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THE EFFECT OF MULTIPLE REPRESENTATION-BASED LEARNING (MRL) TO INCREASE STUDENTS' UNDERSTANDING OF CHEMICAL BONDING CONCEPTS

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ABSTRACT

This study was conducted to determine the effectiveness of multiple representation-based learning (MRL) model compared to discovery learning (DL) model and problem based learning (PBL) model in terms of students' initial abilities. The factorial design was used in this study. The selection of samples in this study was done through a random sampling technique. Three X classes of the same school was chosen. The three classes applied different learning model. The first class employed the MRL, the second class used the DL model, and the last class adopted the PBL model. Overall, the number of samples involved in the study was 117 students. The results of the study showed that the conceptual understanding of students learning using MRL was significantly different from the students learning to use problem-based learning with significant differences in N-gain was 0.0004, but not significantly different from the students using discovery learning. This finding showed that MRL is the most effective model for increasing the conceptual understanding of students with "low" and "moderate" initial ability compared to PBL and DL.

Keywords: multiple representations, conceptual understanding, chemical bonding, initial ability, effectiveness

INTRODUCTION

Chemistry is a science that seeks answers to what, why, and how of natural phenomena in relation to substances, covering structures, compositions, properties, dynamics, kinetics and energetics, which involve skills and reasoning (Chang & Overby, 2011; Huddle & Pillay, 1996). Therefore, studying chemistry should begin with solving daily life problems (Bodner & Herron, 2002; Jaber & BouJaoude, 2012; Gkitzia et al., 2011). Learning through problem solving in real life by applying knowledge of chemistry, participants were expected to develop an understanding of meaningful chemistry concepts (Yuanita & Ibrahim, 2015).

Problem-solving skills to develop meaningful chemistry knowledge could be accomplished with the ability to carry out interpretation and transformation among the three levels of chemistry phenomena (macro, sub-micro and symbolic) through visual, verbal, symbolic, or action representation. The key point in solving the chemistry problems is to develop the ability to represent chemistry phenomena at the submicroscopic level (Davidowizth et al., 2010). Previous studies have shown that students have difficulty in solving chemistry problems during examinations

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due to their inability to visualize the structures and processes that occur at the submicroscopic level and the inability to correlate them with the phenomenon on other chemistry levels (Sunyono & Sudjarwo, 2018; Davidowizth et al., 2010).

In reality, current chemistry learning is limited to two levels of representation including the macroscopic and symbolic level (Jaber & BouJaoude, 2012; Yuanita & Ibrahim, 2015). Unfortunately, students integrate sub-microscopic and macroscopic or symbolic phenomena by themselves. Students try to understand the phenomena through the figures and diagrams in textbooks without teachers' facilitation. Therefore, chemistry learning must be directed to the improvement of students' multiple representations, either verbally or visually, in order to develop the students' representational capabilities so that the ability to associate chemistry phenomena can be increased.

The discovery learning (DL) and problem-based learning (PBL) model have been widely used by teachers either in elementary or high schools. In DL, students are encouraged to learn concepts and principles through their own active involvement and to use thinking skills to solve problems independently (Prasad, 2011). Discovery learning is a teaching strategy that can help students discover and learn scientific concepts by themselves through their active participation in the learning process (Kim, 2013). However, in this discovery process, students accept guidance from the teacher so that students' focus is improved and the learning process as well as goals is achieved completely. Students also play an active role in the learning process by answering various questions and solving problems to find a concept. On the other hand, in learning, teachers only give a few examples to students, provide guidance to students in finding ideas in these examples, and finally draw conclusions to describe the ideas that have been taught to students. (Jacobsen et al., 2008). Learning with DL can guide students to develop the ability to carry out independent discoveries in the future (Carin, 1993; Vitoševic et al., 2014). The application of DL can contribute significantly to students' thinking abilities (Fuad et al., 2017).

Previous studies revealed that the DL model could help students learn in depth. The DL model is more meaningful because it employs individual associations as the core of understanding (Kim, 2013). Janssen et al. (2014) concluded that DL is more effective than conventional learning. In addition, the application of DL model in chemistry learning increases students' achievement and facilitates students to reduce the level of difficulties in understanding a concept (In'am & Hajar, 2017). In contrast to DL model, PBL model is a student-centered learning model in which students define their own key issues based on chemical bonding concepts for real-world problems through collaborative learning activities, also, direct students under the guidance of a teacher (Savoie & Andrew, 1994). Focusing on real-life problems and exploring relevant information allow students to develop their flexible knowledge and meaningful problem-solving skills (Abubakar & Arshad, 2015). PBL consists of the seven (7) following steps: problem identification, knowledge exploration, hypothesis creation, key issue identification, independent study, re-evaluation, the application of new knowledge towards problem-solving, evaluation, and reflection (Prasad, 2011).

