Effect of using problem-solving model based on multiple representations on the students' cognitive achievement: Representations of chemical equilibrium

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Abstract

The objectives of the research were to identify the difficulty level of various types of chemical representation for students and to examine the effects of two different models of teaching and learning chemistry (problem-solving based on multiple representations and problem-solving) on the students' cognitive achievement in chemical equilibrium. This research was a quasi-experimental research with posttest only design. The research was conducted in two different 11th-grade groups in a senior high school. The research was carried out with two groups: an experiment group (problem-solving based on multiple representations model) (26 students) and a control group (problem-solving model) (24 students). The research finding shows that there is a significant difference in the students' mean cognitive learning scores in chemical equilibrium among the two groups. The results showed that the score of the students' cognitive achievement in the experiment group was better than control group.

Keywords: Problem-solving, multiple representations, students' cognitive achievement

Introduction

Chemistry is one of the important sciences to study in senior high school. In fact, the important of chemistry is not in line with students' chemistry achievement. The students' chemistry learning achievement is low because students have difficulty in learning chemistry. Some of the subject matter of chemistry considered difficult by students include orbital and atomic hybridization (Nakiboglu, 2003), chemical bonds (Smith & Nakhleh, 2011), and chemical balance (Pedrosa & Dias, 2000; Sendur, Toprak, & Pekmez, 2010).

Johnstone (1993) says that learning in chemistry should reveal the phenomenon of chemical concepts and principles at the macroscopic, submicroscopic and symbolic levels. Macroscopic representation is a real observation of the chemical phenomena occurring by the five senses. Acquisition of this observation can be through daily experience, laboratory activities in the laboratory, and field studies. Things that can be observed include colour change, temperature, pH and the formation of precipitates during chemical reactions. The submicroscopic representation is a process that occurs at the level of atomic or molecular particles that explain macroscopic phenomena. The submicroscopic term refers to small and unobservable particle size but its existence is real, such as the movement of electrons, molecules, and atoms.

Symbolic representation involves the use of symbols, reaction equations, chemical formulas, stoichiometric drawings, and diagrams. The three representations are interconnected and assist the students in understanding abstract chemical concepts. This is in accordance with Akaygun's (2016) assertion that the learning process in chemistry should involve an understanding of phenomena at the macroscopic, symbolic, and particulate levels. But the process of learning chemistry in high school in general only reveal phenomena at macroscopic, symbolic and mathematical levels whereas phenomena at the sub-microscopic level are still rarely applied. This is due to difficulties in explaining the structure, behavior, and processes that occur at the particulate level and its relation to the macroscopic level so that chemistry is being complecated.

According to Ainsworth (1999), the multi-representation-based learning have three objectives: a) to provide representations that contain complementary information or help complete the cognitive process; b) to limit the likelihood of misinterpretation in the use of other representations, and c) to encourage students to build a deep understanding of the situation. The application of learning based on multiple representations is inseparable from the role of the teacher as a learning facilitator. Teachers must also be able to apply effective learning, hit on the expected goals, and can help students work and think themselves so that learning chemistry will be more meaningful. One of the learning models that can be applied is the problem-solving learning model. Problem-solving is what a person does when the person does not know what to do (Gulacar, Bowman, & Feakes, 2013). Robertson (2001) says that problem-solving is something that involves a path to a goal. Meanwhile, Posamentier & Krulik (2009) said problem-solving is a way of thinking. That is, students can not exploit learning to overcome problems with no regard to techniques in the process. The problem-solving learning model will be possible for improving students' learning motivation and providing challenges for authentic learning.

According to Polya (Polya, 1957), problem-solving is defined as the search for some appropriate action to achieve a goal that is clearly understood but not immediately achieved. Furthermore, he states that there are four steps to be taken to solve the problem: understanding problems, making plans, implementing plans and looking back. Based on the above explanation it can be said that the problem-solving learning model is one of the way for students to solve the problem by analytical thinking for achieving the desired goal. But in fact, many students solve chemical problems using only mathematical strategies but do not understand their chemical concepts well (Cracolice, Deming, & Ehlert, 2008). Therefore, problem-solving learning model based on multiple representations in chemistry can help students to understand the concepts of chemistry.

