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Problem-Based Learning with Multilevel Representation: A Strategy to Master the Ionic Equilibrium in Solution Concepts

Abdul Hamid[1], Nur Hikmah[1], and Arif Sholahuddin[1*]
[1]Chemistry Education Department, Faculty of Teacher Training and Education, Universitas Lambung Mangkurat, Jl. Brigjen H. Hasan Basry, Banjarmasin, 70123, Indonesia
[*]E-mail: arif.science.edu@ulm.ac.id

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Abstract

Mastery of abstract chemistry concepts requires learning strategies to facilitate students to make mental imagery to the submicroscopic level. This study aims to analyze the differences in students' mastery of the ionic equilibrium in salt solutions concept by applying the Problem-Based Learning (PBL) model with multilevel representation. The study applied a quasi-experimental method with a pretest-posttest non-equivalent control group design. The research samples were 61 students of natural science 11th grade SMAN 6 Banjarmasin, which were determined by random cluster sampling. This test instrument is in the form of reasoned-multiple choice with a Content Validity Ratio (CVR) score of 1 (valid), reliability score of 0.96 (very high), difficulty index is moderate to difficult, distinguishing power is moderate to good, and sensitivity item is a sensitive category. Data were analyzed inferentially using an unpaired t_{test}. This research found that the PBL model with multilevel representation increased the students' thinking ability at Higher Order Thinking Skills (HOTS) levels. The student's mastery of the ionic equilibrium in salt solutions concept learned by using the PBL model with multilevel representation was better than by using the PBL model.

Keywords: ionic equilibrium in solution, multilevel representation, PBL model

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1. Introduction

Johnstone divides chemical representations into three levels, which are the macroscopic, symbolic, and submicroscopic levels (Johnstone, 1991; Gkitzia et al., 2011; Santos & Arroio, 2016). Macroscopic representation is a chemical representation obtained through real observations of a phenomenon that can be seen and perceived by our five senses or our everyday experiences. They are such as color changes, temperature, pH of solutions, and formation of gases and deposits. Submicroscopic representation is a chemical representation of the explanation of structures and processes at the particulate level (atoms/molecules) toward the observed microscopic phenomena such as the shape and movement of electrons, molecules, particles, or atoms. Symbolic representation is a qualitative and quantitative representation of chemistry, such as chemical formulas, diagrams, pictures, reaction equations, reaction mechanisms, mathematical calculations, and modeling tools. Symbolic representation is can be considered as a mediator between submicroscopic and macroscopic representations.

This multilevel representation is very important in facilitating conceptual mastery because it serves as a compliment, and a constructor of understanding and interpretation (O'Keefe et al., 2014). Multilevel representation is an effective strategy in learning (Kurnaz & Arslan, 2014). Its effectiveness as a learning strategy was proven in improving conceptual understanding, reducing difficulties in understanding the relationship between different representations, and increasing student interest in learning (Treagust, 2018). Implementation of multilevel representation was useful in improving the performance of students and increasing teaching efficiency (Milenkovic et al., 2014). This is because, the use of multilevel representation can reduce the students' cognitive load (Yakmaci-Guzel & Adadan, 2013). In general, chemistry phenomena can only be interpreted accurately and scientifically if students have reasoning and interpreting skills based on multilevel representation (Kelly et al., 2010).

Unfortunately, the chemistry learning process still tends to apply macroscopic and symbolic representation levels only. On the other hand, students try to connect the three levels of representation through the learning process individually without teacher guidance sufficiently (Chandrasegaran et al., 2007; Jaber & BouJaoude, 2012; Sunyono et al., 2015). In other countries like China, Taiwan, Hongkong, and Turkey, the chemical representations used in the textbooks were mainly macroscopic, symbolic, and hybrid and involved minimally submicroscopic representation. (Chen et al., 2019; Demirdöğen, 2017). Students still have difficulty in understanding the submicroscopic dimensions in relation to chemical concepts (Azzajjad et al., 2020). Thus, students cannot connect the three levels of representation (Nahadi et al., 2018). As a result, they fail to master the abstract chemistry concept well. It was due to their inability to visualize chemical structures and processes that occur at submicroscopic levels and in their ability to connect the multilevel representations to other chemical phenomena (Sunyono & Sudjarwo, 2018).

