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The Effect of Structured Inquiry-Based Chemical Equilibrium Module with Three Levels of Representation on Students' Mental Models

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Abstract

Students find it difficult to understand the material of chemical equilibrium. One of the efforts to overcome these student difficulties is to use a structured inquiry-based module equipped with three levels of representation. This study aims to determine the effect of using the module on students' mental models. This study used a posttest-only control design conducted in two schools. In the design, each school had two groups, namely the experimental group and the control group. The two-tier diagnostic test instrument was used to test the mental models of 134 students. The hypothesis was tested by t_{test} using the SPSS 16.0 program. The results of the t_{test} for each school were 0.011 at SMAN 3 Padang and 0.008 at SMAN 13 Padang, with a 0.05 significance level. The results of the t-test showed that the use of the module affected students' mental models.

Keywords: chemical equilibrium module, student's mental models, three levels of representation

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1. Introduction

Mental models are internal representations created by a person as a result of perspective, imagination, experience, and interaction with real situations (Akaygun, 2016; Wang & Barrow, 2011). Mental models represent ideas in an individual's mind that are used to describe and explain phenomena (Jansoon et al., 2009). Mental models are not rigid, mental models can be improved cognitively when doing tasks (Gilbert & Treagust, 2009). The mental models are strongly influenced by the learning structure carried out by the teacher (Park et al., 2009), so teachers need to know how students build their mental models to ensure that students don't develop wrong mental models (Gilbert & Treagust, 2009; Nahum et al., 2004). In addition, mental models are useful for making predictions, testing new ideas, and solving problems in learning chemistry (Bodner & Domin, 2000; Halim et al., 2013).

Mental models are closely related to three levels of representation (macroscopic level, submicroscopic level, and symbolic level) (Devetak et al., 2009). The ability to interconnect the three levels of representation is reflected in students' mental models (Devetak et al., 2009; Halim et al., 2013; Jaber & BouJaoude, 2012). In science, including chemistry, these three levels of representation play an important role in helping students to gain meaning of learning and understand complete mental models. But in reality, the chemistry learning process emphasizes more on the macroscopic and symbolic levels (Akaygun, 2016; Li & Arshad, 2014), so that students find it difficult to understand at the submicroscopic level

(Demircioğlu et al., 2013). Previous research has shown that students' inability to represent chemistry at the submicroscopic level can hinder their ability to solve chemical problems related to macroscopic or symbolic levels (Chandrasegaran, A. L. et al., 2007; Kozma & Russell, 2005). These difficulties also cause students to get bored, and frustrated. Finally, they learn by cramming without understanding the meaning (Li & Arshad, 2014).

One of the materials taught in high school is chemical equilibrium. This material is considered difficult for students (Barke et al., 2009; Karpudewan et al., 2015; Özmen, 2008; Raviolo & Garritz, 2009) even though this material is a prerequisite for studying further materials such as acid-base and solubility (Özmen, 2008).

One of the efforts to overcome difficulties in chemical equilibrium material is to present three levels of chemical representation in teaching materials in the form of modules. Modules are printed teaching materials that can facilitate students' independent learning so that students can make learning time more efficient and learn according to their respective speeds (Daryanto & Aris Dwicahyono, 2014). Modules equipped with three levels of representation can make it easier for students to find concepts and make learning time more efficient (Sagita et al., 2017; Sari et al., 2018).

The writing of the module needs to be ordered in such a way that it is easy for students to understand the material in it. The order of the teaching materials is from easy to difficult, from known to unknown, and from knowledge to the application (Asyhar, 2012). One of the efforts so that the material in the module can be conveyed properly is by adopting the steps of a structured inquiry learning model. The inquiry learning model is known to have been proven to improve learning outcomes (Bunterm et al., 2014). Inquiry refers to how scientists study the world, proposing explanations from data that has been gathered from the natural environment. The term also includes things like asking questions, planning investigations, and reviewing what is already known from experimental data, this reflects what scientists do (Martin-Hansen, L.. 2002). Inquiry learning is in line with the constructivist approach which emphasizes the idea that knowledge is not passed directly from teacher to student, but is developed by students. Inquiry-based learning varies in the amount of autonomy that teachers give to students, ranging from confirmation inquiry, structured inquiry, guided inquiry, and open inquiry (Zion & Mendelovici, 2012).