Previous studies showed that learning using PBL can improve students' conceptual understanding. Rodríguez & Fernández-Batanero (2017) stated that PBL is one of the learning models that can motivate students to learn chemistry. The research of Kelly & Finlayson (2007) concluded that chemistry learning using PBL model could provide an excellent scope of learning for the development of skills, understanding of chemistry concepts, and laboratory experiment processes. Jones et al. (2013), in their research, found that many elements of the PBL model provide students with internal motivation. The opportunity to motivate students is important because learning using PBL model can influence students' perception of the concept being studied. The motivational opportunity available in PBL is a real asset to students' motivation. Abubakar & Arshad (2015) concluded that students who learn using PBL have been able to develop a deeper understanding and acquire effective problem-solving skills as well as more effective and focus on independent information processing.

Referring to Indonesian national education curriculum, the most suitable science learning is the student-centered approach such as the DL and PBL model. Both learning models focus on learning that prioritize problem-solving through a variety of innovative approaches initiated by teachers. The differences between DL and PBL are implied in the above description. Through the DL and PBL models, students can solve problems in a structured and systematic way so that an accurate and quick problem-solving solution is achieved. In addition, with a structured and systematic problem-solving strategy, students are trained to identify, analyze, and evaluate the problems carefully so that they may develop their critical reasoning to work on problems (De Cock, 2012; Kim, 2013; Rodríguez & Fernández-Batanero, 2017).

Several studies on multiple representation-based learning showed that MRL has been able to improve students' higher-level thinking skills (Davidowizth et al., 2010; Jaber & BouJaoude, 2012; Yuanita & Ibrahim, 2015). Nevertheless, the effectiveness of MRL model needs to be investigated further in chemistry learning by comparing to the PBL and DL model that have been widely known by teachers. Therefore, this study aimed to evaluate the effectiveness of the MRL model compared to the DL and PBL models. Both the DL and PBL learning model have cooperative and collaborative characteristics, while the MRL model has cooperative, collaborative and imaginative characteristics (Yuanita & Ibrahim, 2015). Thus, the question this research poses was "how effective is the MRL model compared to the PBL and DL model in terms of students' initial ability?"

METHODS

In this study, a factorial design was used to compare the increase of students' conceptual understanding through the three different learning models including MRL, DL, and PBL model in terms of students' initial ability (high, moderate, and low).

The random sampling was carried out so that three X classes of the same school were obtained. The first class acted as an experimental class which applied the MRL model while the other two classes were control classes, the control class A used the DL model and the control class B employed the PBL model. The research design is illustrated in Table 1 below.

Table 1. The Research Design

Group	Subject	Pre-test	Treatment	Post-test
Experimental (MRL Model)	R1	O1	X	O2
Control A (DL Model)	R2	O1	C1	O2
Control B (PBL Model)	R3	O1	C2	O2

Description:

R1 = Students in the experimental class used the MRL model of learning (selected randomly) with a total of 39 students.

R2 and R3 = Students in the A and B control class employed the DL and PBL model, with a total of 39 students each

O1 and O2 = Pre-tests and post-tests were administered to measure students' concept mastery (the test results were distinguished based on the students' initial ability of low, medium and high)

X = The implementation of learning by using an MRL model

C1 and C2 = Learning implementation by using the DL and PBL models.

MRL Model = Multiple Representation-Based Learning Model

DL Model = Discovery Learning Model

PBL Model = Problem Based Learning Model

Before the learning implementation, the students in each class were grouped based on their initial abilities. Students' initial abilities were determined through the teachers' assessment data from previous learning. Each class consisted of 13 students with low, medium and high initial abilities, respectively. Pretest and posttest were carried out in each class to obtain the N-gain of students' understanding.