The particulate or submicroscopic level plays an important role in constructing the conceptual understanding in which students need to use their spatial abilities to understand chemistry concepts deeply (Barke, et al., 2012; Darmiyanti et al., 2017). Wiyarsi et al. (2018) argue that multilevel representations can bridge the students' mastery of chemistry concepts.

One of the strategies or learning models that was often used by teachers to help students in understanding and concreting abstract chemical concepts is the Problem-Based Learning (PBL) model. This learning model has the main characteristics such as training a higher order thinking, solving authentic everyday problems, and prioritizing processes over knowledge (Arends, 2012; Rahmawati et al., 2019). Learning through problem-solving in real-life causes students to develop an understanding of chemical concepts meaningfully (Desriyanti & Lazulva, 2016). Meaningful learning will facilitate the students' involvement in connecting knowledge and ideas in their cognitive structures to the new information being learned (Hofstein & Lunetta, 2004; Sholahuddin, 2015). PBL facilitates the solving of real problems which means encouraging more meaningful learning. PBL has the potential to contribute both to students’ learning outcome and their confidence (Gündüz et al., 2016). But the submicroscopic representation of phenomena tends to be neglected even though it is very important for mastering chemical concepts and preventing students’ misconceptions (Ibrahim & Jamaludin, 2019).

Several studies have been conducted regarding PBL and/or multilevel representation in learning science. Martiasari, et al. (2016) have integrated the PBL model in learning biology with multiple representations in the form of verbal (written and oral) and pictures resulting in a better understanding of concepts than the PBL one. Meanwhile, Sunyono & Meristin (2018) found that the use of the multilevel representation-based learning model resulted in better concept mastery than the PBL. In this research, the phenomenon of chemical bonds was studied in three levels of representation (macro, submicroscopic and symbolic) through visual, verbal, symbolic, or action representations. Another study by Kiswandari and Ridwan (2020) proved that the POE (predict, observe, explain) learning model has succeeded in helping students to construct mental models in salt hydrolysis learning through the solving of academic problems, but not authentic problems.

Based on previous research, most of the PBL strategies were applied to train the students' ability to solve authentic problems in a macroscopic view. This study tries to integrate all the excellences of PBL as well as the multilevel representation approach (macro, submicroscopic and symbolic), in the form of visual and symbolic, to strengthen the impact of this learning model on the students' conceptual mastery. By using this combined learning model, students will be able to represent the concept of ionic equilibrium in salt solutions at the submicroscopic level. This integration has several reasons: (1) the PBL model is very popular among educators; (2) integrating multilevel representations in PBL will strengthen students' mastery of concepts and problem-solving abilities; and (3) integrating multilevel will increase PBL's contribution to facilitating meaningful learning.

Based on the above background, this study aims to analyze and compare the students' mastery of the ionic equilibrium in salt solution concepts in chemistry class learned by using the PBL model with multilevel representation.

2. Research Method

This research applied a quasi-experimental method with a pretest-posttest non-equivalent control group design. The sample was determined by cluster random sampling. 11th grade natural science 3 was selected as the experimental class, while 11th grade natural science 2 of SMAN 6 Banjarmasin was the control class. Each class consists of 30 and 31 students respectively who were aged between 15-16 years. The learning activity of ionic equilibrium in a salt solution concept was carried out for six meetings in each class including pretest and posttest. In this study, learning in the experimental class used the PBL model with multilevel representation, while the control class used the PBL model. The learning steps of the PBL-multilevel representation model are presented in Table 2.

The test instrument for mastery of ionic equilibrium in salt solution concept used a ten items of multiple choice followed by reasoning form. The content validity of the test instrument was assessed by five validators consisting of four chemistry education lecturers and one chemistry teacher. Meanwhile, the reliability, difficulty index, distinguishing power, and item sensitivity are based on a field test for 32 students. All qualifications of the test instrument are presented in Table 1.