The selection of structured inquiry is based on the involvement of the teacher who is quite a lot in guiding and directing students so that it can be said that it is suitable for use for difficult material. The structured inquiry learning model has been implemented in geometry learning and the results showed that the structured inquiry learning model is proven to provide better results (Salim & Tiawa, 2014).

Based on the explanation above, a research was conducted on the effect of using a structured inquiry in chemical equilibrium module equipped with three levels of representation of students' mental models.

2. Research Method

The research design was an experimental posttest-only control design. In this design there are two groups, the first group that was treated was called the experimental group and the second group that was not treated was called the control group. If there is a significant difference between the experimental group and the control group, then the treatment given has a significant effect (Sugiyono, 2017). The experiment was carried out in two schools in Padang, namely SMAN 3 Padang and SMAN 13 Padang. Each school was selected for control class and experimental class. Each class was given a posttest. The students that involved in the research were 134 students.

The research instrument was a two-tier diagnostic test. The instrument was adopted from the research results of Haluk Ozmen (Özmen, 2008) who developed a two-tier multiple-choice diagnostic test for chemical equilibrium materials. The instrument was slightly revised by adding a submicroscopic level of representation.

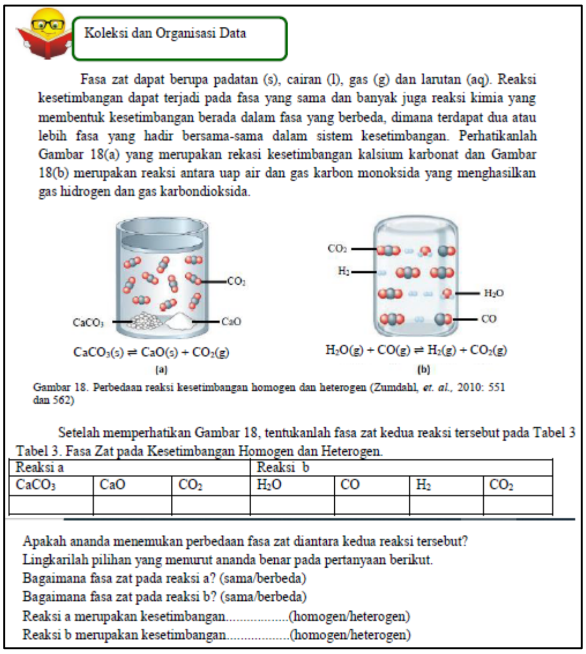
The developed two-tier diagnostic test has two levels. The first level consists of content questions in a multiple-choice format with three choices and the second level consists of four possible reasons for the possible answers from the first part: three incorrect reasons and one correct reason. The scoring system is if students answer correctly in the first level and the reason was correct then the score was 2; if students answer correctly at one level and wrong at another level, then the score was 1; and if students answer incorrectly at both levels then the score is 0 (Bayrak, 2013).

Furthermore, the two-tier diagnostic test scores were classified into 5 categories of mental models, namely target, intermediate 1, intermediate 2, intermediate 3, and unclear (Park et al., 2009). For each category, 2 students were selected to conduct interview to know more deeply about their mental models related to chemical equilibrium material. The procedure for knowing this mental model was modified according to what has been done by Lin et al., (2007). Hypothesis testing to see the effect of using the module was carried out using a t-test based on a two-tier diagnostic test score previously tested for normality and homogeneity.

3. Results and Discussion

The module that used to deliver chemical equilibrium material in the experimental class according to the steps of the structured inquiry learning model. The first step was observation, at this stage students were presented with a phenomenon to lead to the competencies to be achieved. The second stage was making hypotheses based on the phenomenon presented at the observation stage. The third stage was the collection and organization of data, at this stage students conducted investigations and data collection so that new, better knowledge is expected to be formed. In the third stage, students were guided by structured questions so that students are expected to more easily understand the material presented in the module (Figure 1). Next was the conclusion stage. The module is equipped with three levels of representation that are characteristic of chemistry and structured questions.

