Multiple Representations Skill of High School Students on Reaction Rate Material

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Abstract

This reserach discusses student's skill profile in multiple-representation based Chemistry test. Multiple representations which were being investigated covered four level of representations in learning reaction rate material. They are macroscopic, microscopic, symbolic, and mathematic. The reserach subjects were 185 students of grade XI SMA/MA in Yogyakarta. The profile of students' representation skill was analyzed by employing ideal assessment criteria. The research result showed that the profile of students' representation skill in Yogyakarta was categorized low, averaging in score of 64.69. The highest percentage of students' achievements was on macroscopic level and the lowest one was on microscopic level. The order of students' representation skill when learning reaction rate material from the highest to the lowest were macroscopic, symbolic, mathematic, and then microscopic level.

Keywords: multiple representation, chemical reaction rate

Introduction

Chemistry is a field of study which is part of natural science. One of its discussion coverage is an interaction between atoms that makes the explanation tends to be abstract (Kean & Middlecamp, 2010:1-5). In addition to its abstract characteristic, concepts on Chemistry also include mathematical calculation so that it needs a mathematic skill to complete chemical problems (Hafsah, et al, 2014). Gibert (2006) in his research result discussed various problems which frequently happen during the process of teaching and learning Chemistry. The problems are the abundant Chemistry materials which load diverse representations and the process of delivering chemical concepts at school which was opposing the actual fact on the field.

Based on the observation result in SMA in Yogyakarta, Chemistry materials taught at school only covered some concepts which are concrete (macroscopic), for instance conducting a practical work on chemical reaction rate. Students knew that reaction rate of Mg powder is faster than Mg ribbon, which is solid. If the students were questioned why such thing could happen, they would answer that Mg powder has wider surface area than Mg ribbon. Meanwhile, if the question continued to “why does the reaction rate of a substance with wider surface area go faster?” and “how is the picture of interaction between both molecules?”, students were getting confused. Students were not accustomed to express a macroscopic phenomenon from an experiential practice into a microsopic phenomenon which could be represented to a pictorial visualization or symbols.

There were several researches which had been done previously which also revealed that students were still finding difficulties in transforming macroscopic representation into microscopic and symbolic representations (Devetak, et al., 2009 and Davidowitz, et al., 2010). Johnstone (2000) believed that difficulties which are frequently faced by students in learning Chemistry are actually combining the three level of Chemical representations consisting of macroscopic, microscopic, and symbolic. Hafsah (2014) added that Chemistry concepts understood by the students had not been resolved yet if they were not skillful enough in doing mathematical calculation. The problems of students' transforming chemical representation level aforementioned were caused by the multiple-representation based teaching of Chemistry which has not been taught yet to students at school (Sunyono, Yuanita, & Ibrahim, 2015). According to those researches, it can be concluded that Chemistry teaching and learning should be taught by using multiple representation model so that students could thoroughly understand the materials.

Multiple representation is a chemical representation which covers several aspects such as macroscopic, microscopic, symbolic and mathematic (Johnstone, 2000; Cheng & Gilbert, 2009; Hafsah, *et al*, 2014). Kozma (2003) defined multiple representation as a kind of representation which combines text, picture, or graphic. Through multiple representation learning, it is expected to assisst the students in understanding Chemistry concepts from the four level of representations, either macroscopic, microscopi, symbolic, or mathematic level.

Macroscopic is a chemical representation which is acquired from real experience or experiment (Li & Arshad, 2014). The evident form of macroscopic representation can be what we can see, touch, and feel (Johnstone, 2000). On the other hand, microscopic is defined as a chemical representation in the form of visualization of atom, ion, molecule in a chemical reaction (Bucat & Mocerino, 2009). The existence of microscopic representation is expected to give a complete description of chemical reaction (Davidowits, et al., 2010).

Talanquer (2011) defined symbolic representation as a chemical representation which comprises the symbol itself or icon as a medium to describe the symbol of atom, characteristics, phase, and the equation of chemical reaction. Symbolic description in an instrument was expressed through written symbols of unsure, compound, substance phase, graphic and table representation, as well as written chemical reaction which is equal. The next representation level is mathematical representation. Mathematical representation is defined as a representation which covers a chemical calculation. Mathematical calculation represented in Chemistry benefits the understanding of the basic concept of Chemistry in problem sovling (Hafsah, et al., 2014).