Purpose of the study

The purpose of this research was two-fold. The first was to identify the difficulty level of various types of chemical representation for students on chemical equilibrium. The second was to examine the effects of two different model of teaching and learning chemistry (problem-solving based on multiple representations and problem-solving) on the students' cognitive achievement representtions in chemical equilibrium.

Research question of the study

The study aimed to answer the following research questions:

1. What kind/type of representations are most difficult/easily understood by students in chemical equilibrium?
2. Is there significant difference in students' mean cognitive learning scores in chemical equilibrium among the two groups?

Methodology

Research design

A quasi-experimental research design with a non equivalent control group and a posttest-only was used in this study. Two intact groups were utilized in the study. One group used the problem-solving learning model based on multiple representations while the other group used the problem-solving learning model. The problem-solving learning model based on multiple representations was as an experiment group, while the problem-solving learning model was a control group. The research design is listed in Table 1.

Table 1. Quasi-experimental research design with an equivalent control group and a posttest-only

Group	Pre-treatment	Treatment	Post-treatment
Experiment	-	X	P1
Control	-	Y	P1

P_1 = Student's cognitive learning achievement
X = Problem-solving learning model based on multiple representations,
Y = Problem-solving learning model

Sample

The study was carried out with 50 students and was conducted in one of the senior high schools in Yogyakarta (Indonesia) on 11th-grade which divided in two groups: an experiment group (26 students: 11 male and 15 female) and a control group (24 students: 15 male and 9 female). This research was conducted from October to November 2017.

Instruments

The students' cognitive achievement test (SCAT) was prepared and developed by the authors. It was implemented as posttest 29 items were implemented in the research and the items were four choices. The purpose of SCAT is to determine the types of student representation of conceptual understanding related to the topic of chemical equilibrium and to express alternative representations of the subject. The SCAT was carried out after the treatment of experimental model and control model. Other instruments were made by researchers to support teaching and learning process of learning instrument that is Learning Implementation Plan based on the syllabus in school and student worksheet. Two experts in chemistry education reviewed each item and the content validity of the SCAT. The items were revised based on suggestions submitted by the experts. Chemical content, an indicator of competency, type of representation and cognitive level of the instrument are shown in Table 2.

Table 2. Grid question to measure student's cognitive learning achievement

Chemistry content	Indicator of competency	Question No.	Type of representation	Cognitive Level (Bloom)
Reversible and irreversible reaction	Write down the equation for reversible and irreversible reaction	1	Symbolic	C1
		2	Symbolic and microscopic	C4

	Differentiating reversible and irreversible reaction	3	Microscopic	C1
		4	Macroscopic	C4
Dynamic equilibrium	Describes dynamic equilibrium	5	Macroscopic	C2
	Write down the reactions that occur in dynamic equilibrium and explain the mechanisms that occur at the submicroscopic level	6	Symbolic and microscopic	C3
		7	Symbolic	C2
Homogeneous and heterogeneous equilibrium	Distinguish homogeneous and heterogeneous equilibrium	8	Symbolic	C2
		9	Symbolic and mathematics	C3
Factors that affect the shift in equilibrium	Predict the direction of equilibrium shift by using Le Chatelier principle	10	Symbolic and macroscopic	C2
		11	Symbolic and macroscopic	C2
		12	Microscopic and mathematics	C3
		13	Symbolic	C2
		14	Microscopic, symbolic and mathematics	C4
	Analyze the effect of change of concentration, pressure, volume and temperature on equilibrium shift through experiment	15	Macroscopic and symbolic	C4
		16	Macroscopic and symbolic	C2
		17	Macroscopic	C3
		18	Macroscopic, symbolic and mathematics	C4
Equilibrium constant	Determine the equilibrium constant of a reaction	19	Symbolic and mathematics	C2
		20	Microscopic and symbolic	C3
		21	Symbolic and mathematics	C3
		22	Microscopic, symbolic and mathematics	C3
	Calculates the K*c* price based on the concentration of the substance in equilibrium and the K*p* price based on the partial pressure of reactant gas and the reaction product in equilibrium	23	Symbolic and mathematics	C3
		24	Microscopic and Symbolic	C4
		25	Microscopic and mathematics	C3
		26	Symbolic and mathematics	C3
	Determine the relationship between K*c*, K*p*, and degree of dissociation	27	Symbolic and mathematics	C3
		28	Symbolic and mathematics	C2
	Interpreting experimental data on reagent concentrations and reaction products in	29	Symbolic and mathematics	C3