Instruments in the form of learning achievement tests were utilized to measure the level of students' understanding of the chemical bonding concepts. The questions on the achievement test were tested for validity and reliability. The validity and reliability of the test instruments were carried out through trials to 20 students. The validity and reliability of the test instrument were calculated using the SPSS 17.0 program. The validity computation resulted in the validity correlation coefficient (Corrected Item-Total Correlation) > 0.30. Meanwhile, the reliability calculation obtained a value of r_{11} of 0.92 or greater than r_{table}. Thus, the questions used to measure students' understanding of concepts owned high validity and reliability. This test consisted of 30 items with five options. The Pre-test and post-test with same questions were administered to the experimental class and control classes. The students gained 1 score for a correct answer and 0 for an incorrect answer. The concept mastery data was determined by the N-gain scores (Hake, 2002). The N-gain score was grouped based on the students' initial ability. The data were analyzed using analysis of variance (ANOVA) followed by a Tukey test at the 5% level. The analysis was performed using ANOVA factorial design. The hypotheses tested in this analysis were: (1) H_o1: there was no difference in the N-gain of the chemical bonding concept understanding among groups of students based on the different learning models; (2) H_o2: there was no difference in the N-gain of the chemical bonding concept understanding among groups of students based on the differences in initial ability; and (3) H_o3: there was no significant interaction between the learning models and the initial ability of students in chemical bonding concept understanding.

RESULTS AND DISCUSSION

The findings showed that students' concept mastery was higher in MRL model than students' concept mastery in the DL and PBL model. The findings in Figure 1 demonstrated that the results of the pretest and post-test displayed the N-gain average of students' concept mastery in the experimental class and the control classes. Generally, the N-Gain average of students' concept mastery in chemistry learning using the MRL model was higher than the N-Gain average of the DL and PBL model at all levels of student ability. By using the N-Gain criteria, the general average value of the N-Gain obtained by students who learned using the MRL model categorized as "high" for all students with a high and medium initial ability, while for students with a low initial ability, the acquired N-Gain categorized as "medium". In general, the N-Gain average in the "moderate" category was also found in the DL and PBL class for all levels of the students' initial ability.

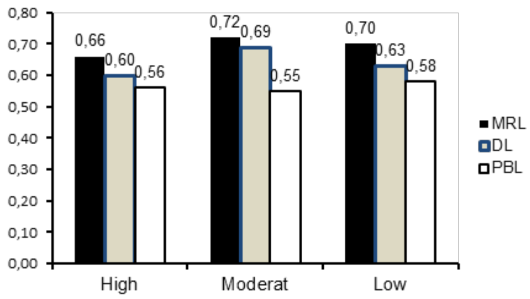

Figure 1. The Experimental Class (MRL model) and Control Classes (DL and PBL model) concept Mastery based on the N-Gain Averages Reviewed from the Initial Ability of Students (High, Moderate, and Low)

The subsequent analysis was accomplished using a statistical analysis to determine the difference in the students' concept mastery among the three learning models in terms of students' initial ability. The ANOVA statistical analysis results for the N-gain of the three learning models are shown in Table 2.

Table 2. The Analysis Results of Variance (ANOVA) on the N-Gain of Students' Chemical Bonding Concept Mastery based on Initial Ability Factors and Learning Models.

Source	F	Sig.
Learning Models	545.151	.000
Initial Ability	0.919	.402
Interaction: Models*Initial ability	0.418	.795

There were significant differences among the N-gain averages as a result of using the various learning models; MRL, DL, and PBL. Thus, a post hoc test (multiple comparisons) using the Tukey test was needed. There was no significant N-gain difference among the students who had different initial abilities (high, medium, and low). Hence, it was unecessary to perform a further test. In addition, there was no significant interaction between the effects of the learning models and the students' level of initial ability (high, medium, and low), so, it was not necessary to conduct a further test. The post hoc analysis results of the learning model effects were achieved through a Tukey test (Table 3).

Table 3. The Tukey Test Results of the Three Learning Models' Effects

Learning Model	Mean Difference	*sig*.(p)
MRL – DL	0,0575	.299
MRL – PBL	0,1278*	.004
DL – MRL	-0,0575	.299
DL – PBL	0,0703	.167
PBL – MRL	-0,1278*	.004
PBL – DL	-0,0703	.167

Based on Table 3, it is clear that one pair of MRL – PBL had a significant difference in the N-gain average of chemistry concept mastery, while the two other pairs (MRL – DL and DL – PBL) had no significant difference in the N-gain average. Thus, it could say that the significant differences in the N-gain average only occurred in the implementation of learning that used the MRL and PBL model. These results indicated that the MRL model had no difference with the DL model in improving the mastery of chemical bonding concepts. However, the MRL model cannot be equated with the PBL model; hence, it was necessary to perform a further test to determine the difference in the N-gain average of the concept mastery from the two different learning models (MRL and PBL) with regards to the initial ability of the same students.

