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# Representational Competence's Profile of Pre-Service Chemistry Teachers in Chemical Problem Solving

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## Abstract

*A preliminary study on the possibility of developing representational competence pre-service chemistry teachers has been done. The aim of this descriptive study was to provide description about representational competence's profile of pre-service chemistry teachers in chemical problem solving and to give consideration about the learning strategy have been conducted. The results showed that most students were unable to provide explanations relating to the representation of sub-microscopic level, which exist between the macroscopic and symbolic levels of representation. There were tendency those students solved problems using a transformation from the macroscopic to the symbolic level of representation and vice versa. Although they should give explanation at sub-microscopic level of representation, they did not understand the role of sub-microscopic representation to explain the macroscopic level or transformed into symbolic level. Presumably, the lack of student representation competence, because the lectures were held tend to separate the three levels of representation and influence the learning process, which they experienced in senior high school. Those problems need serious efforts to find solution.*

**Key Words** : *Representational competence, three levels of chemical representation, chemical problem solving*

## Background

Currently, there is growing agreement among science educators that learning science requires representational practices of this subject matter. Scientific literacy means as knowing how to interpret and construct this literacy of science. From this perspective, learning concepts and the scientific method requires understanding and conceptualization linking multiple representations of this domain (Norris & Phillips in Waldrip, 2006).

Problem-solving ability as one of the high-level thinking skills uses representational competence (Waldrip, 2006; Kozma, 2005). Russel & Bowen (In Davidowitz & Chittelborough, 2009) have identified representational competence (the ability of student to transform representation in one form to equivalent representations in another) as an important aspect of successful problem solving in chemistry. In problem solving context, Bodner and Domin (in Rosengrant, Van Heuleven, & Etkina, 2006) distinguish between internal representations and external representation. Internal representation is a way of solving a problem by store the internal components of the problem in mind (mental models). External representation is something related to representation of symbols or objects and/or processes. In this case, the representation is used to recall the mind through the description, portrayal or imagination (Chittleborough & Treagust, 2006).

The characteristics of chemistry involve three levels of chemical representation, i.e. macroscopic representation, submicroscopic representation and symbolic representation.

a) Macroscopic representations are chemical representations obtained through actual observation (tangible) of phenomena that can be seen (visible) and perceived by the senses (sensory level) or can be a daily experience of learners. For examples: color and temperature change, pH, formation of gases and precipitates in chemical reactions that can observe when chemical reactions take place. The learner could represent the observations or lab activities in a variety of modes of representation, for example as written reports, discussions, verbal presentations, vee diagrams, graphs and so on.

b) Submicroscopic (or molecular) representations provide explanations at the particulate level. Submicroscopic representations closely related to the underlying theoretical model to dynamics explanation of the particle level (atoms, molecules, and ions). Modes of representation at this level can express start from the simple to use computer technology e.g. using words, two-dimensional, three-dimensional images both still and moving (animation) or simulation.

c) Symbolic (or iconic) representations are representation to identify of entities (e.g. those involved in a chemical reaction) using qualitative and quantitative symbolic language, such as a chemical formula, diagrams, pictures, equation, stoichiometry, and mathematical calculations.

(Chittleborough & Treagust, 2007; Chandrasegaran, et.al, 2007).

The three levels of chemical representation are containing inter-connectedness information. While the macroscopic observable chemical phenomena are the basis of chemistry, explanations of these phenomena usually rely on the symbolic and submicroscopic level of representations.

Consequently, the ability of learners to understand the role of each level of chemical representation and the ability to transfer from one level to another is an important aspect of generating understandable explanations.

The simultaneous use of macroscopic, submicroscopic, and symbolic representations has been shown to reduce learners alternative conceptions in the teaching and learning of chemical concepts.

Connecting of the three levels of representations in teaching will give contribution to construct students understanding about chemical phenomena that occur in laboratory scale and daily life experience. In such way, they can use their concept to solve chemical problem.

Generally, teaching and learning was restricted to level of macroscopic and symbolic representations. Many high schoolteachers tend only use macroscopic level and symbolic levels. They do not integrate the three representations in their teaching but move among representational levels without highlighting their inter-connectedness.

Teachers often assume the students are able to connect symbolic to submicroscopic representations on their own. (Tasker, 2006). The use of chemical models are not always appreciated by linking them with two real targets; submicroscopic and macroscopic levels.

Often, the models were seen as a comprehend symbol in mathematical context. Students solved mathematical problems became criterion that student have understood chemical concepts. Presumably, those views could hinder students to achieve representational competence.

Reviews of various empirical studies supported those statements; Devetak, eet.al(2004) stated that first year students had difficulty to describe the scheme and transfer of symbolic to submicroscopic representation in acid-base equilibrium.