	equilibrium to determine dissociation and equilibrium levels			

Table 2 above is an instrument grid that has not been tested for its validity and reliability. Based on the validation result, the question of no 2 da 12 is not valid and reliable so it is not used for the next step.

Validity and Reliability Instrument

Validity

The instrument consisting of 29 multiple choice questions has been validated in the form of content validation and item analysis. The content validation was done by two experts. The items are analyzed by using the RASCH model with WINSTEPS 3.73 program to determine that the item matches the model or not. According to Boone et al. (2014), the criteria used to check the suitability of outliers or misfits in the RASCH model are

- The value of outfit mean square (MNSQ) received: 0.5 < MNSQ < 1.5
- The accepted Z-standard (ZSTD) outfit value: -2.0 < ZSTD < +2,0
- Point Measure Correlation Value (Pt mean Corr.): 0.4 < Pt Measure Corr. < 0.85

Outfit mean square, outfit Z-standard, and Point Measure Correlation (Pt Measure Corr.) values are the criteria used to see the suitability level of items (item fit). If the item does not meet all three criteria, then the item is not good so it needs to be repaired or replaced. But if the item meets at least one of the criteria, then the item can be maintained. Based on Rasch analysis, there two items are deleted because it is not fit to Rasch model.

Reliabilit

Based on the results of analysis using RASCH model of 27 tested questions, obtained the reliability value as follows

a)The Cronbach alpha value obtained is 0.87. This indicates that the interaction between the person and the items as a whole is very good.

b)The value of Person Reliability generated is 0.86 while the Item Reliability value is 0.91. This shows that consistency of students in answering questions is included in the good criteria and the quality of items in the instrument has a very good reliability aspect.

Analysis of items

Wright map analysis (person-Item Map)

This analysis is done to know the distribution of students' ability and distribution of problem difficulty level with the same scale. This analysis will show the most difficult and easiest items to solve by students. The analysis was conducted separately from the experiment group and the control group to be able to determine the effect of applying the problem-solving model based on multiple representations and the problem-solving model.

The questionnaire items consisting of 27 questions tested on the students were analyzed using the Rasch model to determine the distribution of students 'abilities and the distribution of students' difficulty levels. The result of item analysis by Rasch model in the experimental group shows that the item No. 24 and 23 are most difficult, while the No. 3, 10, 16, and 26 are easiest. In the control group, the No. 7, 8 and 22 are most difficult, while the No. 1 and 10 are easiest. The item measure is determined by *logit* number. Table 3 present the *logit* number of the item. The result of analysis of all items are depicted in Figure 1 for both the experiment group and control group.

Table 3. The *logit* number of the item.

Group	**Item number**	**Measure** (*logit* number)	**Difficulty level**
Experimental Group	24	3.03	Most difficult
	23	2.55	
	3	-3.30	Easiest
	10	-3.30	
	16	-3.30	
	26	-3.30	
Control group	7	3.19	Most difficult
	8	3.19	
	22	3.19	
	1	-4.59	Easiest
	10	-4.59	

