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Learning Difficulties in High School Chemistry: The Case of Chemical Equilibrium

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Abstract. Chemistry is considered as an importance science for understanding various phenomena in nature and it is also the base for learning other sciences. However, many students across the world are facing difficulties in learning chemistry, especially chemical equilibrium topic. This academic article reports some problems and obstacles of teaching and learning chemistry at the high school level. Students' difficulties in learning as well as teaching and learning methods for improving students' learning and conceptual understanding of chemical equilibrium are described.

Keywords: Chemical equilibrium, chemistry learning difficulty, high school chemistry

THE NATURE OF CHEMISTRY

Chemistry has played a key role in understanding various processes and phenomena in nature. Because of chemistry topics are based on the science of the composition, structure of matter, properties, and the reaction of the substances. Chemistry curricula were astonished to find that many abstract concepts, which are central to further learning in both chemistry and other sciences (Taber, 2002). The nature of chemistry exists on three levels consisting of the macroscopic level refers to the observable phenomena with the naked eye (Johnstone, 2000). At the submicroscopic level refers to the nature, arrangement, and motion of molecules used to explain properties of compounds or natural phenomena. At the symbolic level refers to the symbolic representations of atoms, molecules, and compounds, such as chemical symbols, formulas, and structures (Bradley & Brand, 1985). The three levels interconnected between these representations (see Figure 1), which can lead to an internal conflict between students. Furthermore, students have difficulties in understanding relating chemical phenomena and concepts that do not result only from the existence of these three levels or from their explanation using abstract concepts, but also from the lack of interconnection between these representations. These representations are invisible and abstract while students' understanding of chemistry relies heavily on sensory information. The ability of students to understand the role of each level of chemical representation and to transfer from one level of another are an important aspect of generating understandable explanations (Treagust et al., 2003). Therefore, educators employing design research to support secondary-level chemistry students' meaningful chemistry learning and higher-order thinking regarding ideas of chemistry.

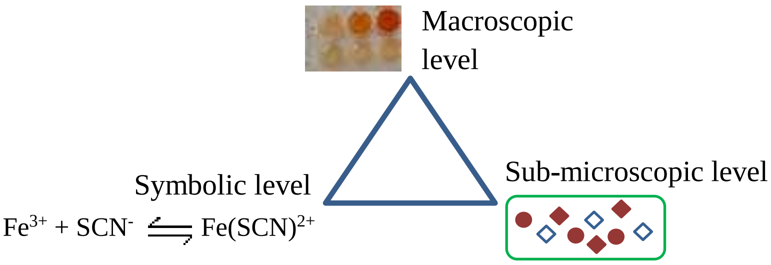

Figure 1: Three levels of chemical representation of the chemical equilibrium.

LEARNING DIFFICULTIES IN HIGH SCHOOL CHEMISTRY

Most difficulties as well as problems and obstacles in teaching and learning chemistry at the high school level are: (1) students did not have enough experience conducting chemistry experiments, (2) traditional experiments did not provide students a chance to carry out a variety of practical experiments, and (3) students did not develop conceptual understanding (Tamuang et al., 2017) Moreover, costs of chemical reagents and equipment have been increased so teachers solve problems using a virtual laboratory or try to reduce the number of laboratory activities to reduce costs. Furthermore, some teachers made changes to their teaching methods by substitution teaching the theory to practice experiments. In addition, the teachers may demonstrate the experiment without student participation.

Chemical education researchers have been trying to propose the teaching and learning approaches that enable students to improve their conceptual understanding of the chemical phenomena. Furthermore, employing design research to support higher-order thinking regarding ideas of chemistry (Aksela, 2005). Besides, teachers might plan to have students effectively interact with their knowledge in the laboratory and apply for daily life. Traditional instruction seems to unsuccessful in enhanced students. Therefore, a new approach to teaching and learning centered on students and their needs has become indisputable for education. Students construct their own understanding and knowledge, through the operation by themselves, problem-solving, and conclusion. Especially, encouraging students to use the chemical experiments or hands on activities to create more knowledge and then students were given sufficient time and opportunities for interaction and reflection. The learning environment emphasized, which can result in enhanced understanding and critical thinking skills. Also, the attitudes toward science, cooperation, and communication skills are intensified (Hofstein & Lunetta, 2004).

CHEMICAL EQUILIBRIUM

Learning chemical equilibrium is important for the chemistry. In the chemistry curriculum, equilibrium is considered as the basic chemistry concepts for senior high school students. Chemical equilibrium refers to a state with equal rates of the forward and reverse reactions. It is a dynamic process in which the reactant and product concentrations are constant, while the conversions between reactants and products are still in progress (Johnstone, 2000; Taber, 2002). Chemical equilibrium especially equilibrium constant (K_c) in particular is one of the most difficult topics in chemistry since it involves many factors that can influence the equilibrium and mathematical calculation (Aksela, 2005; Bradley & Brand, 1985; Treagust et al., 2003). Moreover, it requires an understanding of macroscopic, microscopic and symbolic natures (Hofstein & Lunetta, 2004) and the dynamic nature of equilibrium or the equilibrium law devised by Le Chatelier (Birch & Stickle, 2003). Many students across the country experience these difficulties as revealed in previous studies, i.e., India (Banerjee, 1991), the USA (Voska & Heikkinen, 2000), Australia (Treagust et al., 2003), Thailand (Kajornklin et al., 2020; Tamuang et al., 2017) and Türkiye (Özmen, 2008). The definition of the equilibrium constant (K_c) is given as 'the ratio of the equilibrium concentrations of products over the equilibrium concentrations of reactants each raised to the power of their stoichiometric coefficients' (Johnstone, 2000; Taber, 2002).