Case study conducted by Murniati & Sopandi (2007), showed that high school students have difficulty to represent submicroscopic levels of ionic equilibrium in a weak acid, weak base, hydrolysis of salts, and buffer solution.

Savec, et, al, (2006), Weerawardhana, et.al, (2006) and Akselaa & Lundell, (2008) argued separately these problems due to lack of ability of teachers using various modes of submicroscopic representation and connecting these to the other level of representation.

Students' representational competence tied to learn process in classrooms, practical laboratory and textbooks. The teacher or pre-service chemistry teacher must achieve to internal connection of three levels of representations, as well as re-representing of three levels of representations in their teaching (external representation).

Therefore, they must develop two dimensions of representation, i.e., internal representation and external representation.

Based on consideration that the effectiveness of teaching and learning in school depend on teachers' competence, so the institutions of higher education of teaching have a task to improve quality of their graduates teacher.

One of the efforts is to provide pre-service chemistry teachers with ability of three levels of representation so they can become professional teachers later.

The theoretical and empirical studies need to be conducted before developing learning model design to achieve best results. Therefore, researcher conducted empirical studies at a teacher education program located at Bandung.

The main focuses of this descriptive research method was to acquire representational competence profile's of pre-service chemistry teachers in chemical problem solving and implementation of relevant lectures have been conducted to develop representational competence of pre-service chemistry teachers.

## Method

This research was a part of research and development (R & D) that involve four phases, i.e. preliminary study, design of model, validation and implementation phase. In preliminary research carried out theoretical studies and empirical studies. Research methods used in the first phase was descriptive research method.

Theoretical studies covered to analysis of characteristics of chemical concepts, mapping relationship among concepts and level of chemical representation. For this purpose, researcher chose chemical equilibrium in aqueous solution concept for study, because this concept included one of difficult concept to understand and to teach based on three levels of chemical representation at senior high school.

Empirical studies conducted through field studies at teacher training program that focused on representational competence profile of pre-service chemistry teacher in chemical problem solving and implementation of relevant lectures have been conducted to develop representational competence of pre-service chemistry teacher.

Collection data were done through:

a) Observation of implementation of relevant courses,
b) Distribution of questionnaires to acquire pre-service chemistry teachers feedback on the implementation of courses which have been going on,
c) Interviewing lecturers.
d) Administer of test to acquire representational competence profile of pre-service chemistry teacher in chemical problem solving.

There are four category transform levels of representations i.e. ability to transform level of macroscopic to symbolic representation, level of macroscopic to submicroscopic representation, level of submicroscopic to microscopic representation and level of submicroscopic to symbolic representation.

Two test types were used to obtain ability of transform among level of representation to solve chemical problem i.e. multiple choice with reason of choice and essay tests.

The set of test were administered to 78 pre-service chemistry teachers (sixth semester). Interview to nine pre-service chemistry teacher (randomized chosen) was done to acquired detailed data.

## Result and Discussion

### *The Characteristics of Concept of Chemical Equilibrium in Aqueous Solution*

The concept of chemical equilibriums in aqueous solution is application of key concept of chemical equilibrium. Contextually, this concept plays a crucial role in many biological and environmental processes. For example, the pH of human blood is carefully controlled at a value of 7.4 by equilibrium involving, primarily, the conjugate acid-base pairs ($H_2CO_3$ and $HCO_3^-$).

The pH of many lakes and stream must remain near 5.5 for plants and aquatic to flourish. The process of formation kidney stones also involves the concept of chemical equilibrium, etc. These phenomena require understanding, which involves three levels of representation.

Results of concept analysis, show that there are three of concept type in main concepts of Chemical Equilibriums in Aqueous Solution, i.e.

a) Abstract concepts with concrete examples.
b) Concepts by process .
c) Concepts by principle.

The Levels of representations include macroscopic, submicroscopic, and symbolic representations. Those concepts are complex enough, because they need prerequisite concepts covered three levels of representations, i.e.

a) Proton transfer reaction (Bronsted-Lowry acid-base concepts),

b) Weak acid, weak base and water dissociation,
c) The strength of acid-base and ph,
d) Solubility.

Those prerequisite concepts must be understandable to achieve three main concepts, i.e. 1) salt hydrolysis; 2) buffer solution; 3) solubility equilibrium.

Equilibrium constant (K) is the key concept to connect three of main sub concepts in chemical equilibrium in aqueous solution. The value of K shows to measure of dynamic equilibrium occurrence. At equilibrium, reactions take place continuously with same rate reactions for both directions, between the product formation and decomposition. Chemical equilibrium is represented symbolically with value of K (equilibrium constant). The equilibrium process is represented in term of mathematics and chemical notation with two-way arrows. In chemical equilibriums in aqueous solutions, K value can be expressed with Kh, Kw, Kb, Ka and Ksp. That's various values for K refer to different processes of dynamic equilibrium type occur in aqueous solution i.e. salt hydrolysis, buffer solution and solubility equilibrium. (Table 1 is describing result of concept analysis for main concepts).