According to the definitions aforementioned, macroscopic representation can be understood as chemical representationa which is studied through tangible observation. The observation can be done through daily life phenomena or experiments. If it relies on an experiment, how a reaction happens could be revealed. The process of chemical reaction is investigated through microscopic representation. The result of the experiment can be described in the form of table, graphic, picture and reaction equation. A capability in describing the result is studied through symbolic representation. Chemical reaction could possibly happen fast and slowly. The rate of a reaction needs mathematical calculation in order to decide how big the rate of reaction being investigated is through mathematical representation.

Cheng & Gilbert (2009) conducted a research on an attempt of improving chemical representations skill through pictures. This research carried out a study on how students could represent a chemical reaction in a picture. One of representative aspects being measured was microscopic representation skill. On the exercise, it was delivered a reaction between $NiCl_2$ and NaOH. Students were asked to draw the reaction result of $NiCl_2$ and NaOH. Those who had good microscopic representation would draw appropriate reaction result based on the shape of the molecules and its numbers in reaction equation which is equal.

Chemistry concepts which are based on multiple representation can be implemented appropriately in teaching and learning process as well as in the evaluation of students' learning result. Profile of students' multiple-representation skill can be measured by using an instrument of multiple-representation based Chemistry test. The instrument being arranged should meet valid criteria that is able to have absolute measurement when measuring things that are wanted to be measured and to be reliable (consistent or stable) in assessing what should be assessed (Rahman, et al., 2016). Multiple-representation based Chemistry test aimed to make the test being arranged represent the four chemical representations level, i.e. macroscopic, microscopic, symbolic and mathematic.

Method

This research used a qualitative descriptive research design. The subject of measuring chemical representations profile was 185 students in grade XI of SMA/MA in the city of Yogyakarta. The schools taking part in this research were chosen only if they implemented Curriculum 2013. Students' profile was measured by using instrument of multiple-representation based Chemistry test which has been proven valid and reliable. The test instrument consisted of 27 test items with medium level of difficulty. Profile analysis on chemical representations skill of the students was measured by using ideal criteria of assessment which is delivered on Table 1.

Table 1. Ideal Criteria of Profile Assessment

No.	*Score range*					*Categoty*
1	$\vec{X}_i + 1{,}8\ SB_i$	$<$	X			*Very high*
2	$\vec{X}_i + 0{,}6\ SB_i$	$<$	X	$\leq$	$\vec{X}_i + 1{,}8\ SB_i$	*High*
3	$\vec{X}_i - 0{,}6\ SB_i$	$<$	X	$\leq$	$\vec{X}_i + 0{,}6\ SB_i$	*Fair*
4	$\vec{X}_i - 1{,}8\ SB_i$	$<$	X	$\leq$	$\vec{X}_i - 0{,}6\ SB_i$	*Low*
5			X	$\leq$	$\vec{X}_i - 1{,}8\ SB_i$	*Very low*

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Result and Discussion

Chemical representations skill brought up in this research are students' skill in answering multiple-representation based Chemistry test. Multiple representations being studied consisted of several representations namely macroscopic, microscopic, symbolic, and mathematic (Johnstone, 2000; Cheng & Gilbert, 2009; Hafsah, *et al*, 2014). According to the analysis result, it generates a conclusion that students' chemical representations skill was categorized low, averaging in score of 64.69. The spread of students' multiple representation skill profile in grade XI is exposed in Figure 1.

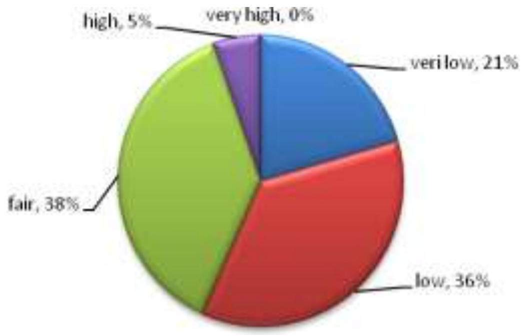

Fig. 1. The spread of students' multiple representation skill in grade XI SMA/MA

Figure 1 informs the spread of students' multiple representation skill in grade XI SMA/MA. According to Figure 1, it can be concluded that the greatest spread of students' multiple representation skill was categorized low by 38% percentage in points. Multiple representation investigated in this research covered 4 level of representation, which are macroscopic, microscopic, symbolic, and mathematic. The result of the spread of students' multiple representation skill was analyzed further to find out the percentage of students' achievement in each level of representation. The analysis result of percentage of students' achievement in each level of representation is shown on Figure 2.

