding of concepts which is suggested by Perkins as troublesome knowledge [7]. Troublesome knowledge as an explanation for why students find certain types of knowledge difficult [8]. Perkins identifies types of knowledge that are difficult for students are ritual, inert, conceptually difficult, and alien. Ritual knowledge is obtained based on routine or social rituals but not understanding conceptual meanings [7]. Inert knowledge is information that you know, but it is rarely used in your daily life.
Conceptually difficult knowledge may involve a combination of several different information or may be counterintuituitive. Alien knowledge is the knowledge that different from what you believe or foreign to your understanding. Meyer and Land suggested the expansion of the types of troublesome knowledge to include tacit knowledge and troublesome language [9]. Tacit knowledge is characterized as implicit and contains subtle differences. Troublesome language is troublesome that caused by using terms that same with everyday language but has different meanings.

There is a closely linking between troublesome knowledge and misconceptions. Troublesome knowledge is essentially troublesome because of the misconception students bring with them into the classroom [10]. Misconceptions and troublesome knowledge are important to identify. By knowing misconceptions and troublesome knowledge, the teachers and lecturers can determine the compatible learning strategies and overcome the barriers in learning to improve students' understanding of concepts [5,7]. Therefore, this research aims to find out misconceptions and troublesome knowledge on chemical equilibrium.

2. Method
This research uses a qualitative method that is conducted semi-structured interview with five prospective chemistry teachers. Their understanding of chemical equilibrium investigated uses the CaCO$_3$ equilibrium system, NO$_2$-N$_2$O$_4$ equilibrium system, and FeSCN$^{2+}$ equilibrium system. Misconceptions of chemical equilibrium identified based on the analysis of their responses. Furthermore, the prospective chemistry teachers are asked about concepts on chemical equilibrium that are considered difficult or troublesome according to their learning experiences. Troublesome knowledge identified based on the analysis of misconceptions findings [11] and prospective chemistry teachers' responses about the concept that considered troublesome [12].

3. Result and Discussion

3.1. Misconceptions on chemical equilibrium
We will discuss misconceptions on chemical equilibrium that obtained based on interview result. Misconceptions in this study generally are grouped under the general headings of the dynamic equilibrium, the equilibrium constant, and the application of Le Chatalier’s principle. In this study, the prospective chemistry teachers are not able to predict that radioactive CaCO$_3$ pure solids will be formed if into CaCO$_3$ equilibrium system added some of gas radioactive CO$_2$. So, they believed that no reaction occurs at equilibrium and the equilibrium is static. This finding is consistent with Pekmez [14]; Canpolat, et al. [14] and Griffiths [15] findings. Then, when prospective chemistry teachers asked to draw graphs of N$_2$O$_4$ decompositions to give NO$_2$, some of them draw graphs shown in Figure 1.

![Figure 1. Prospective chemistry teacher graphs of N$_2$O$_4$ decompositions to give NO$_2$](image-url)
This finding shows that prospective chemistry teachers held misconceptions that the concentration of product and reactants are equal at equilibrium. A similar misconception was reported by Karpudewan et al. [16] and Özmen [17]. Karpudewan et al. [16] found that 14.3% of students believed at equilibrium the concentrations of all the products in the reaction mixture of PCl₅(g) ⇌ PCl₃(g) + Cl₂(g) same as the PCl₅(g). Özmen [18] reported that 23.3% of participants thought equilibrium reached when concentrations of substances on both sides of an equation are equal. Özmen [18] said this idea probably because students misinterpret about statements “dynamic equilibrium is reached when the forward and reverse reactions rate become equal, and there are no further changes in concentrations”. So, they maybe think that the concentration of reactants and products also become equal at equilibrium. Prospective chemistry teachers who held this misconception, draw N₂O₄ and NO₂ molecules as shown in Figure 2.

![Figure 2. Prospective chemistry teacher’s drawing for N₂O₄ molecules decompositions to give NO₂ molecules](image)

Based on Figure 2, the prospective chemistry teachers are unable to translate the chemical equation of N₂O₄⇌ 2NO₂ (the symbolic level) to the submicroscopic representation. They drew one molecule of N₂O₄ decomposes to one molecule NO₂. It showed that prospective chemistry teachers have difficulty in translating chemical representations from one level of representation into another level. This finding is relevant to Gkitzia et al. [19] finding. Gkitzia et al. [18] have investigated 11th grade Greek students’ and 3rd-year undergraduate chemistry students’ ability to translate between different types of chemical representations. The result showed that students’ ability to move across the three levels of chemistry is very low and students held many misconceptions. Gkitzia et al. [18] suggested teachers and textbook writers should consider how to get students to think about the connections between the three levels of chemical representations because students cannot easily hold these connections by themselves.

Another misconception in this study is prospective chemistry teacher thought that the numerical value of $K_{eq}$ (equilibrium constant) changes with amounts present of reactants or products. This misconception is similar to Barke et al. [6]; Erdemir et al. [19] and Hackling & Garnet [20] findings. Prospective chemistry teacher also held misconceptions that when more products are added to an equilibrium system at a constant temperature, $K_{eq}$ will increase. Özmen [18] and Voska and Heikkinen [21] reported a similar misconception. These findings show us the student’s difficulties with the idea “Keq is constant for a specific reaction at a defined temperature” and they have uncertainty as to when the equilibrium constant is in fact a constant [21,23].