**Table 1 Result of Concept Analysis for Main Concepts**

| No | Main Concept | Sub Concept | Concept type | Level of Representation |
|---|---|---|---|---|
| 1. | Equilibrium Constanta (K) | Ka, Kb, Kw, Kh, Ksp | Concept by principle | Macroscopic<br>Symbolic |
| 2. | Dynamic equilibrium | Chemical Equilibriums in Aqueous Solution | Concept by process | Submicroscopic<br>Symbolic |
| 3. | Chemical Equilibriums in Aqueous Solution | Salt hydrolysis,<br>buffer solution,<br>solubility equilibrium. | Concept by process | Macroscopic<br>Submicroscopic<br>Symbolic |
| 4. | Salt hydrolysis | Totally hydrolysis, Partly hydrolysis : cation and anion hydrolysis | Concept by process | Macroscopic<br>Submicroscopic<br>Symbolic |
| 5. | Buffer solution | Acid buffer solution Base buffer solution | Abstract concepts with concrete examples | Macroscopic<br>Submicroscopic<br>Symbolic |
| 6. | Solubility equilibrium | Saturated Solution<br>Solubility<br>Common ion effect | Concept by process | Macroscopic<br>Submicroscopic<br>Symbolic |

The concepts of dynamic equilibrium belonging to level of submicroscopic representation can be used to explain equilibrium phenomena in solution. The concepts are internally hard to be learned and taught.

The process of dynamic equilibrium in the electrolyte solution between dissolve ions and insoluble molecules or particles will be difficult to be understood and imagined when it is only explained by using words or two-dimensional static images or only symbolically expressed by using the equation.

On the other hand, exploration of this concept through a macroscopic representation (for example; the lab activity) could not show the actual dynamics that occur at submicroscopic level.

**Result of Empirical Study**

There are four categories of representation, which traced the transformation levels in this study i.e. the ability to transform

a) level of macroscopic to the symbolic representation,
b) level of macroscopic to submicroscopic representation,
c) level of submicroscopic to the symbolic representation
d) level of submicroscopic to the macroscopic representation.

The main findings of pre-service students representation competence in solving chemistry problems are below:

***The ability to transform level of macroscopic to symbolic representation***

The ability to transform the macroscopic to the symbolic level expressed through a series of questions that show macroscopic representation, i.e. the characteristics or physical phenomena derived from the observation / measurement, such as Ka / Kb data, solution molarity, solution volume, solution properties (acidic or alkaline), size of the substance.

Using these data the students were asked to solve problems related to the symbolic level that is; using the equation and solve chemical calculations.

The results of data analysis, show that as many as 70% of students (N = 78) are able to solve problems regarding:

a) the relationship between the strength of the acid / base and a value of Ka / Kb,
b) calculate the pH of the reaction product between a weak acid and a strong base with a molar equivalent amount,
c) calculate the pH of a buffer solution based on the reaction of weak acid and strong base,
d) calculate the pH of salt solution which undergoes hydrolysis,
e) express the equation of solubility equilibrium of the saturated salt solution which is difficult to dissolve,
f) calculate the solubility of saturated salt based on the value of Ksp data.

It shows most of the students can transfer the macroscopic to the symbolic level of representation.

Students who are unable to provide the right solution, including:

a) cannot be relate between the value of Ka/Kb data and the strength of the acid/base,
b) consider the results of acid-base neutralization reaction with a molar equivalent amount always generating a neutral salt (do not consider the power pairs acid or its conjugate base),
c) Wrong calculation operations and convert its chemical formula to the equation Ksp.

***The ability to transform level of macroscopic representation to submicroscopic***

This ability is expressed by the students' ability to provide a sub-microscopic explanation of macroscopic phenomena:

a) how the buffer solution to maintain the pH of the solution,
b) the occurrence of hydrolysis reaction of salt,
c) the phenomena of saturated solution and
d) common ion effect on the saturated solution.

As many as 60% of students give explanation the properties of buffer solution by using arguments based on the symbolic level of representation. They proved through calculation of pH of the solution when add slightly acidic or alkaline solution, both, before, and after it happens.

Their answers have not linked explicitly with common ions effect (due to the addition of slightly acidic or alkaline solution) and proton transfer reactions that cause a shift in equilibrium (sub-microscopic level). Other students who cannot solve the problem stated that buffer solution could keep up pH stable, because it contains a mixture of weak acid and its salts.

Almost all students (90%) gave explanation about the properties of the acidity or alkalinity of a solution of salt based on the origin of salt-forming acid or base. They claim $CH_3COONa$ is alkaline, because the salt is derived from the neutralization reaction of strong base (NaOH) and weak acid ($CH_3COOH$).