Table 1. Qualification of the Test Instrument

Parameter of Instrument	Score / Index	Category
Validity	CVR = 1 (*Content Validity Ratio*)	Valid Cohen & Swerdlik (2010)
Reliability	KR-20 = 0.96	High Reliability (Arikunto, 2018)
Difficulty indeks	Questions 1-3 & 9-10 (p = ***0.31-0.6***)	Moderate
	Questions 4-8 (p = ***0.22-0.29***)	Difficult (Arikunto, 2018)
Distinguishing power	Questions 1 (***P = 0.50***)	Good
	Questions 2-10 (***P = 0.25-0.38***)	Moderate (Arikunto, 2018)
Sensitivity Items	Questions 1-10 (***s = 0.32-0.88***)	Sensitive (Purwanto, 2002)

Research data were analyzed descriptively and inferentially by using unpaired t_{tests}. The N-gain score was used to analyze the increase in students' mastery of the ionic equilibrium in a salt solution concept after attending the learning process. The classification of N-gain score is $<g>$ = 0.7 to 1.0 (good category), 0.3 $\leq <g> \leq$ 0.7 (moderate category) and <0.3 (low category) (Hake, 2002).

The data normality test used the Liliefors (L_o) test, while the data homogeneity test was carried out using the F test at the significance level of 0.05. Furthermore, the data were analyzed by using an unpaired t_{test} (Sugiyono, 2018).

Table 2. The Stages of the PBL-Multilevel Representation Model

Learning Stages	Learning Activities
Orientation of students to the problems	1. Students solve the problems regarding ionic equilibrium in a salt solution posted by the teacher. 2. Based on the posted problems, students have to solve them involving the macroscopic, symbolic, and microscopic levels.
Organizing students	1. Students perform their literacy for problem-solving using three levels of representation. Students look for sources of information such as books, online, etc. Teachers create a learning environment to make students motivated and enthusiastic.
Guiding Investigation	1. Students carry out practicum according to laboratory procedures to determine the pH value in some salt solutions. This illustrates the application of the macroscopic level. 2. Students discuss and calculate the pH of ionic equilibrium in a salt solution. Students discuss the properties and processes of a salt solution when it is hydrolyzed or not. Those describe the application of the symbolic level. 3. Students discuss the microscopic depiction of salt solution whether hydrolyzed or not. This shows the microscopic level. 4. Students evaluate the right data according to observation and pH calculation of ionic equilibrium in a salt solution.
Developing and presenting the works	1. Students analyze the practicum data that has been obtained and write it down on the Student Worksheet. 2. Students write down the discussion results from the pH calculation, the nature and process of the salt solution according to the problems, and the right pH calculated. 3. Students in their groups also describe the microscopic representation of the ionic equilibrium in salt solution when the hydrolysis occurs or not by determining what ions and molecules are involved in the solution system.
Analyzing and evaluating the work	1. Students make conclusions based on the learning and explain the obstacles they face in the problem-solving process. 2. The teacher evaluates the students' work.

3. Result and Discussion

3.1. Research Results

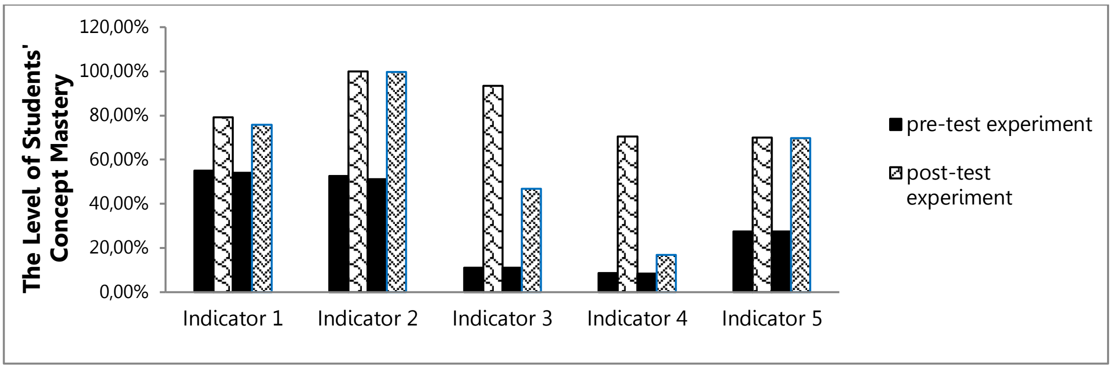

Figure 1. The Level of Students' Mastery of The Ionic Equilibrium in Salt Solution Concept