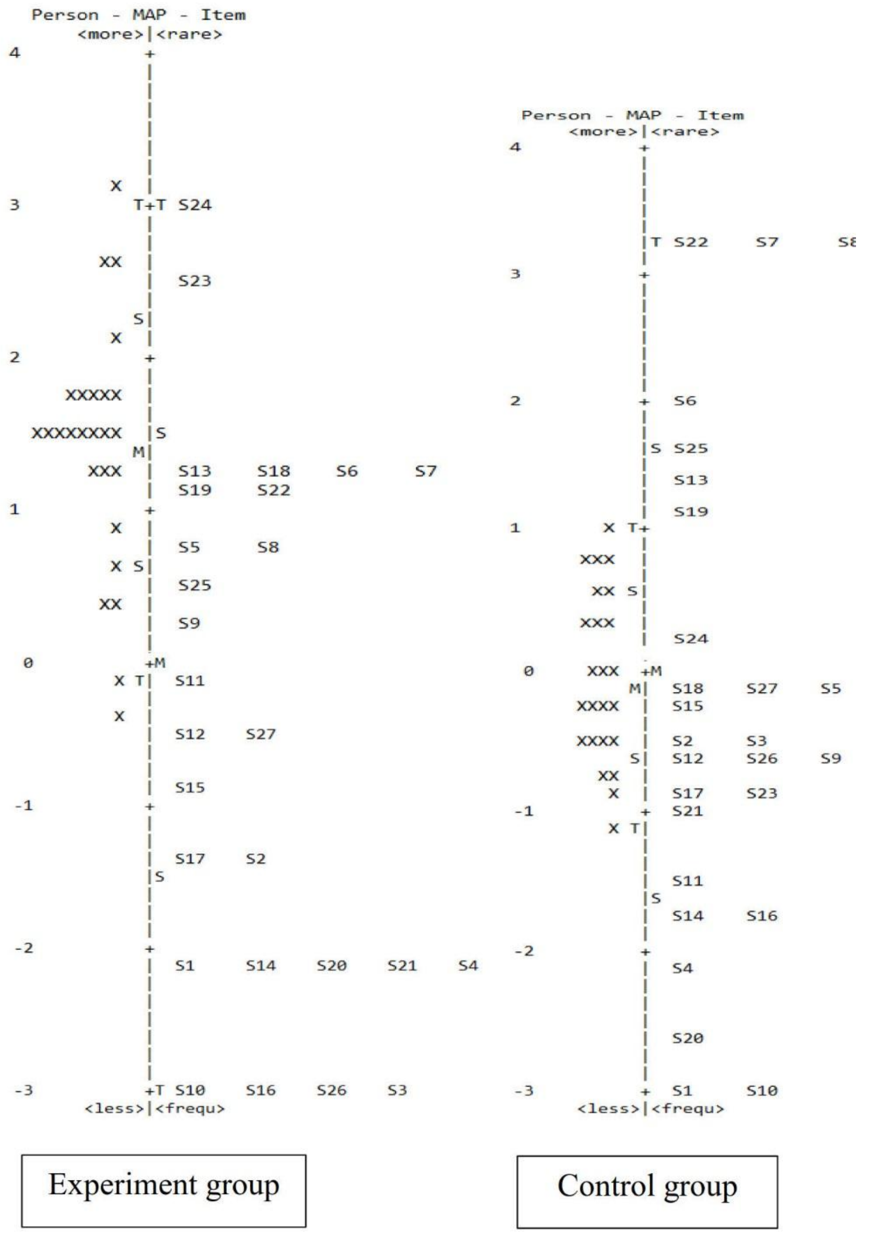


Figure 1. Item map in the experiment group and the control group

Data analysis technique

Prior to the inferential statistical analysis, it is necessary to perform prerequisite analysis first with the data normality test and homogeneity test of each sample.

a) Normality Test

Normality test using Kolmogorov Smirnov (K-S) test (Chakravarti, Laha, & Roy, 1967). The test criteria are data derived from normally distributed populations if the probability of significance value ($p > 0.05$), and the population is not normally distributed if the value of significance ($p < 0.05$).

b) Homogeneity test

Homogeneity test used in this research is Levene test (Levene, 1960). Homogeneity test aims to find out the homogeneity of variance for each class. Homogeneity test in this research using test result data on previous material that is reaction rate. Testing criterion is experiment class variance and control group is homogeneous if value significance > 0,05 whereas if significance value <0,05 then stated data distribution is not homogeneous.