About 40% of students completed these answers by writing $CH_3COONa$ hydrolysis reaction. They stated that solution became alkaline due to formation of OH- ions. They could write the equation of the hydrolysis reaction but they could not explain how the protons transfer reaction in the hydrolysis reaction to produce OH-ions.

It shows that they have not been able to solve problem by transforming macroscopic to the sub-microscopic level, because transformation of sub-microscopic level should consider on proton transfer reactions. To determine the strength of the conjugate acid or base, they must compare value of Ka of acid or Kb of base with the value of Kw.

Allege incompetence because :

a) they cannot distinguish which one strong/weak conjugate acid / or strong/weak conjugate base;
b) the role of water solvent that can influence on the solute when dissolution occurs,
c) students usually distinguish that salt of acidic, alkaline and neutral with reference to the Arrhenius acid-base model.

Most students (80%) can explain that the solubility of salts containing the conjugate base anions will increase when pH decreases. Nevertheless the reasons given are not using a sub-microscopic arguments, but in term symbolic representation.

They can recognize the common ions in salt solution, but they cannot explain the decrease in pH can lead to transfer of protons from hydronium ion ($H_3O^+$) and strong base conjugate, thus shifting the equilibrium reaction from the left (the formation of solid insoluble) to the right (towards the formation of soluble ions).

***The ability to transform level of submicroscopic representation to symbolic and macroscopic***

To determining these capabilities, students were asked to choose the representation of sub microscopic and give reasons for the selection of answers based on the representation of symbolic and macroscopic.

Submicroscopic representation presented as image / particle models. Based on the representation of sub-microscopic, they are asked :

a) to compare the acid strength,
b) to select a representation that show the state of buffer solution and hydrolyzed salt solution,
c) to determine the stages of reaction titration of weak acid and strong base.

62 % of students are able to determine the acid is stronger than other is. They refer to the number of $H_3O^+$ ions are depicted by the sub-microscopic representation.

44% of students could choose a representation that shows the state of a buffer solution with good reason. However, none of student could select correctly, which sub microscopic representation showing the state of hydrolyzed salt solution.

47% of students can choose an appropriate representation that shows the stages of titration occurs, but the reason is not true.

Most students tend to make overgeneralization; They stated that the $A^-$ anion represents the salt which is always neutral. They do not refer to whether the anion A- is a strong conjugate base or weak (as seen from the pair of ion salts), so they fail to recognize the A- is alkaline due to hydrolysis reactions that produce OH- ions that decrease $H_3O^+$ ions concentration in solution.

The weakness of the ability of student representation also due to their learning experience at senior high school. Generally, for the three of sub-concept (buffer solution, salt hydrolysis and equilibrium solubility) teachers put more emphasis on presenting the macroscopic to the symbolic.

The results of interview of number of students revealed that teachers at senior high school taught those concepts further reinforced on the concepts relating to the calculation (the symbolic level). While the declarative concepts that actually associated with sub microscopic level more frequent be taught by method of assignment summary and answer questions. The fact is in accordance with the results of research Sopandi & Murniati (2007).

Base on the results of observations on one subject, which aims to deepen knowledge about the important chemical concepts related to learn in senior high schools. There is tendency that student were more amplified at the macroscopic and symbolic levels.

Explanation in sub-microscopic level was often ignored. Lecturer has given the reason that the explanation is related to the concept of chemical bond that will be studied in another class. Strength understanding of the sub-microscopic level using the modeling (as images and the use of molecular models molymod) is not connected to macroscopic phenomena.

Lecturer used these models only for interpretation in the context of the symbolic (showing the chemical bonds in the compound), but sub-microscopic dynamics of chemical processes are not discussed. In addition, the courses did not cover the concepts that often lead to misconceptions among high school students. In building the knowledge, interaction among students and lecturers is less developed, due to time constraints.

**CONCLUSION**

This study showed that most students have difficulties to provide explanation regarding the representation of sub-microscopic provided by macroscopic and symbolic representations.

Students tend to solve problems by using macroscopic transformation to a symbolic level, or vice versa. Students do not fully understand the role of model or drawing (sub-microscopic representations) to explain phenomena that occur at the macroscopic level and transforming them into symbolic representations.

Presumably the lack of these competencies', because their lectures tend to teach separate the three levels of representation and influence of the learning process that they experienced in senior high school .

Therefore, it is suggested, students are given the ability of chemical representation through:

a. Use of visualization tools to explain the processes that occur in a molecular (sub-microscopic) without separating its association with the symbolic representation and the macroscopic.
b. Development of course models that support the representational competence, especially at the lectures that aim to prepare teaching skill in senior high school, for example; Capita Selecta of Chemistry at School.

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