Effect of Learning Based on Multiple Representations to Increase Students' Understanding of Chemical Bonding Concepts

by Sunyono Et Al.

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Abstract

This study was conducted to determine the effectiveness of multiple representations based learning models compared to discovery learning models and problem based learning models in terms of students' initial abilities. The factorial design was used in this study. The selection of samples in this study was done through random sampling techniques so that one school with three classes was obtained from class X. The three classes consisted of 1 (one) class as a sample with learning using the MRL model; one class as a class with learning using the DL model; and one class with learning using the PBL model. Overall the number of samples involved in the study were 117 students. The results of the study showed that the conceptual understanding of students learning using multiple learning representations was significantly different from students learning to use problem-based learning with significant differences in N-gain was 0.0004, but not significantly different from students using discovery learning. This finding shows that multiple representation learning is the most effective model for increasing the conceptual understanding of students with initial "low" and "moderate" abilities compared to problem-based learning and discovery learning.

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

INTRODUCTION

Chemistry is a science that seeks answers to the what, why, and how of natural phenomena in relation to substances, covering structures, compositions, properties, dynamics, kinetics and energetics, which involves 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, student participants were expected to develop an understanding of meaningful chemistry concepts (Sunyono et al. 2015; Wood 200 Learning through solving problems in real life by applying chemical knowledge, students were expected to develop an understanding of chemical concepts with more meaningful (Sunyono et al. 2015; Wood, 2006).

Problem solving 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 actional 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 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 and Sudjarwo, 2018; Sunyono et al. 2015; Davidowizth et al., 2010).

In reality, current chemistry learning is limited to two levels of representation, including the macroscopic and symbolic levels (Jaber & BouJaoude 2012; Sunyono et al. 2015). Unfortunately, students integrate submicroscopic and macroscopic or symbolic phenomena by themselves. Students try to understand the phenomena through the figures and diagrams in textbooks without the facilitation of a teacher. 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) models have been widely used by teachers either in elementary or high schools. In discovery learning, 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 (Lee et al., 2013). However, in this discovery process, students accept guidance from the teacher so that students' focus is improved and the learning process and goals are 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, the teacher only gives a few examples to students, then the teacher gives guidance to students in finding ideas in these examples, and finally the teacher gives conclusions to describe the ideas that have been taught to students. (Jacobsen et al., 2008). Learning using the discovery model can guide students to develop the ability to carry out independent discoveries in the future (Carin, 1993; Vitošević et al., 2014). The application of the discovery / question model in the classroom can contribute significantly to students' thinking abilities (Fuad et al., 2017).

Previous studies revealed that the DL model could help students learn in more depth. The DL model is more meaningful because it employs individual associations as the core of understanding (Lee et al., 2013). Janssen et al. (2014) concludes that DL is more effective than conventional learning. In addition, the application of the 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 the DL model, the PBL model is student-centered learning models in which students define their own key issues based on the Chemical bonding concepts solve real-world problems through collaborative learning activities and direct students under the guidance of a teacher (Savoie & Andrew, 1994). Focusing on real-life problems and exploring relevant information can help students develop their flexible knowledge and meaningful problem-solving skills (Abubakar & Arshad, 2015). Problem-based learning consists of the seven (7) following steps: problem identification, knowledge exploration, hypothesis creation, key issue identification, independent study, re-evaluation, and the application of new knowledge toward problem-solving, evaluation and reflection (Prasad, 2011).

Previous studies show that learning using PBL can improve students' conceptual understanding. Rodríguez & Fernández-Batanero (2017) states that PBL is one of the learning models that can motivate students to learn chemistry. The research of Kelly & Finlayson (2007) concludes that chemistry learning using the PBL model can provide an excellent scope of learning for the development of skills and understanding of chemistry concepts and laboratory experiment processes. Jones et al. (2013), in their research, find that many elements of the PBL model provide students with internal motivation. The opportunity to motivate is important because learning using the PBL model can influence students' perception of the concept being studied. The motivational opportunities available with PBL can be a real asset to learning in motivating students to learn. Abubakar & Arshad (2015) conclude 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 focused independent information processing.