Description:
Indicator 1 Determining the hydrolysis characteristics of some salts in water and their properties (C1, C2)
Indicator 2 Calculating the pH of salt hydrolysis theoretically (C3)
Indicator 3 Analyzing the microscopic representation when salt was hydrolyzed (C4)
Indicator 4 Analyzing the difference in the microscopic representation between hydrolyzed and unhydrolyzed salt (C4)
Indicator 5 Evaluating the determining the proper mass of salt regarding the problems through the pH calculations of salt hydrolysis (C5)

Figure 1 shows the level of students' mastery of the ionic equilibrium in salt solution concepts. Students in both classes have the best mastery of the concepts at the application cognitive level (indicator 3). Students, especially in the control class, have a poor ability at the analytic cognitive level due to the submicroscopic level (indicators 3 and 4). Some students were wrong in writing down the ionization reaction equation of salt solutions, doing stoichiometric calculations, and have difficulties in changing the microscopic representation of salt hydrolysis.

The results of the homogeneity test/F test and normality/Lilliefors test data were presented in Table 3 and Table 4. Meanwhile, the summary of the unpaired t_{test} analysis of students' mastery of the ionic equilibrium in salt solution concept among participating classes was presented in Table 5.

Table 3. Result of Homogeneity Data Test

Data	Class	N	db	SD	SD2	F_{count}	F_{Table}	α = 0.05	Conclusion
Pretest	Experiment	30	29	6.03	36.36	1.48	1.89	$F_{count} < F_{table}$	Homogeneous
	Control	31	30	4.95	24.50				
Posttest	Experiment	42.90	29	6.55	42.90	1.39	1.89	$F_{hit} < F_{table}$	Homogeneous
	Control	31	30	5.55	30.80				

Table 4. Results of Normality Data test

Data	Class	N	L_o	L_{table}	α = 0.05	Conclusion
Pretest	Experiment	30	0.09688	0.161	$L_o < L_{table}$	Normal
	Controls	31	0.13934	0.159	$L_o < L_{table}$	Normal
Posttest	Experiment	30	0.11475	0.161	$L_o < L_{table}$	Normal
	Controls	31	0.14709	0.159	$L_o < L_{table}$	Normal

Table 5. Results of Unpaired t_{test} of Students' Mastery to the Ionic Equilibrium in salt Solution Concept

Results	Class	db	$\bar{x}$	SD^2	t_{count}	t_{table}	Conclusion
Pretest	Experiment	59	26.58	36.36	0.32	2	Not significant
	Control		26.13	24.50			
Posttest	Experiment	59	84.00	42.90	4.10	2	Significant
	Control		58.87	30.80			

3.2. Discussion

3.2.1. The Students' Mastery of the Ion Equilibrium Concepts in Salt Solution Concept

Principally, two classes participated as the research samples used the same learning model, PBL. The difference between them is that the experimental class was combined with a multilevel representation approach to deepen conceptual understanding at the submicroscopic level through visual depiction, while the control class was not designed for learning concepts at the submicroscopic representation level.

Chemistry learning was guided by a teacher using students' worksheets. According to the PBL model paradigm, learning always begins with a stimulus in the form of an authentic problem that is relevant to the concept of ionic equilibrium in a salt solution or salt hydrolysis. For example,

"Isotonic drinks often use sodium citrate ($Na_3C_6H_5O_7$) as a flavor enhancer such as" Isoplus". However, a consumer named Dinda wanted to know the properties of sodium citrate and its microscopic image or representation. Help Dinda, please! ".

Furthermore, through the PBL stage (Table 2) students solve problems, as well as deepen their mastery of the ionic equilibrium in salt solution concepts in three representation levels (macroscopic, symbolic, and submicroscopic).