The module that developed aims to build students' mental models on chemical equilibrium material well. The diagnostic test instrument to reveal students' mental models that consist of 10 questions, namely two questions about the concept of equilibrium, three questions about the equilibrium constant, two questions about heterogeneous equilibrium and three questions about Le Chatelier's principle.
The levels of students' mental models were listed in Table 1 to Table 4. The results of the t-test showed that the module had a significant effect on students' mental models with a t-test score of 0.011 at SMAN 3 Padang and 0.008 at SMAN 13 Padang.


Koleksi dan Organisasi Data

Fasa zat dapat berupa padatan (s), cairan (l), gas (g) dan larutan (aq). Reaksi kesetimbangan dapat terjadi pada fasa yang sama dan banyak juga reaksi kimia yang membentuk kesetimbangan berada dalam fasa yang berbeda, dimana terdapat dua atau lebih fasa yang hadir bersama-sama dalam sistem kesetimbangan. Perhatikanlah Gambar 18(a) yang merupakan rekasi kesetimbangan kalsium karbonat dan Gambar 18(b) merupakan reaksi antara uap air dan gas karbon monoksida yang menghasilkan gas hidrogen dan gas karbondioksida.

$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$ (a)

$H_2O(g) + CO(g) \rightleftharpoons H_2(g) + CO_2(g)$ (b)

Gambar 18. Perbedaan reaksi kesetimbangan homogen dan heterogen (Zumdahl, *et. al.*, 2010: 551 dan 562)

Setelah memperhatikan Gambar 18, tentukanlah fasa zat kedua reaksi tersebut pada Tabel 3

Tabel 3. Fasa Zat pada Kesetimbangan Homogen dan Heterogen.

Reaksi a			Reaksi b			
$CaCO_3$	CaO	CO_2	H_2O	CO	H_2	CO_2

Apakah ananda menemukan perbedaan fasa zat diantara kedua reaksi tersebut?
Lingkarilah pilihan yang menurut ananda benar pada pertanyaan berikut.
Bagaimana fasa zat pada reaksi a? (sama/berbeda)
Bagaimana fasa zat pada reaksi b? (sama/berbeda)
Reaksi a merupakan kesetimbangan..................(homogen/heterogen)
Reaksi b merupakan kesetimbangan..................(homogen/heterogen)

Figure 1. Module Display on the Data Collection and Organization Stage

3.1. Mental Models of Chemical Equilibrium Concept

In Table 1, the mental models of the experimental class of target category in both schools showed a higher percentage than the control class. Students with target mental models answered questions and reasons correctly, while students with other mental model categories answered questions correctly with wrong reasons or vice versa.

The question about the concept of equilibrium measures students' understanding of how the system has reached equilibrium. Misunderstandings of students regarding the concept of chemical equilibrium include students assuming that when the system reaches equilibrium, the concentrations of products and reactants are the same, previous studies also found the same case (Al-balushi et al., 2012; Demircioğlu et al., 2013; Özmen, 2008).

In addition, students understand that the equilibrium reaction which is indicated by an alternating arrow indicates that the forward reaction is completed first and then followed by a reverse reaction, this is also in line with the findings of previous research by Barke, *et.al.* (Barke et al., 2009) and Al-balushi (Al-balushi et al., 2012).

Another understanding that appeared was that when the system reaches equilibrium, the rate of the forward reaction is greater than the reverse reaction because the product is formed, the same finding is also found in a previous study by Özmen (Özmen, 2008).