A statistical test to examine the differences in the average of the two different samples was administered by using a T-test. The tested hypothesis (Ho) was "there were no differences in the N-gain average of the chemistry concept mastery between the students learning with the MRL model and those learning with the PBL model with the same initial ability level". The t-test results analysis of the N-gain average for students' concept mastery is summarized in Table 4.

Table 4 shows that the N-gain averages were significantly different for the concept mastery of students at the medium and low initial ability level in the MRL and PBL model. On the other hand, there was no difference in the N-gain average of the high initial ability between the students using the MRL and PBL models. This result suggested that the learning process using the MRL model improved the students' concept mastery compared to the learning process using the PBL model for students with "medium" and "low" initial ability.

Table 4. The T-test Results of the N-gain average on Students' Concept Mastery from the Three Learning Models of the Same Initial Ability.

Pair	N	Df	t	p
MRL High><PBL High	13	12	1,193	0,256
MRL Medium >< PBL Medium	13	12	2,563	0,025
MRL Low><PBL Low	13	12	1,917	0,031

This study revealed that chemistry learning using the MRL model was more effective than using the PBL model yet had no difference with learning using the DL model in improving concept mastery and problem-solving skills on chemical bonding topic especially for those with moderate and low initial ability. This comparison indicated that the MRL model is the most recommended suitable model among the three models of learning applied to provide learning on chemical bonding. The results suggested that learning with various representations could stimulate the students to be actively engaged to solve chemical problems especially to interpret and transform macro, sub-micron, and symbolic phenomena. Through the exercises of various learning models, the students acquired easier ways to understand the chemistry concepts deeply (Rodríguez & Fernández-Batanero, 2017) and stronger ability to perform meaningful reasoning of chemical phenomena (Coll, 2008; Sunyono & Sudjarwo, 2018).

Based on the observations in the classroom, increasing students' concept mastery using the MRL model was supported by the use of high learning activities. This process also appeared in the teaching activities using the DL model but not the PBL model. In the MRL model, the teacher played a role as a facilitator and mediator in the learning activities. This model consistently indicated that learning has provided the opportunity for students to explore knowledge in discovering chemistry concepts to solve problems. This achievement was supported by the high activity of the students through the learning. These results showed that learning with MRL was carried out attractively, collaboratively, and cooperatively so that the students had more experience in solving the chemistry problems. The same results occurred through the DL model. The observation results revealed that both learning models were capable of making students become highly active in their exploration of knowledge. This finding is consistent with the report by In'am & Hajar (2017) that the implementation of learning using the DL model with a scientific approach can be accomplished to improve student learning activities to improve students' understanding of a concept. Furthermore, Vitošević et al. (2014) in their research revealed that DL procedures explore higher order thinking about real life issues and situations. Learning with the DL model can generate the interest and motivation of the students. This relation is in line with the previous statement that the DL model could generate chemical bonding concept mastery that is not significantly different from the MRL model because both models equally provide simplified learning materials by using sufficient media to reduce the level of difficulty in learning. Teaching through discovery learning by using mobile technologies could increase students' curiosity and interest in science as well as students' scientific knowledge (Kim, 2013).

MRL model is an effective learning model to optimize students' imagination capability; as a result, the students' ability to think and reason in solving problems is increased (Yuanita & Ibrahim, 2015). In the exploration activities during the learning process in the MRL model, the students were given the opportunity to broaden and deepen their knowledge by searching information through the internet or textbooks, observing demonstration or animation activities, analyzing sub-micro visual images, and building concepts through reasoning in an effort to improve mastery of their concepts. The use of information technology (such as web pages/weblogs) in the MRL model could stimulate students' interest in searching for information. Through the learning process, the student-student and student-teacher interaction were very common. This condition was not much different from the learning under the DL model. Thus, it can be said that learning with the MRL model can be equated with the DL model yet was more effective than the PBL model. The ineffectiveness of the PBL model compared to the MRL model was due to the lower level of activity and motivation of the students. Based on the data during the observation, most of the students had a low ability to formulate an actual problem. This difference in the problem formulation phase was one of the causes that made learning with the MRL model more effective, where learning did not use computer-based media. The results of this study seem to be in line with Jaber & BouJaoude (2012) who stated that computers can be used as a tool to aid students to gain the ability to visualize the systems and processes at the molecular level. Relevant to this result, although PBL has been known as a model to improve student learning achievement, the lack of media usage in the learning has caused the results to be less favorable.