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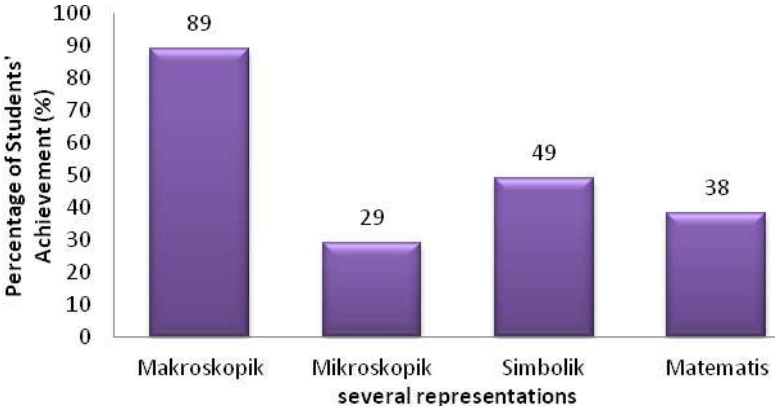

Fig. 2. Percentage of Students' Achievement in Each Level of Representation

Discussion in this research comprises 2 steps, that are analysis of representation level and students' chemical representations skill profile. Analysis of representation level being discussed was several representation levels which cover macroscopic, microscopic, symbolic and mathematic. On the other hand, students' Chemical representations skill profile that will be discussed are mostly concerned on students' profile in Chemical representations on macroscopic, microscopic, symbolic, and mathematic level.

Analysis of Representation Level

Test instrument used in measuring chemical representations skill profile was in the form of a multiple representation based test on chemical reaction rate material. Reaction rate was chosen since this material loads chemical representations, either macroscopic, microscopic, symbolic or mathematic. Macroscopic level can be observed through reaction rate, both fast and slow reaction. On the other hand, microscopic level can be considered through whether a chemical reaction is effective or not. Symbolic representation is investigated through picture, table, graphic, chemical pattern, and the equation of chemical reaction. Mathematic representation is studied through the calculation of the average of reaction rate and the chemical reaction order (Herawati, et al., 2013).

Macroscopic Representation

Macroscopic representation is a chemical representation which can be obtained from the real eperience or experiment (Li & Arshad, 2014). The real form of macroscopic representation can be in the form of what we see, touch, and feel

(Johnstone, 2000). Macroscopic representation in the test instrument was developed into 7 test items. The example of macroscopic representation developed in the instrument was depicted in Figure 3 and 4.

7. Tia melakukan percobaan untuk menguji faktor laju reaksi kimia. Tia meletakkan 2 gelas beker di atas meja. Gelas beker pertama diisi paku dengan massa 0,2 gram, sedangkan gelas beker kedua diisi serbuk Fe dengan massa yang sama yaitu 0,2 gram. Masing-masing gelas kemudian ditambahkan 10 mL larutan HCl 2 M secara bersamaan. Hasil pengamatan dapat disajikan pada gambar berikut.

Gambar 1. Reaksi Paku + HCl 2 M   Gambar 2. Reaksi serbuk Fe + HCl 2 M

Pertanyaan:

a. Amatilah kedua gambar di atas, kemudian tuliskan informasi apa saja yang kamu dapatkan dari kedua gambar di atas?

Fig. 3. Macroscopic representation of Nail Reaction and Fe powder + HCl solution

Figure 3 reveals an example of macroscopic representation in the instrument. Macroscopic representation delivered in the picture was a reaction between nail and Fe powder in HCl solution. On the test item, students were asked to write down any information that they obtained after observing the pictures. The test item shown on Figure 3 makes the students answer the problems easily and correctly. The majority of students answered that reaction rate on Fe powder was faster than on nail. This can be seen through the number of bubbles produced after being reacted to HCl 2 M solution. Nail is solid so that it only has one-sided surface. Bubbles it produced only appeared on its surface as well. On the other side, Fe powder which has many surface area created well-spreaded bubbles all over its surface. Another macroscopic representation can be observed on Figure 4.