Table 1. Mental Models of Chemical Equilibrium Concept

School	Mental Model	Mental Model of Chemical Equilibrium Concept	
		Experiment Group (%)	Control Group (%)
SMAN 3 Padang	Target	61,11	34,28
	Intermediate 3	19,44	42,85
	Intermediate 2	5,56	22,85
	Intermediate 1	11,11	0
	Unclear	2,78	0
SMAN 13 Padang	Target	35,48	18,75
	Intermediate 3	45,16	37,5
	Intermediate 2	9,67	28,12
	Intermediate 1	9,67	15,62
	Unclear	0	0

In the experimental class, the module used displays modeling in the form of images of molecules in equilibrium reactions. Some studies had stated that modeling is needed to explain a chemical concept at the submicroscopic level because this will affect a person's mental model (Akaygun, 2016; Coll & Treagust, 2003).

The module also presents the material with structured questions about the number of molecules from the beginning of a reaction until the reaction reaches equilibrium, so it is clear that the same concentration of products and reactants does not indicate the system has reached equilibrium. Then the module displays a graph of the relationship between concentration and time where students were led to read a graph that the concentration of the reactants at the beginning of the reaction is higher than the concentration of products, but over time products will form, causing an increase in product concentration. At a certain time, the concentrations of the products and reactants will be constant.

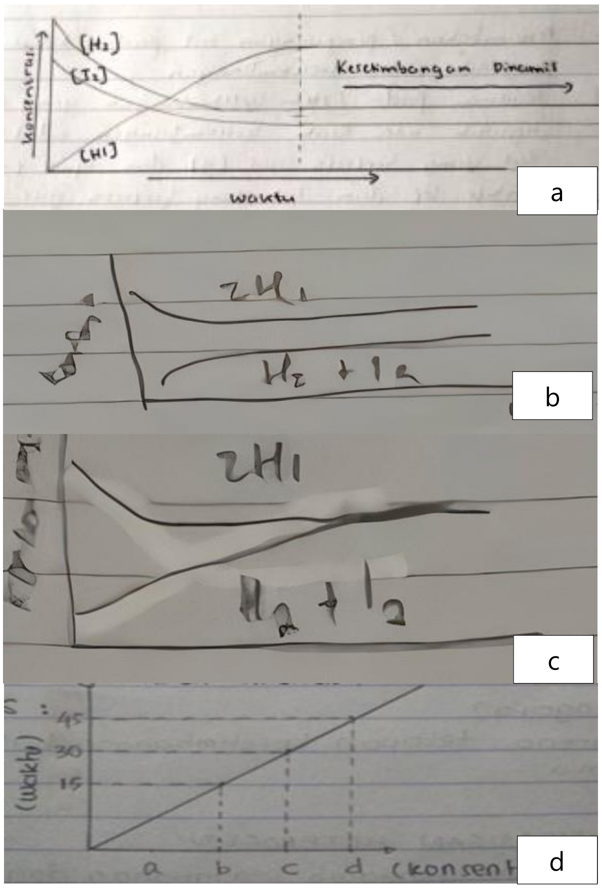


Figure 2. Students' Mental Models on the Concept of Chemical Equilibrium (a) Category 4 (b) Category 3 (c) Category 2 (d) Category 1

Based on interviews, students with the target mental model category also described and explained the graph of the relationship between concentration and time well (Figure 2a), while students with intermediate mental model 3 (Figure 2b) could only describe the graph between concentration and time, but could not yet fully explain. Students with intermediate category 2 (Figure 2c) drew a graph of relationship between concentration and time, but there were still doubts about the answer. Students with intermediate category 1 (Figure 2d) provided a picture of the relationship between concentration and wrong time.

3.2. Mental Models of Equilibrium Constant

The percentage of target mental models in both schools was higher in the experimental class than in the control class. It shown in Table 2.

Table 2. Mental Models of Equilibrium Constant

School	Mental Models	Mental Models of Equilibrium Constant	
		Experiment Group (%)	Control Group (%)
SMAN 3 Padang	Target	66,66	54,28
	Intermediate 3	16,67	22,85
	Intermediate 2	16,67	20
	Intermediate 1	-	2,86
	Unclear	-	-
SMAN 13 Padang	Target	51,61	31,25
	Intermediate 3	32,25	31,25
	Intermediate 2	9,67	18,75
	Intermediate 1	3,22	15,62
	Unclear	3,22	3,12

Students with target mental model answered questions correctly with the right reasons, but students with other types of mental models had an understanding that is not correct so that the answer was wrong with the right reason or vice versa and wrong in both the answer and the reason.