Figure 1 showed that the student's mastery of the ionic equilibrium in salt solution concept is good at the cognitive level of C1-C3 (indicators 1 and 2) which are classified as Lower Order Thinking Skills (LOTS). Students have to be accustomed to solve chemical problems at a higher cognitive level or Higher Order Thinking Skills (HOTS). Until now, most of the learning processes and chemical assessments tend to be in the LOTS category. One of the reasons is the lack of the educators' ability to manage the learning process and design HOTS-oriented assessments. So, both professional training Khaldun et al. (2019) and good supervision by the principal is needed to overcome this problem.

Other previous studies also showed similar results where the students tend to achieve the conceptual understanding better at low cognitive levels. The student's achievement level in the nature of the salt hydrolysis concept is 86.00% or the good category (Savitri et al., 2019). Although, other studies have reported there were students who were not careful in writing down the ionization reactions of salt hydrolysis (Boncel et al., 2017).

Students in the experimental class could analyze ionic equilibrium in salt solution problems at the submicroscopic level. Then they achieved a good conceptual mastery according to their posttest. However, students in the control class did not improve their conceptual mastery as high as in the experimental class. This is presumably because students in the control class did not learn through the integration of concepts at the submicroscopic level properly.

Indicators 3 and 4 are categorized as analyzing cognitive level or HOTS category. The conceptual mastery of the experimental class with the PBL-multilevel representation model was better than the control class learns by using the PBL model. These results indicate that habituation of analytical skills through the integration of the representation level affects the students' analytical skills and mastery of the ionic equilibrium in salt solutions concept. The student's mastery of the concept just achieved 70% and it still needs to be improved to master the chemistry concept optimally. Integrating the level of submicroscopic representation in ionic equilibrium in solutions learning is expected to improve the students' analytical skills, visualization of abstract concepts, and mastery of these concepts.

Figures 2 and 3 illustrated the relating submicroscopic indicators of hydrolyzed and unhydrolyzed salts. For students to be able to draw this microscopic representation of chemical phenomena they must understand the salt hydrolysis concepts, they have to write the symbolic representation as an ionic reaction equation, then they have to draw submicroscopic representations in the form of molecular or ionic images.

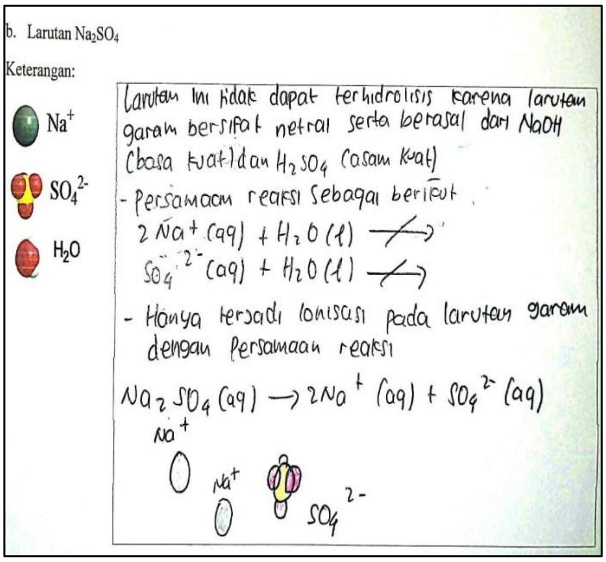

Figure 2. Examples of Students' Answers Regarding Submicroscopic Representation of Unhydrolyzed Salt

Indicator 4 is analyzing the difference in the microscopic representation between hydrolyzed and unhydrolyzed salts that has achieved the lowest mastery of concepts by 70% for the experimental class and 17% for the control class (Figure 1). It indicated that students, especially in control class, have difficulty in making mental imagery of abstract chemical phenomena. Interpreting phenomena to submicroscopic representation requires good visual, analytical, and evaluation skills. Even, Tima and Sutrisno (2018) reported a similar result on the topic of chemical equilibrium that both students who used learning by using the problem-solving model with multilevel representation and those who used the problem-solving model had difficulty in describing submicroscopic representations.

According to a previous study, students who are trained to apply microscopic representations will be able to connect the three levels of representation so that concept mastery is better (Pavlin et al., 2019). The more the understanding of the submicroscopic level, the more the students' mastery of concepts increases. This is because this submicroscopic representation helps a person build mental imagery of a phenomenon that cannot be seen to be able to explain structures and processes at the molecular level (Wicaksono, 2016). The success of students in solving problems also depends on a person's ability to construct mental imagery (Rakhmawan et al., 2018).