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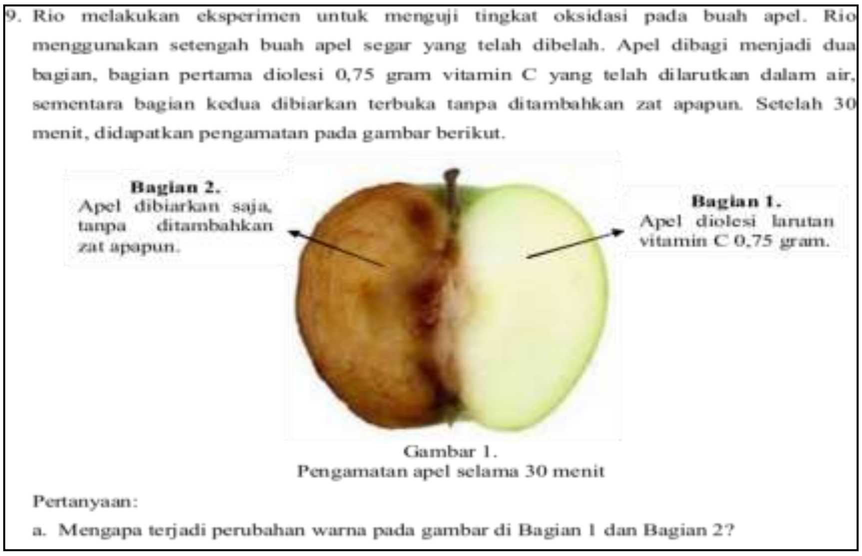
9. Rio melakukan eksperimen untuk menguji tingkat oksidasi pada buah apel. Rio menggunakan setengah buah apel segar yang telah dibelah. Apel dibagi menjadi dua bagian, bagian pertama diolesi 0,75 gram vitamin C yang telah dilarutkan dalam air, sementara bagian kedua dibiarkan terbuka tanpa ditambahkan zat apapun. Setelah 30 menit, didapatkan pengamatan pada gambar berikut.

Gambar 1.
Pengamatan apel selama 30 menit

Pertanyaan:

a. Mengapa terjadi perubahan warna pada gambar di Bagian 1 dan Bagian 2?

Fig. 4. Macroscopic Representation on the reaction of Apple Oxidation

Figure 4 also shows an example of macroscopic representation in a test being developed. Macroscopic representation which was developed comprised an observation on an apple which was let open in an open air and another one was lubricated with vitamin C. On the test item, students were asked to explain why there had been a color change on the apple lubricated with vitamin C and another one which was not.

There were a few students who could answer the question exposed on Figure 4 correctly. The test item on Figure 4 was related to the oxidation reaction of the apple. Vitamin C added to the first part was used as the inhibitor of oxidation, since vitamin C is actually an antioxidant. The additional vitamin C in part 1 made the apple's surface being covered by vitamin C so that the reaction between the apple and the air was inhibited. In contrast to the second part of the apple which was let open without any additional substance, it directly interacted with air. This interaction caused the apple oxidated which was marked by the change of apple color which was browned. Most of the students found it difficult to explain the role of vitamin C added to the apple. There were many students who stated that vitamin C was the reaction catalisator instead of the inhibitor.

Microscopic Respresentation

Microscopic representation studied in the test instrument was in the form of visualization of atom, ion, molecules in a chemical reaction (Bucat & Mocerino, 2009). Microscopic representation developed in the test instrument comprised 4 test items. The example of microscopic representation developed in the test instrument can be seen in Figure 5.