TEACHING METHODS TO IMPROVE STUDENTS' LEARNING OF CHEMICAL EQUILIBRIUM

Several effective activities have been developed to enhance students' experience and understanding of chemical equilibrium as shown in Table 1.

These include, hands-on activities (van Driel et al., 1998), analogies (Thomas & Mcrobbie, 2002), demonstration (Akkus¸ et al., 2003) and laboratory experiment (Bilgin & Geban, 2006; Doymus, 2008; Maia & Justi, 2009), etc. Many of these activities, however, have a disadvantage in that they are mostly performed on a traditional scale and method with high-cost and insufficient scientific instruments making them unsuited for classes especially at a high school level. On the other hand, small-scale experiments (Figure 2), i.e. small-scale experiment (Tamuang et al., 2017) on a well plate and screen-printed paper-based device (Kajornklin et al., 2020) could diminish these limitations. The laboratory experiment is considered as one of the most effective activity in promoting students' visualization and conceptualization of this topic as well as engagement during the class (Aksela, 2005; Maia & Justi, 2009). Many laboratory experiments can promote students' conceptual understanding of equilibrium; however, they are often not suitable for the educational context of many schools and some universities due to limitations of access to reliable scientific instruments (Maia & Justi, 2009). Hence, alternative experiments using inexpensive facilities, quick process, and easy to carry out are highly advocated.

(a) Tamuang et al. (2017) (b) Kajornklin et al. (2020)

Figure 2: Small-scale experiment on a well-plate (a) and screen-printed paper towel-based experimental device (b).

In the field of chemical equilibrium, researchers show similar trend of misconceptions. These misconceptions include the approach to chemical equilibrium, characteristics of chemical equilibrium, the conditions of change in chemical equilibrium as well as predicting the conditions of equilibrium, the distinction between the conditions that characterize completion and reversible reactions, and the impact of factors on the value of the equilibrium constant. The topic of chemical equilibrium is unique because when teaching the misconceptions may occur due to the similarity with everyday experience as well as the abstractness of this phenomenon. Herein, we will focus more on the teaching of the concepts of chemical equilibrium. Therefore, we have developed a simple and direct method to fabricate paper-based microfluidic devices that can be used for demonstrating a lot of alternative conceptions on chemical equilibrium.

Table 1: **Reports of previous research studies on chemical equilibrium**

Title	Teaching methods	References
Developing secondary students' conceptions of chemical reactions: the introduction of chemical equilibrium	Teaching strategies which promote conceptual change	van Driel et al. (1998)
Collaborating to enhance student reasoning: Frances' account of her reflections while teaching chemical equilibrium.	Constructivist approach	Thomas & Mcrobbie (2002)
Effectiveness of instruction based on the constructivist approach on understanding chemical equilibrium concepts.	Constructivist approach	Akkus¸ et al. (2003)
The effect of cooperative learning approach based on conceptual change condition on students' understanding of chemical equilibrium concepts.	Cooperative learning approach	Bilgin & Geban (2006)
Teaching chemical equilibrium with the jigsaw technique.	Cooperative learning (JIGSAW)	Doymus (2008)
Learning of chemical equilibrium through modelling-based teaching	Modelling-based Teaching	Maia & Justi (2009)
A teaching sequence for learning the concept of chemical equilibrium in secondary school education.	Teaching strategies which promote conceptual change	Ghirardi et al. (2014)
Investigating high school students' understanding of chemical equilibrium concepts.	Demonstrations, animations, & problem solving	Karpudewan et al. (2015)
Implementing an equilibrium law teaching sequence for secondary school students to learn chemical equilibrium.	Trial-and-error approach.	Ghirardi et al. (2015)
A colorful demonstration to visualize and inquire into essential elements of chemical equilibrium.	Demonstration	Eilks & Gulacar (2016)
A new multimedia application for teaching and learning chemical equilibrium.	Self-learning mediated by the use of multimedia animation	Ollino et al. (2018)
Geometrical description of chemical equilibrium and Le Châtelier's principle: Two-component systems.	Graphical presentations	Novak (2018)
Development of Chem in Action instructional media based on drill and practice in chemical equilibrium material for students in senior high school	Drill and practice	Masruroh & Diniaty (2020)
Demonstration of the factors affecting chemical equilibrium and chemical equilibrium constant	Paper towel-based experimental device	Kajornklin et al. (2020)

CONCLUSION

Chemical equilibrium is considered as one of the key concepts in chemistry since it relates and affects some chemistry topics such as chemical kinetics or chemical reaction rate. However, the chemical reaction has been found to be difficult to understand for high school as well as college students. These difficulties arose from many obstacles and complexity of this topic since it involves all three levels of chemical representation, lack of link among these representations, and requires some mathematics calculation. To understand chemical equilibrium meaningfully, students should have a chance to experience macroscopic information from practical experiment, explain it by using stadard symbolic explanation, and then link these data to what is happening at the intangible submicroscopic level. Many teaching and learning methods can be used to improve students' learning and conceptual understanding of this concept. The small-scale experiments that can be implemented under a normal high school classroom context are highly advocated since it is low-cost, less time requirement, portable, convenient and easy to perform by high school students. This type of experiment has been proven to be effective for enhancing students' conceptual understanding not only the chemical equilibrium, but also other chemistry topics as reported in many scientific journals.

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