Psychologically, the habit of applying the submicroscopic representation level can develop a person's visual-spatial ability through the depiction of molecules or chemical species based on color (Oliver-Hoyo & Babilonia-Rosa, 2017), which strongly supports the development of the ability to solve the chemical problems scientifically.

Integration of multilevel representations in chemistry learning can provide a learning experience that is fundamental, analytical, and deep. In addition, the use of authentic problem stimuli can increase the meaningfulness of the learning experience. As a result, students in the experimental class experienced an increase in mastery of the concept higher than in the control class.

Indicator 5 measures the cognitive level of evaluation. It means that students need to have a good cognitive ability of C1 to C4. If the lower cognitive abilities are still problematic, the mastery of concepts will fail at this cognitive level. For example, if the student's algorithmic ability is low (Cindiana et al.,2020). The following is an example of an instrument to measure indicator 5 in this study.

"Researchers conducted trials of planting mustard greens using a variation of ZA, Zwavelzure Ammonium fertilizers $(NH_4)_2SO_4$). Researchers made variations in fertilizer application, namely 0.5 g, 1 g, 1.5 g, 2 g, and 2.5 g (Mahaputra et al., 2016). The effective pH value when ZA fertilizer, if dissolved in 100 mL of distilled water, is 4.71. The correct dose in giving ZA fertilizer on the fast growth of mustard plants (Mr $(NH_4)_2SO_4$) = 132; Kb $NH_4OH = 10^{-5}$) is .... "

In the above case, students must understand the hydrolysis reaction, write down the ionic reaction equation, apply the concept of hydrolysis pH calculation, compare the calculation results and finally have to make the right decision. The problem-solving process involves cognitive levels from C1 to C5. Example of a student answer as presented in Figure 3.

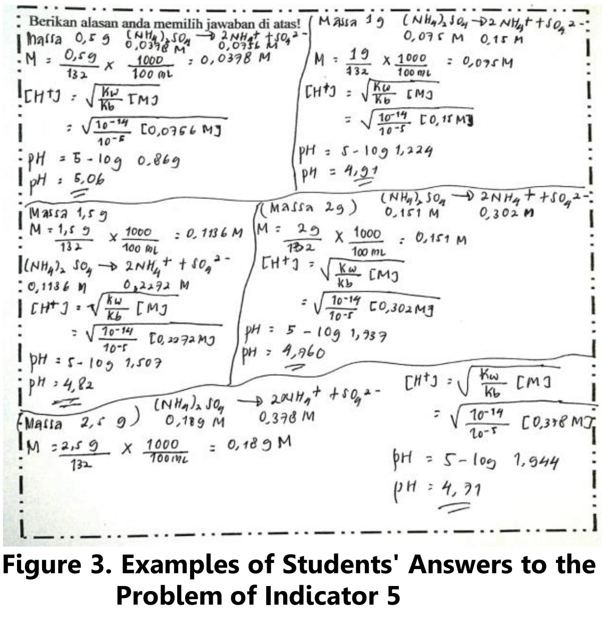

Figure 3. Examples of Students' Answers to the Problem of Indicator 5

Another question that may be asked to students is *"Describe the microscopic representation of the hydrolysis reaction of the ZA, $(NH_4)_2SO_4$ fertilizer!"*

The equation of the ionization reaction of the ZA salt in water,
$(NH_4)_2SO_4(aq) \rightleftharpoons 2NH_4^+(aq) + SO_4^{2-}(aq)$

The equation of the hydrolysis reaction is,
$2NH_4^+(aq) + 2H_2O(l) \rightleftharpoons NH_4OH(aq) + 2H^+(aq)$

So, the microscopic representation of the ZA hydrolysis with all particles including the trace one is presented in Figure 4.