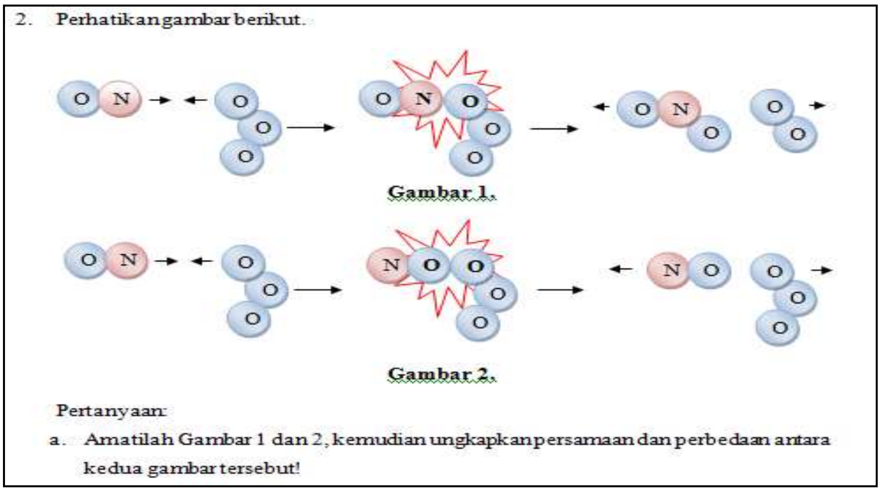

Fig. 5. Example of microscopic representation

Figure 5 informs the example of microscopic representation which was developed into test item. The item loads a concept of a collision between atoms which could create effective and ineffective collision. Students were asked to analyze and state the similarities and differences in regards to the interaction between atoms in both pictures shown.

There were several students who were capable of answering the question in Figure 5 correctly. The test item in Figure 5 is related to the effectiveness of a collision between particles which creates a reaction. One of students' representation in answering the question in Figure 5 is exposed in Figure 6.

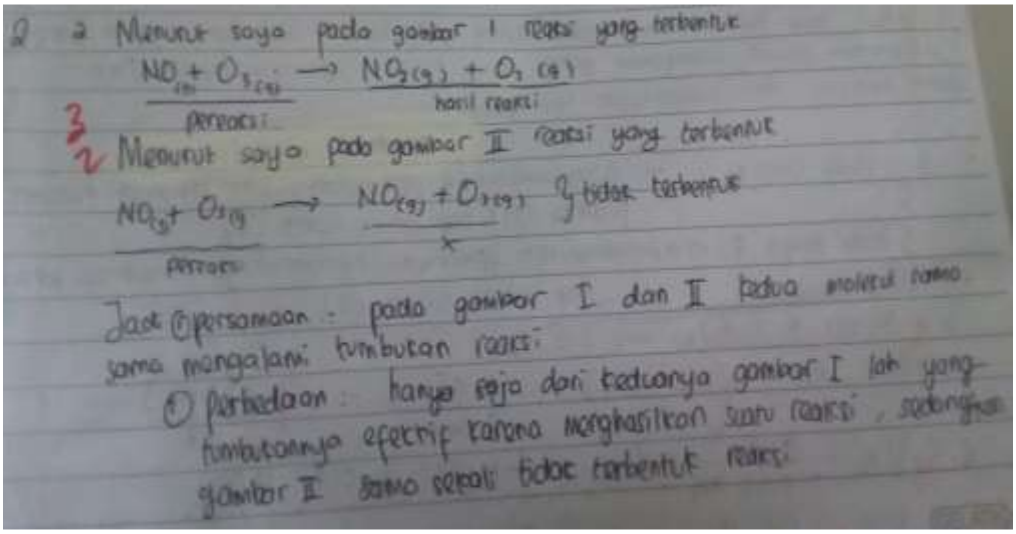

Fig. 6. Student’s answer in representing a collision betwen particles

Figure 6 reveals an information on student’s answer in representing a collision between particles. Most of the students stated the same answer for question in Figure 5 as a sample portrayed in Figure 6. Student’s answer is correct yet incomplete. The student was only capable of describing that picture 1 is an effective collision while picture 2 is not. If they were questioned further, why a collision happened in picture 1 while picture 2 did not, students would be confused. It is difficult for them to organize their ideas about the effectiveness of a collision between particles. The answer of question shown in Figure 5 should be: there shown an effective collision in picture 1 as the particles collided each other was different in types, so that it creates a trade-off between particles and caused the making of new compound. The collision between particles in picture 2 involved two similar particles that are O and O so that the orientation of the particles is not exact that it cannot create a new compound.

Symbolic Representation

Symbolic representation in the test instrument was in the form of description of graphic, table, molecule symbol, and written chemical reaction. Symbolic representation developed in the test instrument comprised 11 test items. The example of symbolic representation can be seen on Figure 7.