In the Indonesian national education curriculum, the most suitable science learning is the student-centered approach, such as the DL and PBL models. Both learning models focus on learning that prioritizes problem-solving through a variety of innovative approaches by teachers. The difference between DL and PBL is 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 the students can develop their critical reasoning to work out problems (De Cock, 2012; Lee at al., 2013; Rodríguez & Fernández-Batanero, 2017).

Based on the above description, it can be said that the DL and PBL models have proven to be effective in improving students' thinking skills, while the effectiveness of the multiple representations learning (MRL) model still needs to be tested further. Therefore, this study aims to evaluate the effectiveness of the MRL model compared to the DL and PBL models. Both the DL and PBL learning models have cooperative and collaborative characteristics, while the MRL model has cooperative, collaborative and imaginative characteristics (Sunyono et al., 2015). Thus, the question this research poses is "how effective is the multiple representations-based learning models performed compared to the discovery learning and problem-based learning models in terms of initial student 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 a multiple representations and cooperative models (discovery learning and problem-based learning) in terms of initial student ability (high, moderate / medium, and low).

School sampling was carried out through random sampling techniques so that a school with three classes of class X was obtained. The three classes consist of one class as an experimental class sample (the class using the MRL model) and two classes designated as control class A (the class using the DL model) and control class B (the class using the PBL model), as shown in Table 1.

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Table 1. Research design

Group	Subject	Pretest	Treatment	Posttest
Experiment (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 using the MRL model of learning (selected randomly) with a total of 39 students.
R2 and R3 = Students in the A and B control classes using the DL and PBL models, with a total of 39 students in each class.
O1 and O2 = Pretests and post-tests were administered to measure students' mastery of the concepts (the test results are distinguished based on initial student 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 Representations Model
DL Model = Discovery Learning Model
PBL Model = Problem Based Learning Model

Before the implementation of learning, students in each class were grouped based on their initial abilities. Students' initial abilities are determined through teacher assessment data from previous learning. To apply learning in the experimental class of all selected schools, the MRL model is used. While learning in the control class “A” was carried out using the DL model, and learning in the control class “B” was carried out using the PBL model. 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 N-gain of students' understanding.

Instrument to measure the level of student understanding of the concept of chemical bonds using the test of learning achievement. The questions on the achievement test were tested for validity and reliability. This test consists of 30 items with five options. Pretests and post-tests with same questions were administered to the experiment and control classes. The pretest and post-test results were assessed by a scoring standard: score 1 for a correct answer and 0 for an incorrect answer. Concept mastery data regarding the chemical bonding concept is determined by N-gain scores (Hake, 2002). The N-gain score was grouped based on the initial ability of students. 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

Ho1: there was no difference in the N-gain of concept mastery among groups of students based on the different learning models.

Ho2: there was no difference in the N-gain of concept mastery among groups of students based on the differences in initial ability.

Ho3: there was no significant interaction between the learning models and the initial ability of students in the achievement of concept mastery.

RESULTS AND DISCUSSION

Results

The findings show that students’ concept mastery was higher in MRL model than students’ concept mastery in the DL and PBL models. The findings in Figure 1 demonstrate that the results of the pretest and post-test display the N-gain average of students’ concept mastery in the experimental class and the control class. Generally, the N-Gain average of students’ concept mastery in chemistry learning using the MRL model was higher than the N-Gain average from the DL and PBL models of learning 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 was 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 was categorized as "medium". In general, the N-Gain average in the "moderate (medium)" category was also found in the DL and PBL classes for all levels of initial student ability.

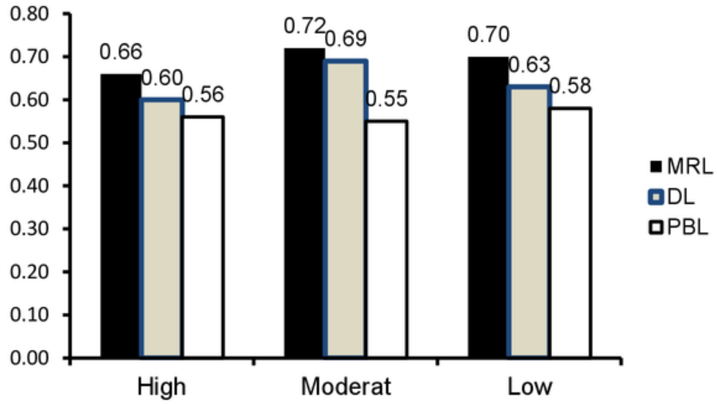

Fig. 1. The experimental class (MRL model) and control classes (DL and PBL models) concept mastery N-Gain averages reviewed based on the initial ability of students (high, moderate / medium, and low)

The subsequent analysis was accomplished using a statistical analysis to determine the difference in 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. ANOVA of the N-gain student of concept mastery based on the initial ability factor and the learning models.