c)The Independent t- test

If normality and homogeneity are met, then it is followed by an independent test of t-test (Snedecor & Cochran, 1989). This test is used to find out whether there is an average difference between two unpaired samples. The basic decision-making in this test is:

- If Sig. (2-tailed) < 0.05, then there is a significant difference in student cognitive achievement between the experimental group and the control group
- If Sig. (2-tailed) > 0.05, there was no significant difference in student cognitive achievement between the experimental group and the control group

Results and interpretations

The most difficult and easiest type of chemical representation is answered by the students in the experiment group

Based on the results of the above analysis, of the 27 questions given the most difficult questions answered by students in the experiment group are No. 24 and 23. Problem No. 24 only successfully answered by 5 students while the No. 23 successfully answered by 7 students. Both of the two questions are questions that have a kind of mathematical representation. The type of problem is as follows

- ***Item No. 24***

In a space of 5 L at a certain temperature, there is equilibrium

$2SO_3(g) \leftrightarrow 2SO_2(g) + O_2(g)$. If 160 grams of SO_3 (Ar S = 32, O = 16) is heated to that temperature until equilibrium is reached, and the mole ratio of SO_3: O_2 = 4: 2 then the equilibrium constant of the reaction is ...

- ***Item No. 23***

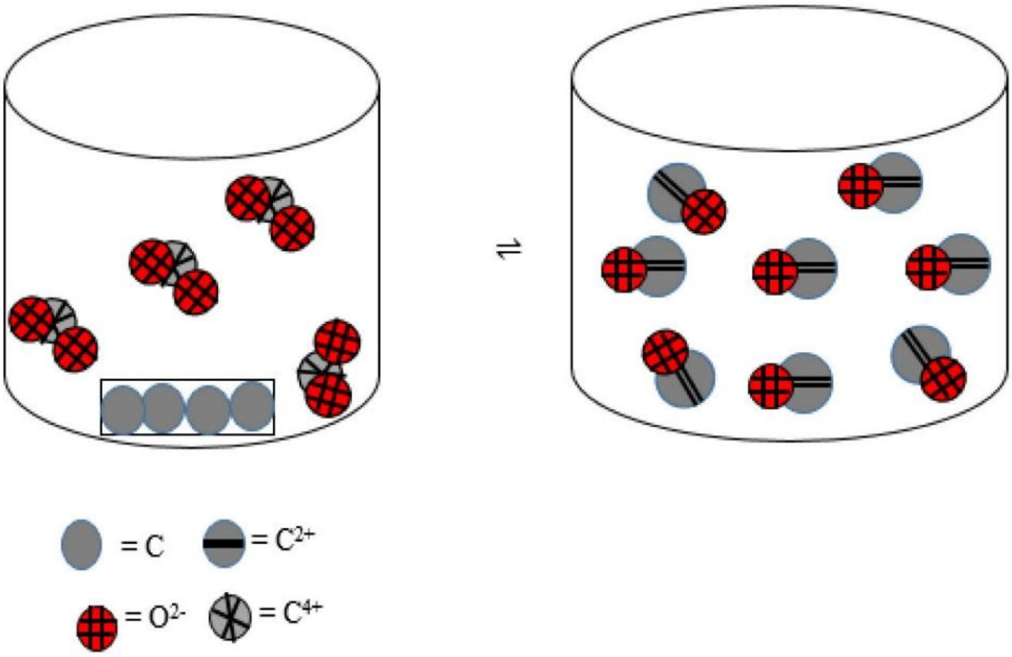
Into a 10 L volume container, 8 mol of NH_3 is introduced so that the reaction occurs: $2NH_3$ (g) ↔ N_2 (g) + $3H_2$ (g). If in equilibrium state there are 4 mol of NH3, then the Kc price for the equilibrium reaction is ...

While the most easily answered questions by students in the experiment group are questions No. 3, 10, 16, and 26. Problem No. 10 is a symbolic representation, while No. 3, 16, and 26 are symbolic and macroscopic representations.