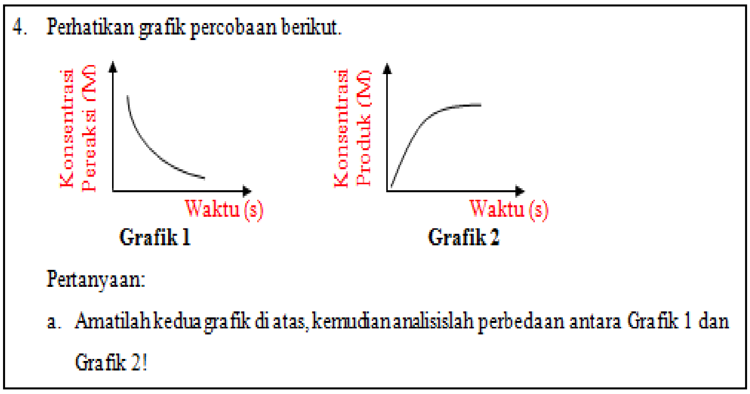

Fig. 7. The example of symbolic representation

Figure 7 gives an example concerning on symbolic representation on the test instrument developed. On the test item, 2 graphics on a relationship between concentration and time were exposed. Students were asked to analyze the differences between the two graphics.

Majority of the students could complete the problem delivered in Figure 7. Students' skill in symbolic representation is quite high so that they could answer a test item which is related to symbolic representation. One of students' answers to question in Figure 7 can be seen on Figure 8 below.

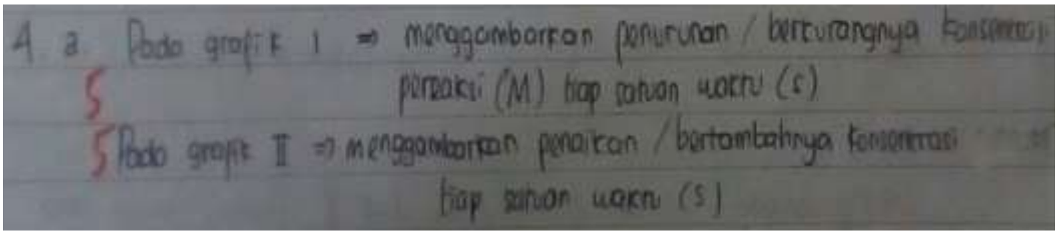

Fig. 8. Student's answer in representing the graphic of reaction rate

Figure 8 informs an example of one of students' answers in representing the graphic of reaction rate as depicted in Figure 7. On Figure 8, students could answer correctly that the differences of the two graphics showed a reduction of reagent's concentration per unit of time as portrayed in graphic 1 while graphic 2 describes the increased of product's concentration in each unit of time. Student's answer was right yet not comprehensive enough. Students could add their answers by stating that the concentration of the reagent always lowers because the reactant reacts to create a product so that the reduction on reagent's concentration happened and product's concentration increases.

Mathematic Representation

Mathematic representation in the test instrument loads a calculation on the average of reaction rate and reaction order. Mathematic test items developed in the istrument were 5 test items. The example of mathematic test instrument developed can be seen through Figure 9.

c. Reaksi $NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g)$ didapatkan data sebagai berikut.

No.	Konsentrasi (M)		Laju Reaksi
	[NO]	$[O_3]$	(M/s)
1	0,2	0,1	x
2	0,2	0,3	3x
3	0,4	0,1	4x

Jika konsentrasi [NO] 0,3 M dan $[O_3]$ 0,2 M, maka laju reaksinya adalah ....

Fig. 9. An example of mathematic representation

Figure 9 informs the example of mathematic representation on the test instrument developed. On the test, it was delivered a table of experiment result in the form of data of concentration and reaction rate. Students were asked to determine the reaction rate of a certain concentration that was a reaction rate on [NO] 0.3 M and $[O_3]$ 0.2 M concentrations.

Students were capable of answering the question depicted in Figure 8 correctly. On the test item, it was drawn a table of experiment result, a reaction between [NO] 0.3 M and $[O_3]$ 0.2 M reactions. Students were asked to determine the reaction rate between [NO] 0.3 M and $[O_3]$ 0.2 M. The first step to complete this problem is determining the order of NO and O_3, continued by determining the rate constant, and finally the reaction rate between [NO] 0.3 M and $[O_3]$ 0.2 M can be determined. The example of student's answer is shown in Figure 10.

