The Binary System Laboratory Activities Based on Students Mental Model

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Abstract. Generic science skills (GSS) are required to develop student conception in learning binary system. The aim of this research was to know the improvement of students GSS through the binary system laboratory activities based on their mental model using hypothetical-deductive learning cycle. It was a mixed methods embedded experimental model research design. This research involved 15 students of a university in Papua, Indonesia. Essay test of 7 items was used to analyze the improvement of students GSS. Each item was designed to interconnect macroscopic, sub-microscopic and symbolic levels. Students worksheet was used to explore students mental model during investigation in laboratory. The increase of students GSS could be seen in their N-Gain of each GSS indicators. The results were then analyzed descriptively. Students mental model and GSS have been improved from this study. They were interconnect macroscopic and symbolic levels to explain binary systems phenomena. Furthermore, they reconstructed their mental model with interconnecting the three levels of representation in Physical Chemistry. It necessary to integrate the Physical Chemistry Laboratory into a Physical Chemistry course for effectiveness and efficiency.

1. Introduction

Physical chemistry is a branch of chemistry that is studied in college. Physical chemistry can be interpreted as a study based on the principles of physics and mathematical language that determines the properties and behavior of chemical systems. It can be studied at the level of macroscopic, sub-microscopic and symbolic. Students when studying physical chemistry that refers to the phenomena observed (macroscopic), then they can explain the phenomenon through sub-microscopic explanation. It explains what was observed at the macroscopic level, using things like the movement of electrons, molecules, atoms, or ions in sub-microscopic ways. Explanation at sub-microscopic level strongly supports by symbolic explanation that can be derived as formula or equation of phenomena observed. Students need to interconnect the phenomenon of macroscopic, sub-microscopic and symbolic in studying Physical Chemistry. It is intended that the students have a holistic understanding of the chemical [1]. The ability of students to interconnect those levels reflects their mental models [2]. Conception is often viewed as a mental model therefore it also describes someone conception [3]. Researches on the students conception or comprehension in studying Physical Chemistry describes their mental models are considerably varied. Several studies identified that students had alternative
conceptions, misunderstandings and misconceptions about some topics of Physical Chemistry [3-14]. Binary system is part of phase equilibrium that studied in Physical Chemistry. The results of research concerning student mental model about phase equilibrium showed that most of the students had three mental models of vapor pressure. It showed an alternative conceptualization of the entity or the properties of vapor pressure and connectedness in the system [12]. There was misunderstanding of the concept of evaporation, melting, the effect of temperature and pressure on the transitions phase. Although students understanding were inadequate [5].

The analysis of research result about binary system showed that all researches were focused on the study in the laboratory [15-16]. These researches focused on investigating the behavior of binary systems with emphasis on the symbolic level of the data obtained in the laboratory. In thermodynamics, closed system is an equilibrium condition if it fulfills the criteria of thermal, mechanical, and chemical equilibrium. We suppose the closed system which is in thermal and mechanical equilibrium in $P-V$ work only has not yet reached phase equilibrium. A two-phase system is exemplified $\alpha$ phase and $\beta$ phase. In certain conditions, if $T^* > T^\beta$, heat flows spontaneously from $\alpha$ phase to the $\beta$ phase until the temperature in both phase is the same ($T^\alpha = T^\beta$). If $P^* > P^\beta$, “work” flows spontaneously from $\alpha$ phase to the $\beta$ phase until $P^\alpha = P^\beta$. Similarly, if $\mu^\alpha > \mu^\beta$ then $i$ component in the system flows spontaneously from $\alpha$ phase to the $\beta$ phase until $\mu^\alpha = \mu^\beta$ [17]. Two component systems that may exhibit two liquid phases are often discussed in relation to Gibbs phase rule [18]. Students regularly have difficulty with interpretation of a $T-X$ diagram and the implication of the Gibbs phase rule. At a temperature and bulk composition within the immiscible region, coexisting liquids, $Liq_A$ and $Liq_B$, are connected by tie line at their compositions ($x_1$ and $x_2$ respectively). The Lever rule is used to determine their relative amounts (because the Gibbs phase rule says nothing about quantities), nothing that length of Lever arm inversely correlates with amount [19]:

$$\frac{Liq_A}{Liq_B} = \frac{x_2 - x_0}{x_0 - x_1}$$

Binary system practices based on students mental model using hypothetical-deductive learning cycle is one of the efforts that have been made to learn them on this matter by interconnect three levels of representation. Students should be examined their hypothesis against their scientific concepts and determine the appropriate results of the investigation in the laboratory through hypothetical-deductive reasoning and experimentation. This approach required that students had to meet their intellectual needs in improving understanding of the concept and improve thinking skills [20]. Based on this, students activities in laboratory facilitate the increasing of GSS. GSS are important for learners to develop skills in their discipline area. Some GSS indicators are logical self-consistency, concept formation, direct observation, mathematic modeling, and symbolic language [21]. Generic skills are “employability” skills used in the application of knowledge. The degree to which students develop these skills determine solving problems, writing reports, functioning in teams, self-assessing and performing reviews of others, learning new knowledge, and managing stress in confronted with change [22]. Overall, the purpose this study was to determine the improvement of students GSS through the binary system laboratory activities based on their mental model using hypothetical-deductive learning cycle. However, research on how to learn and improve GSS of students by interconnect the three levels of representation in the binary system has never been done previously.