The type of representation most difficult and most easily answered by students in the control group

Based on the results of the analysis, of the 27 questions given, there are 3 questions that are considered the most difficult by students that are the No. 7, 8 and 22. The three questions above include submicroscopic and mathematical representations. Type of question is as follows

- ***Item No. 7***



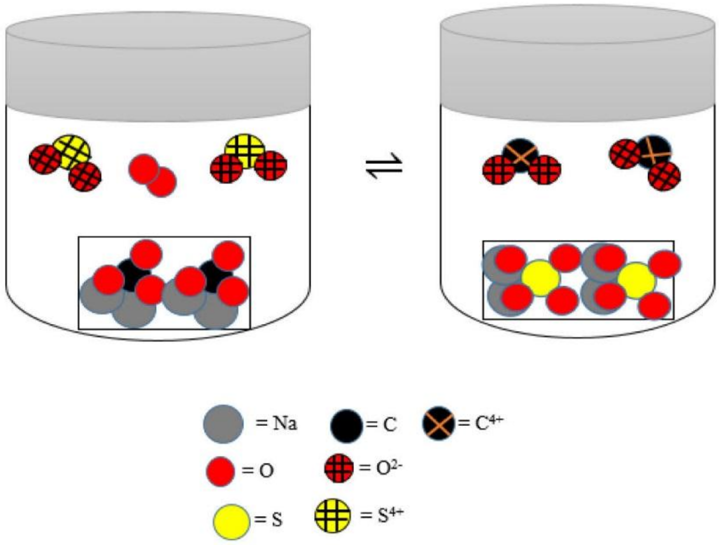
If at a temperature of 270C, the price of Kc = 1.6 x 10-2 Kp price is ...

- ***Item No. 8***

At a certain temperature, in space, 1L HI gas is introduced and decomposes according to the equilibrium reaction of 2HI (g) ↔H_2 (g) + I_2 (g). If the equilibrium state of H_2 is equal to HI mol, then the degree of dissociation HI is…

- ***Item No. 22***

Consider the mechanism of equilibrium reaction at the following submicroscopic level



The equilibrium constant (K*c*) of the reaction is ...

The most easily answered questions by students are questions of No. 1 and 10 that contain a type of symbolic representation.

Parametric statistical test

Prior to the parametric statistical analysis, a preliminary analysis is necessary to perform the data normality test and homogeneity test of each sample.

- ***Normality Test***

Normality test results data between experiment and control groups can be seen in Table 4.

Table 4. Normality test results

Class	Sig. Kolmogorov Smirnoff	Conclusion
Experiment	0,678	Normal
Control	0,722	Normal

Based on the above table it can be seen that the significance value of the calculation results in each class is greater than the significance value $\alpha = 0.05$. Thus the data comes from normally distributed populations and meets the assumptions for performing statistical parametric tests.

- ***Homogeneity Test***

Homogeneity test used in this research is Levene test. Homogeneity test used to know the homogeneity of variance for each class. Homogeneity test in this research using test result data on previous material that is reaction rate. Testing criterion is experiment class variance and control group is homogeneous if value significance > 0,05 whereas if significance value <0,05 then stated data distribution is not homogeneous. The results of the analysis can be seen in the Table 5.

Table 5. Homogeneity test results

Group	Uji Levene				Conclusion
	F	df1	df2	Sig	
Experiment and control	1,668	1	48	0,682	Homogenous

From the table above can be seen that the value of significance obtained by 0.682 greater than the significance value $\alpha = 0.05$. Thus this data is homogeneous and meets the assumptions for parametric statistical tests.

Based on the normality and homogeneity test which states that the data is normalized and homogeneous, then it is continued with the hypothesis test. Hypothesis test in this research using independent sample t-test. The test was performed to determine whether there were differences in the mean of two unpaired samples. The results of the independent sample t-test test shows that there is a significant difference in the students' cognitive learning outcomes between experiment group with a control group on chemical equilibrium. The value of significance (2-tailed) produced is 0.000 < 0.05.