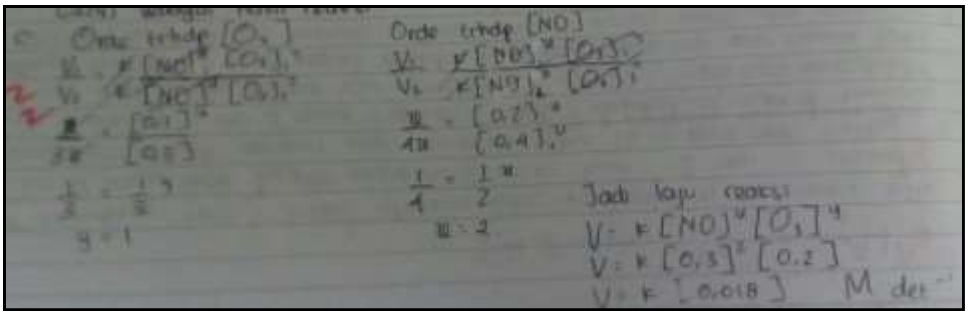

Fig. 10. The answer of student 1 in mathematic representation

Figure 10 exposes one of students' answers in mathematic representation for question given in Figure 9. The answer given by the student depicted in Figure 9 was incorrect as s/he had not decided the rate constant earlier. Majority of the students found it difficult to decide the constant so that most of their answers were incorrect. A mathematic representation from one of students' answers which was appropriate can be seen throguh Figure 11.

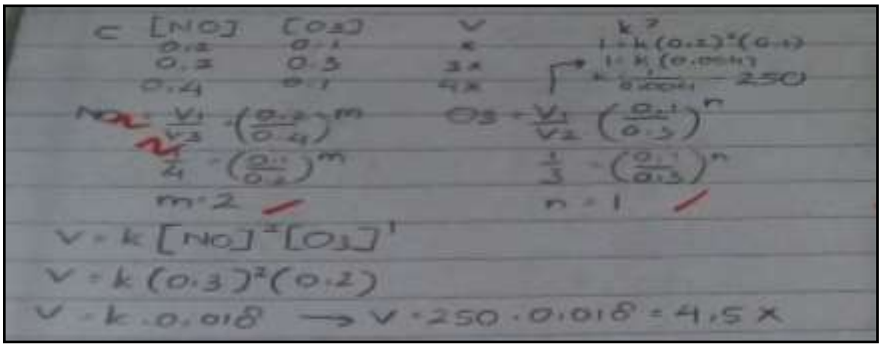

Fig. 11. An answer given by student 2 in mathematic representation

Figure 11 shows the answer given by the second student in mathematic representation. The answer depicted in Figure 11 is correct, completed by details starting from determining reaction order, rate constant, then determining the reaction rate on NO 0.3 M and O_3 0.2 M concentrations. Rate constant obtained was as big as 250 with reaction rate which is 4.5 times.

2. Chemical Representations Profile

Chemical representations skill's profile of the students can be perceived from students' skill in representing the whole test items and their achievement in representing the concepts of Chemistry on each level of representation. Test items which were represented consisted of 27 items which loaded the concept of chemical reaction rate which is based on multiple representation. The analysis result showed that students' representation skill was categorized low, averaging in score of 64.60.

According to Figure 1, it was found that the low representation skill of students in representing reaction rate material obtained the highest spread in fair category by 38% percentage in points. The percentage acquired was still fallen into low category with low-category different by 2%. The analysis result is in line with a

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research done by Li and Arshad (2014) stating that chemical representations of 10th graders in Kuala Lumpur is still categorized low since it was not easy for most of them to correlate Chemistry concepts on Redoks material in representation level.

Further analysis was conducted in order to know the percentage of students' achievement in representation level. Based on the analysis result on Figure 2, the conclusion draws the highest representation level of the students on macroscopic level, whilst the lowest one was on microscopic level. This result is equivalent with a research conducted by Talanquer (2011) revealing that students' were easier to grasp the concepts of Chemistry when it was carried out in macroscopic representation through practical work and simple experiment instead of understanding Chemistry on microscopic level.

Students' skill on microscopic representation was categorized low since a skill to identify and analyze the abstract pattern of interaction between molecules is needed (Davidowits & Cittleborough, 2009). Microscopic representation in test instrument consisted of 6 test items. One of the test items which demanded students' microscopic representation was on item 23 (item number 8c). The example of students' microscopic representation on item 23 which describes the shape of molecule of reaction result between Mg metal and HCl solution can be seen through Figure 12.