Factors	**Analysis Results**		
	F	**Sig.**	**H_o**
Learning Models	545,151	0,000	Rejected
Initial Ability	0,919	0,402	Accepted
Interaction: Models*Initial ability	0,418	0,795	Accepted

There were significant differences among the N-gain averages as a result of using the various learning models, MRL, DL, and PBL, so a post hoc test (multiple comparisons) using the Tukey test was needed. There was no significant N-gain difference among students who had different initial abilities (high, medium, and low), so it was not necessary 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. Post hoc analysis results of the effects of learning models were achieved through a Tukey test (Table 3).

Table 3. Tukey test result of the effects of the three learning models

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

Based on Table 3, it is clear that one pair of MRL – PBL had a significant difference in the N-gain average the mastery of chemistry concepts, while the two other pairs (MRL – DL and DL – PBL) had no significant difference in the N-gain average. Thus, it could be said that the significant differences in the N-gain average only occurred in the implementation of learning that used the MRL and PBL models. This result indicates that the MRL model is equal to the DL model, particularly in increasing the chemical bonding concept mastery of the students. However, the MRL model cannot be equated with the PBL model, so 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 regard 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) is "there were no differences in the general N-gain average of the chemistry concept mastery between students learning with the MRL model and students learning with the PBL model with the same initial ability levels". The results of the t-test analysis of the N-gain average for students' concept mastery are 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 levels in the MRL and PBL models. On the other hand, there was no difference in the N-gain average of the high initial ability students between students using the MRL and PBL models. This result suggests that a learning process using the MRL model improves students' concept mastery compared to a learning process using the PBL model for student groups with "medium" and "low" initial ability.

Table 4. The results of the t-test of the N-gain average of students' concept mastery from the three learning models of the same initial ability.

Pair	N	Df	T	P	Ho
MRL High><PBL High	13	12	1,193	0,256	Accepted
MRL Medium >< PBL Medium	13	12	2,563	0,025	Rejected
MRL Low><PBL Low	13	12	1,917	0,031	Rejected

Discussion

The present study reveals that chemistry learning using the MRL model is more effective than using the PBL model but is similar to learning using the DL model in increasing students' concept mastery and problem-solving skills in chemical bonding, especially for students with medium and low initial ability. This comparison indicates that the MRL model is the most recommended suitable model among the three models of learning applied in providing learning of materials on chemical bonding. The results suggest that learning with various representations can stimulate students to be actively engaged to solve chemical problems, especially to interpret and transform macro, sub-micro, and symbolic phenomena. Through the exercises of various learning models, students acquire both easier ways to understand the chemistry concepts and a deeper knowledge (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 appears 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 indicates 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. This result shows that learning by MRL was carried out attractively, collaboratively, and cooperatively, so the students had more experience solving the chemistry problems. The same result occurred through the DL model. The observation results show 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; the DL model can generate a chemical bonding concept mastery that is not significantly different from the MRL model because both models equally provide simplified learning material by using sufficient media to reduce the level of difficulty in learning. Teaching through discovery learning by using mobile technologies can increase students' curiosity and interest in science as well as increase students' scientific knowledge (Lee et al., 2013).