Discussion

The most difficult and easiest type of chemical representation is answered by the students in the experiment group

This study aims to find out the most difficult and easiest representation types for students and to know differences in chemical equilibrium learning outcomes in the experiment group and control group. Jhonstone (1993) says that studying chemistry should involve macroscopic, submicroscopic and symbolic representations so that when students learn will connect the three representations. Meanwhile, the research conducted by Chandrasegaran, Treagust, and Mocerino (2007) revealed that there are indications of students experiencing confusion about the chemical representation. Students are confused in connecting macroscopic representations with microscopic as well as having a limitation of caution about symbolic representations. This is what underlies the application of problem-based problem-solving model based on multiple representations. Selection of problem-solving model based on multiple representations is expected not only students can solve problems from the mathematical aspect, but can comprehend the concept of chemistry as a whole.

In this study, students were given tests of material that included macroscopic, submicroscopic, symbolic and mathematical representations, and contained cognitive levels from C1 to C4. Based on the results of the analysis using RASCH Model, from 27 questions given problems that are difficult to answer by students is a matter of No. 24 and No. 23. Problem No. 24 only successfully answered by 5 students while question No. 23 successfully answered by 7 students. Both of the above questions are a matter of loading the kind of mathematical representation. Students in the experiment group have difficulty in answering because of miscalculation. However, in the case of macroscopic, submicroscopic and symbolic representations, most of the students in the experiment group can answer it can be seen on the wright map above. While the most easily answered questions by students in the experiment group are questions No. 3, 10, 16, and 26. Problem No. 10 is a matter of symbolic representation, while No. 3, 16, and 26 contain symbolic and macroscopic representations.

The most difficult and easiest type of chemical representation is answered by the students in the control group

Students in the control group are taught with a problem-solving learning model without multiple representations. Based on the results of the analysis, of the 27 questions given, there are 3 questions that are considered the most difficult by students that are the questions of No. 7, 8 and 22. Each of these problems can only be answered correctly by one student.

The three questions above include submicroscopic and mathematical representations. While the most easily solved problem by students is the No. 1 and 10 questions that contain a type of symbolic representation. Based on this result, it can be said that the students in the control group have difficulty in solving the chemical problems based on multiple representations. This aligns with the result of research by Wang & Barrow (2013) indicating a learning method which did not integrate sub-micro and symbolic representations, results in the students having difficulties drawing and explaining the Bohr atom model in detail (and accuracy). According to Kosma & Russell (1997), this can happen because students do not understand how to relate submicroscopic representations to symbolic representations, whereas Krajcik (1991) says that students find interpretations of a phenomenon presented in a symbolic type that is difficult to interpret into appropriate submicroscopic types. Therefore, chemistry learning should be able to direct students to truly understand the submicroscopic representation so that students can understand the chemical concept correctly.

Differences in student cognitive achievement between experiment and control groups

Based on the result of difference test of student achievement between experiment and control group, obtained value of significance (2-tailed) resulted is 0.000 < from 0,05. This shows that there is a significant difference in the students' cognitive learning outcomes between the groups taught by the problem-solving learning model based on multiple representations and the problem-solving learning models without multiple representations on chemical equilibrium materials. Based on the result of posttest given, the mean score of the experiment group student is 73,42 while the control group is 55,08. The results of this study are in line with research conducted by Sunyono, Yuanita & Ibrahim (2015) who say that the learning method which integrates all three phenomena (macro, sub-microphone and symbolic) in chemistry education becomes very important in improving the students' reasoning abilities. Meanwhile, Guzel and Adadan (2013) showed that a learning method designed with comprehensive representation instruction may result in a more indepth comprehensive of chemical representation, which can be retained for up to 17 months. The results research conducted by Mocerino (2009) also show that treated groups in the form of multi-representation-based learning have higher learning achievement.

Conclusion

Based on the results of this study it can be concluded

1. The type of representation most difficult to solve by the students in the experiment group (problem-solving based on multiple representations model) is the mathematical representation, and the easiest are the macroscopic and symbolic representation. While in the control group (problem-solving model), the type of representation most difficult to solve by the students are the submicroscopic and mathematical representation, and the easiest is the symbolic representation.
2. There is a difference of students' cognitive learning achievement mean score between the experimental group and the control group.

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