Students with an incorrect understanding had several patterns in constructing their thoughts about the equilibrium constant, including the equilibrium constant will change with the addition of the number of products at a fixed temperature, eventhough every chemical equilibrium reaction has a fixed equilibrium constant value at a certain temperature. In addition, students assumed that an increase in temperature will increase the value of the chemical equilibrium constant.

In the experimental class, learning activity by using the module at the data collection and organization stage presented data from the experimental results of the $N_2O_4 \rightleftharpoons 2NO_2$

equilibrium reaction which showed that different equilibrium concentrations do not affect the equilibrium constant at a certain temperature. Then, the module also guided students through structured questions to prove for themselves that different equilibrium concentrations in the same reaction and the same temperature do not affect the value of the equilibrium constant.

Thus, students are no longer confused when asked about the equilibrium constant. In the module, students were guided to understand the meaning of the equilibrium constant by presenting molecular pictures of a chemical equilibrium reaction and then counting the number of reactant and product molecules at a certain equilibrium constant value.

Furthermore, students were directed to determine the relationship between the equilibrium constant value and the temperature of an equilibrium reaction, so that students understand that temperature affects the value of the equilibrium constant of an equilibrium reaction, but it cannot be concluded that the higher the temperature, the higher the value of the equilibrium constant.

Based on interviewing students with the target mental model, they explained well about the meaning of the equilibrium constant. Students with intermediate mental model 3 could answer questions correctly but with incomplete reasons. Students with intermediate mental model 2 answered correctly, but the reasons were not correct. Students with intermediate mental model 1 answered correctly with the wrong reasons. Students with unclear mental models answered incorrectly.

3.2 Heterogeneous Equilibrium Mental Models

In Table 3, the experimental class has a higher percentage than the control class of students with the target mental models. Students with target mental model could explain well that solids do not affect the equilibrium system because the volume of solids is the volume of the object and not the volume of the container so the concentration does not change eventhough the volume changes. A good understanding will be achieved if students can interconnect the three levels of representation, namely the macroscopic level, the submicroscopic level, and the symbolic level (Jaber & BouJaoude, 2012).

In the question of heterogeneous equilibrium, there are three levels of representation, but not all students can understand them. If students are able to understand the three levels of representation, then students can answer questions with the right answers and the right reasons. However, students understand that the addition of solids will increase the number of products because the added solids will be decomposed into products. The same thing is also found in Özmen's research (Özmen, 2008).

Table 3. Heterogeneous Equilibrium Mental Models

School	Mental Model	Heterogeneous Equilibrium Mental Model	
		Experiment Group (%)	Control Group (%)
SMAN 3 Padang	Target	58,33	3,14
	Intermediate 3	19,44	34,28
	Intermediate 2	22,22	22,85
	Intermediate 1	0	11,42
	Unclear	0	0
SMAN 13 Padang	Target	35,48	18,75
	Intermediate 3	45,16	34,37
	Intermediate 2	9,67	28,12
	Intermediate 1	6,45	9,37
	Unclear	3,22	9,37

Based on interviews, students with intermediate 3 mental model understood that solids do not affect the chemical equilibrium system but could not explain the reasons.

Students with intermediate 2 mental model stated that the reaction occurs in the gas and liquid phases only. Students with intermediate 1 mental model assumed that solids do not affect the equilibrium system because they do not participate in the reaction. Students with unclear mental models did not clearly understand that solids are decomposed when they react, so solids affect the equilibrium system.