The improvement of students' concepts mastery is the result of student activities in the MRL model. Through this learning model, students are encouraged to engage in the knowledge exploration process by reading textbooks and/or web pages/web blogs and to pay attention to the teacher's explanation. In addition, the implementation of learning in phases puts more emphasis on students' thinking ability, such as during the exploration-imagination phase, which can assist students in optimizing their thinking capacity and independently discovering solutions to problems being faced. These results are in line with the research of Sunyono et al. (2015) that indicates that the MRL model is an effective learning model to optimize students' imagination capability, so students' ability to think and reason in solving problems is increased. In the exploration activities during the learning process, students are given the opportunity to broaden and deepen their knowledge by performing a search of information via the internet or textbooks, observing demonstrative activities or animation, analyzing sub-micro visual images, and building concepts through reasoning in an effort to improve their mastery of concepts. Thus, students' opportunity to enrich their understanding in this exploration activity is provided; the enriched understanding is indicated by students' critical questions, such as why and how questions. The emergence of these questions indicates that the students are ready to tackle the imagination activities. Badia et al.(2013) stated that in the exploratory phase, teachers arouse the interest and curiosity of the students about the topics to be taught, so the students will be more motivated in participating and paying attention to the learning activities at the next phase. In the so-called phase, the teacher provides more opportunities for students to search for information through web pages/weblogs. The use of information technology (such as web pages/weblogs) in the MRL model can stimulate students' interest in searching for information. Through the learning process, interaction activities among students and between students and teachers were very common. This condition is not much different from the conditions of learning under the DL model. Thus, it can be said that learning with the MRL model can be equated with the DL model but is more effective than the PBL model. The ineffectiveness of the PBL model compared to the MRL model is due to the lower level of activity and motivation of the students using the PBL model. Based on the data during the observation, most of the students have a low ability to formulate an actual problem. This difference in the problem formulation phase is one of the causes that made learning with the MRL model more effective than the PBL, where learning did not use computer-based media. The results of this study seem to be in line with Jaber & BouJaoude (2012) who state 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 the use of media in the learning has caused the results to be less favorable.

Exploration activities in the MRL model learning are always coupled with imagination activities. Imagination activities are necessary to perform mental imagery of the representation of submicroscopic phenomena to be able to transform it to the macroscopic or symbolic phenomena representations or vice versa. The exploration-imagination activity is the most important stage of the MRL model learning to foster the power of reason and trigger the creativity of the students. Haruo et al. (2009) state that the power of imagination will increase the desire to enhance the learners' skills and conceptual knowledge. In addition, Bland (2012) states that imaginative learning can result in creative student work and can improve conceptual knowledge. Similarly, the study conducted by Ren et al. (2012) concludes that teachers who include imagination in learning are able to foster the creativity of students to improve the students' conceptual knowledge. This imagination activity is exactly what the DL and PBL models have not implemented. Thus, this exploration-imagination phase is the most distinguished learning phase that contributes to the more effective outcome of the learning process of the MRL model compared to the PBL model and is as effective as that of the DL model.

The learning process using the MRL model is 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 a class using the PBL model, while 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 indicate that the MRL model is very suitable for students with a medium and low initial ability, especially in improving chemical bonding concept mastery.

The previous studies suggest that students with different initial ability have the same chance to increase their concept mastery through the MRL model. Carroll's theory (Joyce and Weil, 2003) states 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 appropriate learning strategy to increase the abilities of low and medium academic achievers so that they are on par with students with the high academic ability is a cooperative, collaborative and imaginative learning strategy. This idea is suggested because being cooperative, according to Slavin (2006), motivates learners to support and help each other in mastering the 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 format of the representation 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 also reinforce the research that was conducted by De Cock (2012) that found that grouping the students based on initial capabilities in the learning of all subjects provides the same positive effect on learning outcomes, except in social studies where the effect may be negative. Similarly, Koenig et al. (2012) reported that there was an insignificant difference between students with low, medium, and high formal capabilities in increasing their understanding of a concept. Lastly, 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. Furthermore, Kingir et al. (2012) found that with the SWH approach students who previously had low and medium initial abilities can significantly surpass students with the same initial ability who learn through a conventional model, but students with a high initial ability did not differ significantly. Thus, the results of this study align and complement the findings of previous research. The findings in this study, indicating 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.

CONCLUSION

Based on the analysis and interpretation of the research results, the researcher concludes that the MRL model is capable of improving students' concept mastery of chemical bonding that is no different from the DL model; the MRL model of learning is more effective than the PBL model in increasing chemical bonding concept mastery; and the MRL model of learning is very suitable for chemical learning for students with medium and low initial abilities compared to the PBL and DL models.

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