2. Methods
This study was a mixed methods embedded experimental model research design [23]. This research involved 15 students in chemistry education department of a university in Papua, Indonesia. They were divided into six groups (2-3 students per group) based on similar students initial mental models. The students initial mental model was seen from the individual hypothesis formulation on their worksheets. Two students groups worked on the same binary system. Binary system was used in this study were acetic ethyl and water, 1-butanol and water, also cyclohexane and water systems. Those students designed laboratory activities collectively in their own group and consulted it to their lecturer. Lecturer
observed students activities during investigation in laboratory and providing guidance if necessary. Students made discussion about anything they found in the investigation. Lecturer facilitated the class discussion at the next meeting. During the class discussion, students of other group were given the opportunity to give their response. Otherwhile the stages of binary system practices based on mental model to improve students GSS was presented in Table 1.

| Stages of learning | Students Activity |
|--------------------|-------------------|
| Engagement phase   | Students were given binary system phenomena to create cognitive conflict and motivated them to conduct practical activities. |
| Exploration phase  | Students developed hypotheses (if.....then......) based on the issues contained in the passages individually and evaluated each hypotheses, selecting hypotheses to be tested. |
| Explanation phase   | Students designed a binary system laboratory activities to test the hypotheses that had been formulated. Having decided upon the experimental method to be used. They made observations and measurements to collect data. |
| Elaboration phase   | Students made discussion about anything they found out in the investigation. Analysis of the laboratory results allows for hypotheses was rejected or retained. Lecturer helped in facilitating class discussion in the next meeting. During the in-class discussion, students of group should be responded. |

Written test which used to analysis the improving of students GSS was essay form. It was consists of 7 items. Each questions and answers was designed to interconnect macroscopic, sub-microscopic and symbolic levels. The results showed the validity of question number 2 and 6 were revised while five others were valid. The reliability of this test was 0.78 and was considered high [24]. The Increase of students GSS could be seen from their N-Gain. The N-Gain value formula as $<g>=\frac{(post-test –pre-test)}{max –pre-test} \times 100\%$ [25]. N-Gain value adapted in percentages [26]. The results were then analyzed descriptively. The GSS indicators which were enhanced in each stage of learning in the binary system were presented in Table 2.

| Stages of Learning | GSS Indicators |
|--------------------|----------------|
| Engagement and exploration phase | Logical self-consistency |
| Explanation phase   | Concept formation |
| Elaboration phase   | Indirect observation |
|                     | Mathematical modelling |
|                     | Symbolic language |
|                     | Logical self-consistency |

3. Results and Discussion

3.1. Results
Students were grouped by similarity of their initial mental model based on their hypothesis formulation in their worksheets. Each group designed laboratory activities of binary systems by themselves. They did investigation in the laboratory to prove their hypothesis created. All students of six groups managed to obtain data on each model of liquid-liquid equilibrium of two components, i.e.
the liquid-liquid equilibrium system of acetic ethyl and water, 1-butanol and water, and cyclohexane and water systems. Students skills in deciding temperature system from cloudy mixture turned clean through indirect observation influenced the accuracy of the data. These skills can only be trained to students through laboratory activities (hands on). Students mental model was improved from this study. Example reconstruction of student initial mental model through this model was presented in Table 3.

### Table 3. Reconstruction of Student Initial Mental Model

| Macroscopic Level | Symbolic Level | Interconnection of macroscopic and sub-microscopic Levels | Symbolic Level |
|-------------------|----------------|-----------------------------------------------------------|----------------|
| Adding water into 1-butanol will yield two layers. | Adding 3.2 ml water into 5 ml 1-butanol yield two layers. | Example, top layer is symbolized as α and bottom layer as β, so that $\mu_\text{water}^\alpha = \mu_\text{water}^\beta$ and $\mu_{1\text{-butanol}}^\alpha = \mu_{1\text{-butanol}}^\beta$. |

Based on Table 3, at first, student only interconnected macroscopic and symbolic levels to explain binary systems phenomena. Furthermore, student reconstructed their mental model with interconnecting the three levels of representation. The results of the increasing students GSS was presented in Table 4.