3.3 Mental Models of Azas Le Chatelier

The students' misunderstanding of Le Chatelier's principle is that students are confused about whether the equilibrium shifts towards the products or the reactants, especially on the effect of temperature. When there is an increase or decrease in temperature, students do not pay attention to whether the reaction is exothermic or endothermic. Table 4 show the mental models of Azas Le Chatelier from SMAN 3 Padang and SMAN 13 Padang

Table 4. Mental Models of Azas Le Chatelier

School	Mental Model	Mental Models of Azas Le Chatelier	
		Experiment Group (%)	Control Group (%)
SMAN 3 Padang	Target	69,44	51,43
	Intermediate 3	19,44	20
	Intermediate 2	8,33	22,86
	Intermediate 1	2,78	5,71
	Unclear	0	0
SMAN 13 Padang	Target	41,93	28,12
	Intermediate 3	29,03	18,75
	Intermediate 2	22,58	34,37
	Intermediate 1	6,45	9,37
	Unclear	0	9,37

The delivery of Le Chatelier principle material in the module is equipped with three levels of representation so that students do not only memorize the system experiencing a shift to products or reactants but students through structured questions are also directed to be able to interconnect the three levels of representation. Students with target mental models could explain well about Le Chatelier's principle, but students with other types of mental models clarified by the rote system and even some students were wrong in giving answers.

Overall, students in the experimental class had a better understanding than those in the control class of chemical equilibrium material. The fundamental difference in the learning process is the provision of a structured inquiry-based chemical equilibrium module with the presentation of three levels of representation. The existence of the module helps students understand the material that has been taught by studying outside class hours. Independent learning by using modules can provide space for students to learn with their learning style. Learning styles that are matched with appropriate learning methods will significantly affect student learning outcomes and performances (Buckley & Doyle, 2017). One of the limitations of learning in schools is that teachers cannot facilitate students to learn with each student's learning style because each student has a different learning style. This limitation can be helped by the existence of a module that facilitates independent learning. In addition, learning at school has limited time so students with slower learning speeds can be helped by the module.

The learning process with the module is also helped by the structured inquiry learning model adopted into the module. The structured questions in this module help students in finding concepts, especially on difficult materials such as chemical equilibrium material (Karpudewan et al., 2015; Özmen, 2008). The results of Su-Chi Fang's research (2016) showed that students' understanding of conceptual knowledge is getting better, meaningful, and interconnected after learning use a structured inquiry model. Learning with structured inquiry is also able to make students obtain a better understanding of a concept and remember information for a longer time, as well as directing students to sustainable knowledge (Schmid & Bogner, 2015).

In addition, the module is also equipped with three levels of representation in the form of colored pictures that affect the interest of students to learn it (Jalius et al., 2013). The presentation of these three levels of representation is so that students learn how to construct their knowledge from real phenomena (macroscopic level) to abstract levels (symbolic level). In the process of constructing this knowledge, structured questions also play a role in guiding students to interconnect the three levels of representation.

Students tend to find it difficult to understand at the submicroscopic level (Davidowitz et al., 2010; Li & Arshad, 2014), so the submicroscopic level delivery in the module is made by modeling such molecular shapes. This modeling is used to analogize the submicroscopic level that is not visible to the senses. Scientists often use analogies to explain abstract scientific concepts or when they develop their mental models (Coll et al., 2005). Therefore, three levels of representation in the module helps students build a complete mental model. The correlation data between mental models and learning outcomes is showed in Table 5.

Table 5. Correlation Between Mental Models and Learning Outcomes

School	Variable	R_{count}	r_{table}	Sig
SMAN 3 Padang	Mental Model → Learning Outcomes	0,752	0,230	0,05 (5%)
SMAN 13 Padang	Mental Model → Learning Outcomes	0,550	0,244	0,05 (5%)

Mental models are closely related to learning outcomes. Complete mental models identify that understanding of the material is also comprehensive so that it affects learning outcomes. As the results of trials in this study showed a correlation between mental models and learning outcomes. The experimental class which has better mental model results than the control class also has better learning outcomes. Thus, the mental models were directly proportional to the learning outcomes.

4. Conclusion

This study used a post-test control plan only carried out at two schools. In the design, there were two groups in each school, the experimental group and the control group. The two-tier diagnostic test instrument was used to test the mental models of 134 students. The results of the t_{test} for each school were 0.008 at SMAN 13 Padang and 0.011 at SMAN 3 Padang, with a 0.05 significance level. This study concludes that a structured inquiry-based chemical equilibrium module with three levels of representation can influence students' mental models.

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