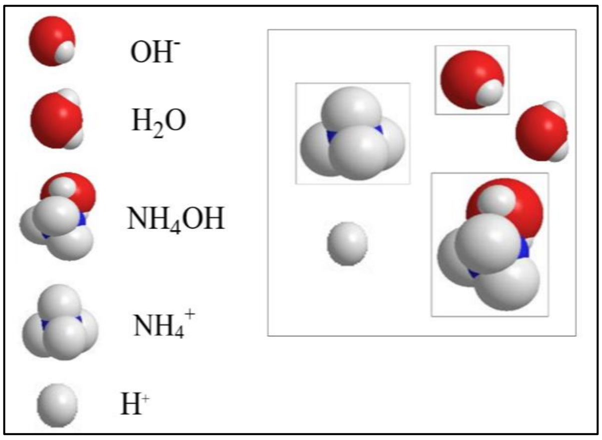

Figure 4. Microscopic Representation of $(NH_4)_2SO_4$ Salt Hydrolysis

The mean score of the N-gain of the experiment class was 0.78 or in the high category, while 0.44 or in the moderate category of the control class. Thus increasing the students' mastery of ionic equilibrium in salt solution as the effect of the learning model used. The experimental class experienced a greater mastery of concepts than the control class after learning using the PBL-multilevel representation model.

3.2.2. The Difference in Students' Mastery of Ionic equilibrium in Salt Solution between Experimental and Control Class

After the data proved to be homogeneous and normal based on the results of the F test (Table 3) and the Liliefors test (Table 4), then the posttest data were analyzed using an unpaired t_{test}. The t_{test} was aimed to determine the differences in conceptual mastery between the experimental class (learning by using the PBL model with multilevel representation) and students in the control class (learning by using the PBL model) (Table 5). The results indicate that there are significant differences in conceptual mastery between students in the experiment class and students in the control class. It can be concluded that the PBL model with multilevel representation is better than the PBL model in instilling mastery of the ionic equilibrium in the salt solutions concept.

The results supported several previous studies, although in the different learning materials with the same strategy or different strategies with the same learning material. The integration of multilevel representations, especially submicroscopic representations in learning, has a significant impact on increasing students' mastery of concepts (Martiasari, et al., 2016; Sunyono & Meristin, 2018). Investigation-based or problem-solving learning strategies/models such as POE, and PBL can facilitate the formation of mental models of abstract chemical concepts (Kiswandari & Ridwan, 2020; Martiasari, et al., 2016).

The ability of 11th grader in Greece showed lower performance in translating from submicroscopic representations to symbolic and macroscopic representations of the concepts of "chemical compounds" and "aqueous solutions" than those related to the concepts of "chemical elements" and "states of solids" (Gkitzia et al., 2020). These facts indicated that understanding multiple representations for the concept of aqueous solutions including ionic equilibrium in salt solutions is still challenging and difficult for students. However, according to this research, the PBL model with multilevel representation can be an alternative strategy to improve students' mastery of chemical concepts effectively.

Students also responded positively to the application of the PBL model with multilevel representation in the ionic equilibrium in solution concept learning. As many as 97% of students responded well to the model implementation chemistry classroom. Some of the reasons why did students give a positive response are: the learning process takes place in a structured and systematic manner, involves authentic problem solving, student-centered learning conditions with the teacher as facilitators; and the existence of interactive discussion activities in class allows students to solve the problems up to the submicroscopic level.

4. Conclusion

PBL is a learning model that aims to train higher order thinking skills and authentic problem solving to facilitate more meaningful learning. Integration of PBL model with a multilevel representation approach (macroscopic, symbolic, and submicroscopic) was able to provide added value in mastering the chemistry concepts deeply. This study found that the PBL model with multilevel representation was able to increase the students' ability to think at a higher order thinking skills level through the solving of an authentic problem. The student's mastery of the concept of ionic equilibrium in salt solutions who learned by using the PBL model with multilevel representation was better than by using the PBL model. Even though some things that must be considered in applying the PBL model or PBL integration with other approaches are the limited learning time so teachers have to manage the time well so that the application of the PBL model with a multilevel representation approach runs optimally. Further research needs to be carried out not only to focus on student problems but also on how teachers or prospective teachers should facilitate student learning activities with multilevel representations and transitions between these representation levels. In addition, this multilevel representation can be studied within the framework of a sociocultural approach because concept formation is strongly influenced by the student's previous knowledge and experiences.

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