### Table 4. The Increasing of students GSS in binary system

| No. | GSS Indicators        | Item | N-Gain, % |
|-----|-----------------------|------|-----------|
| 1.  | Logical self-consistency | 1    | 44.70     |
|     |                       | 5    | 12.89     |
|     |                       | 6    | 43.89     |
| 2.  | Concept formation     | 2    | 34.13     |
| 3.  | Indirect observation  | 3    | 47.67     |
| 4.  | Mathematic modelling  | 4    | 56.84     |
| 5.  | Symbolic language     | 7    | 38.89     |

According to Table 4, all students GSS in binary system was improved. Logical self-consistency indicator that increased in this research was to find out logical relation between two rules or more. After the implementation of this learning model, there were an increase of the N-gain for the logical
self-consistency of 44.70% for item 1 (moderate category), 12.89% for item 5 (low category), and 43.89% for item 6 (moderate category). Concept formation develops further the idea of an object or process in order to understand a phenomenon that cannot be done with daily conversational language. The results showed an increase of 34.13% (moderate category). Indirect observation in this study was enabling the students to determine the temperature system by using thermometer (item 3). Students also trained to be able to explain at the sub-microscopic level about the increasing of temperature system until cloudy mixture disperse. The N-gain increase after the implementation of this learning model was of 47.67% (moderate category). Mathematic modeling is a formula that describes the law for the natural phenomena using mathematic language. Being able to formulate with this language is an application of mathematical modeling. The N-gain increase for the mathematical modeling indicator was of 56.84% (moderate category). Symbolic language is the language used to talk about natural phenomenon that cannot be expressed with plain conversational language. The indicator of the symbolic language that increased in this study was when determining the upper absolute temperature of n-hexane and water system based on the curve gained (item 7). The rise of the N-gain of the symbolic language was of 38.89% (moderate category).

3.2. Discussion
A number of approaches to generic skill development have been formulated and proven to be effective in science and engineering education [27]. Similarly, the result has shown that there was an increase in students GSS for five indicators which focused of this research. The indicators mentioned are logical self-consistency, concept formation, indirect observation, mathematical modeling, and symbolic language. Specifically, the highest increase of students GSS occurred on the mathematic modeling with the result of 56.84% (moderate category). While, the lowest one was 12.89% (low category) occurring on the logically self-consistency. These indicate that students mental model based learning of binary system via hypothetical-deductive learning cycle can enhance students GSS. Such learning accommodates students in conducting experiments at laboratory by interconnecting the levels of macroscopic, sub-microscopic, and symbolic for their meaningful knowledge and skill gains. The understanding chemistry on the macroscopic, sub-microscopic, and symbolic levels is necessary for the development of students skills like the capacity for abstraction, logical reasoning, and the understanding of natural phenomena and themselves in the world [28]. The researches show the importance of discussing this topic and for researchers to help teachers improve their class work.

In addition, most of students prefer conducting experiments because they can obtain valuable skills such as a skill to solve contrary data. Such laboratory activities can improve the mental process of learners dealing with science. They can examine their assumptions towards the scientific concepts and identify them based on findings of the research via deductive hypothesis considerations and experiments [29]. The primary emphasis of laboratories should not be limited to learning certain scientific methods or laboratory techniques, but rather laboratories should allow students to investigate phenomena by using the methods and procedures of science thereby enabling them to solve problems [30]. Learners can learn to think better if they are learning by doing. In this respect, the majority of science programs assume that a laboratory study is a stepping stone due to students’ active learning engagement. Moreover, this laboratory activity can be categorized into the student-learning centered strategy [29]. The development of any skills is best facilitated by giving students practice and not by simply talking about or demonstrating what to do [27].

This study indicates that the enhancement of students GSS on logically self-consistency indicator was the lowest. In this respect, students understanding about Lever rule to determine each component into two phases and their understanding about intermolecular forces influenced their generic science skills achievement. Students have alternative conceptions about intermolecular forces [11]. So, this concept was a difficult concept. It is abstract concept. Besides that, students must become able to not only interpret symbolic expressions and perform mathematical manipulations but they must also develop an understanding of the physical significance of the symbolic representations. As instructors of chemistry, we hope that students become able to interpret and work with mathematical expressions.
such as this with understanding, not just routinely apply algorithms and formulae. However, instructors should be aware of how these symbolic forms contribute to student reasoning in various contexts if they are to meaningfully facilitate student’s reasoning with such inscriptions [6].

4. Conclusion
Students mental model and generic science skills were improved from this study. They were interconnect macroscopic and symbolic levels to explain binary systems phenomena. Furthermore, they reconstructed their mental model with interconnecting the three levels of representation in Physical Chemistry.

Acknowledgments
The researchers show gratitude to the chairperson of Chemistry Education Department, the head and assistants of Chemistry Laboratory, Universitas Cenderawasih in Jayapura Papua for their facility supports towards the process of this study. The appreciation is also forwarded to the students who were willing to be the subjects of this research.

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