Furthermore, when prospective chemistry teachers asked to predict the color of FeSCN²⁺ solutions which originally orange, after more drop Fe³⁺ solutions added into equilibrium mixture. They answer that the color FeSCN²⁺ solutions become pale yellow because of the equilibrium shift to the Fe³⁺ side. They held misconceptions that when a substance is added to equilibrium mixture, equilibrium will shift to the side of the addition. This finding is consistent with Demircioğlu, et al. [24] and Özmen [18] findings.
Kousathana & Tsaparlis [2] argued that misconceptions on chemical equilibrium are not only caused by the concepts that are “unique” and hard to understand, but also the student must understand other concepts such as mole, stoichiometry, gases, and the ideal gases law. Kousathana & Tsaparlis [2] stated that the dynamic nature and Le Chatelier’s principle become the most difficult concept to understand for students especially when dealing with the direction of a reaction or the disturbance of equilibrium.

The misconceptions can be caused by the inability of a student in connecting three levels of chemical representation which are macroscopic, symbolic, and submicroscopic. For example, at the macroscopic level, when the system reaches equilibrium appear natural, macroscopically as stable and static systems. On the other hand, on the microscopic level, the system is dynamic not only because of molecular movement but also because of the process of breaking and creating bonds go on with the net result of zero. If students failed to connect between phenomena (macroscopic level) to the submicroscopic level, it can lead to misconceptions [19]. Furthermore, Erdemir et al. [19] said some misconceptions about chemical equilibrium might be the result of instruction that underlines correct concepts without highlighting common conceptual errors. The teachers should be aware of students' prior knowledge and misconceptions. They must investigate why misconceptions occur and use compatible learning strategies to eliminate misconceptions.

3.2. Troublesome knowledge on chemical equilibrium

Troublesome knowledge on chemical equilibrium identified from analysis of misconceptions findings in this study, and responses of prospective chemistry teachers about difficult or troublesome concepts on chemical equilibrium according to their learning experiences. The statements of prospective chemistry teachers about the troublesome concept of chemical equilibrium according to their learning experiences are shown in Table 1. The dynamic equilibrium, the equilibrium constant, and Le Chatelier's principle are considered troublesome because they can be conceptually difficult and alien. It is related to misconception findings.

| Troublesome concept | Example of prospective chemistry teacher statement | Type of troublesome knowledge |
|---------------------|---------------------------------------------------|-------------------------------|
| Dynamic equilibrium | “I must imagine something abstract and it’s difficult. It’s hard for me to connect what I see in real to the molecular level.” (Prospective chemistry teacher #1) | Conceptually difficult |
| Equilibrium constant | I feel difficult to determine the direction of reaction...” (Prospective chemistry teacher #4 and #5) Since I first learn chemical equilibrium and until now, I feel hard to determine the concentration of reactant and product at the equilibrium conditions...” (Prospective chemistry teacher #2) It’s difficult for me when I must determine the concentration of reactant and product and attribute it with $K$ value.” (Prospective chemistry teacher #3) | Conceptually difficult |
| Le Chatelier’s principle | “Sometimes I feel confused predicting or determining the color of the product (the means is the color of solution) after the equilibrium conditions change”. (Prospective chemistry teacher#3) | Alien, Conceptually difficult |

Based on Table 1, dynamic equilibrium becomes troublesome knowledge because it is conceptually difficult. The concept is abstract, complex and it can lead the student to the misconceptions. Park & Light [7] argued that the difficulty of knowledge can be caused by the complexity and level of abstraction of a concept. The equilibrium constant is also troublesome knowledge because it is
conceptually difficult. The concept is complex, involves abstract concepts, mathematical calculations, and graphs. In this study, we found that prospective chemistry teachers are unable to determine the concentration of reactant and product at the equilibrium conditions. They are also confused to determine the direction of the reaction. Then, Le Chatelier’s principle is troublesome knowledge because it is alien and conceptually difficult. We found that prospective teachers feel difficult to determine the color of the FeSCN$^{2+}$ solution, after more drops of Fe$^{3+}$ solutions are added to the equilibrium mixture. They are confused and unable linking it with the direction of the reaction and shift of equilibrium. It is not just because the concept is abstract, but it also contradicts what they believe. They have misconceptions because of their everyday experience. Al-Balushi et al. [25] reported that almost one-half of their participants believed that the addition of water to the blue color of (CoCl$_2$)$_2^-$ solution in the equilibrium system: $[\text{Co(H}_2\text{O)}_6^{2+}] (aq) + 4\text{Cl}^- \rightleftharpoons [\text{CoCl}_4^{2-}] (aq) + 6\text{H}_2\text{O} (l)$, would dilute the blue color of the solution, instead of changing it to pink (the color of Co(H$_2$O)$_6^{2+}$ solution) by reversing the direction of the reaction. They misunderstood because of their everyday experience, water usually dilutes the solution.

Beside alien and conceptually difficult, another type of troublesome knowledge on chemical equilibrium is troublesome language. In chemical equilibrium, we use terms such as equal and balanced, we also use terms shift and stress in Le Chatelier’s principle topic. Those terms are different meanings from our everyday language. Erdemir et al. [19] argued that using such terms can drive students to very different visual images. Furthermore, Erdemir et al. [19] suggested the different features of equilibrium and chemical equilibrium must be analyzed and presented to overcome the confusion of these concepts.

4. Conclusion
The common misconceptions on chemical equilibrium in this research regarding the dynamic nature of chemical equilibrium, the constancy of the equilibrium constant, and the shift of equilibrium. Meanwhile, the dynamic equilibrium, the equilibrium constant, and Le Chatelier’s principle are thought troublesome knowledge, because they can be conceptually difficult, alien, and troublesome language.

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