The learning process using the MRL model was suitable for students with medium and low initial ability. The increase in the chemical bonding concept mastery of students with medium and low initial ability in the MRL class was higher than that of students with the same initial ability in the class using the PBL model. Meanwhile, for students with a high initial ability, the increase in concept mastery for those using the MRL model was insignificantly different compared to that of students using the PBL model. These results explained that the MRL model was very suitable for students with a medium and low initial ability, especially in improving chemical bonding concept mastery.

The previous studies suggested that students with different initial ability have the same chance to increase their concept mastery through the MRL model. Carroll's theory (Joyce & Weil, 2003) stated that learning achievement is not solely influenced by previous academic ability but is also influenced by the quality of learning, the learning environment, talent, and available time. The right learning strategy to improve low and middle achievement academic ability to be equivalent to students with high academic abilities is a cooperative, collaborative and imaginative learning strategy. This idea was suggested by Slavin (2006) that cooperative learning can motivate students to support and help one another in mastering learning materials. De Cock (2012) stated that teachers need to provide convenience in the problem-solving process by providing opportunities for students to find or apply their own ideas and students will use different problem-solving strategies, depending on the representation format in which the problem is stated. Based on the above description, it can be said that the MRL model, which is characterized by being collaborative, cooperative, and imaginative, will be consistent with Carroll and Slavin's perspective.

The results of this research also reinforced the research conducted by De Cock (2012) which found that grouping the students based on initial capabilities in the learning of all subjects provide the same positive effect on learning outcomes, except in social studies where the effect may be negative. Similarly, Kingir et al. (2012) reported that the Science Writing Heuristic (SWH) approach, by involving the submicroscopic and symbolic phenomena in the learning of the chemical transformation and mixtures topics, significantly influences student learning performance and achievement. Thus, the results of this study align and complement the findings of previous research. The findings indicated that the MRL model appears to be more applicable to learning the concept of chemical bonding than the DL and PBL models, especially for students with low and medium initial abilities.

The findings of this study implicated for learning chemistry in schools, considering that chemical materials always involve macro, submicron, and symbolic phenomena, so, learning with multiple representations is very important. Through this MRL model, we provide advice to focus on the bonds formed between two atoms. Presentation of chemical bonds (including hydrogen bonds and Van der Waals bonds) using a model of interaction between two atoms in a gas state, including using an animation model to correlate macro phenomena (e.g. reactions between Na and Cl_2), sub-micron (electron handover movements), and symbolic (complete presentation of chemical reactions that occur). In this study, it should be noted that the students' ability to distinguish between ionic, covalent, hydrogen bonds, and Van der Waals based on length, energy, and other important characteristics (such as directivity). Although all chemical bonds can be presented at the sub-micron scale (such as bond strength, bond energy, etc.), the students must obtain a qualitative understanding of the chemical strength of the bond and its characteristics. Therefore, learning with the MRL model is able to provide the demand for learning the concept of chemical bonds as suggested above.

In addition, when compared with DL and PBL models, learning with the MRL model will be better able to examine the questions about why ions formed in the solution form ionic lattices? Is it because the solution is a solution of an ionic compound? In this case, learning must focus on the electric interactions between ions. However, we suggested that in introducing the concept of ionic bonding, it begins with the introduction of chemistry without the need to focus on ion formation. Learning begins by giving a little understanding of chemistry by considering discrete neutral atoms. At the beginning of this learning, it is better to start with a macroscopic approach, namely by demonstrating the formation of ionic solids with neutralization and evaporation (e.g. NaCl) and/or by precipitation (e.g. $FeCl_3$). Furthermore, learning is done by using animations to explain sub-micro phenomena, such as the release of one electron from Na and into the Na^+ ion, and the capture of the electron by the Cl atom and becoming the Cl^- ion. The final step is to explain the occurrence of symbolic ionic bonds by writing down the ionic reaction equation that occurs. Likewise, in learning about hydrogen bond concepts and so on, it is necessary to consider a macro, sub-micron, and symbolic scale approach. Learning chemistry by considering macro, submicron, and symbolic phenomena will be able to increase students' reasoning power (Devetak et al., 2009; Jaber & BouJaoude, 2012; Yuanita & Ibrahim, 2015) and the conceptual knowledge gained will be more profound and maintained long enough in students' brains (Yakmaci-Guzel & Adadan, 2013).

CONCLUSION

Based on the analysis and interpretation of the research results, the researcher concluded that the MRL model was capable of improving students' concept mastery of chemical bonding yet had no difference from the DL model. The MRL model was more effective than the PBL model in increasing chemical bonding concept mastery, and the MRL model was very suitable for chemical learning for the students with medium and low initial ability compared to the PBL and DL model.

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