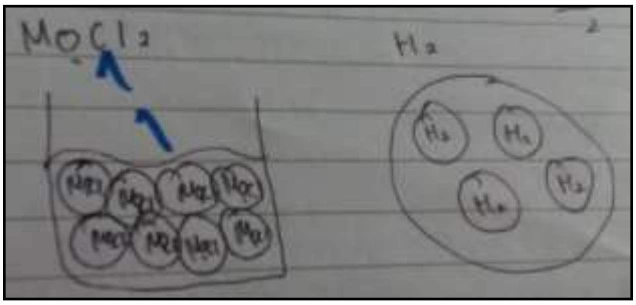

Fig. 12.Microscopic representation of student 1 in drawing the shape of molecul of reaction result of Mg and HCl

Figure 12 gives an information about students' skill on microscopic representation in depicting the profile of molecule of reaction result between Mg and HCl. According to the picture, it was revealed that students' microscopic representation was less appropriate due to some reasons. The first reason is that instead of writing $MgCl_2$, they wrote MgCl. The second reason is that molecule $MgCl_2$ and H_2 produced were put in different containers, however the reaction result of the molecules was actualy a unity. Another student's representation can be seen through Figure 13.

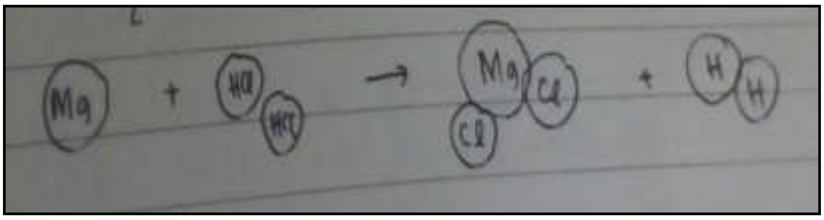

Fig. 13. Microscopic representation of student 2 in drawing the shape of molecul of reaction result of Mg and HCl

According to Figure 13, it is revealed that student's microscopic representation was incorrect. The imprecision can be seen form the shape of molecules drawn by students. They drew a Mg atom which was bigger than Cl. However Cl has bigger radius than Mg's, so that the drawing should have portrayed Cl's bigger radius than Mg's. Besides, there was no interaction of electron involved in a reaction depicted on the drawing. The other student's microscopic representation can be seen through Figure 14.

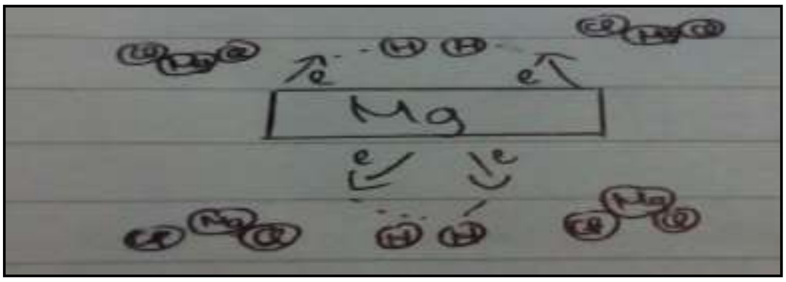

Fig. 14. Microscopic representation of student 3 in drawing the shape of molecul of reaction result of Mg and HCl

Figure 14 informs student's microscopic representation in drawing the reaction result between Mg and HCl which approximates to the answer key. The picture drawn had exposed the interaction of electrons in a reaction. Meanwhile, students' answers were still incorrect. The unsuitable answers given by students can be perceived from the drawing which depicted H_2 molecule. They drew the shape of molecule H_2 separatedly.

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In consonance with the analysis result of students' answers, it was still hard for majority of students to draw the shape of molecule as the result of microscopic representation. The portrayal of a shape of molecule must need high imagination and skill in collaborating several materials of Chemistry such as chemical bonds, shapes of molecules, reduction-oxidation reactions, and chemical reaction rate (Bucat & Mocerino, 2009).

The second lowest representation in profile analysis of students' chemical representation skill was on mathematic level by 38% percentage in points. Test item 27 loading mathematic level was also included as the most difficult item in this test instrument. Test item 27 can be seen through Figure 15.

d. Reaksi yang terjadi pada apel kemudian dilanjutkan dengan memvariasi konsentrasi vitamin C dan konsentrasi ekstrak apel. Vitamin C dimisalkan X dan ekstrak apel dimisalkan Y. Hasil pengamatan didapatkan data berikut.

No.	Konsentrasi X (M)	Konsentrasi Y (M)	Waktu (detik)
1	0,01	0,1	864
2	0,02	0,4	54
3	0,03	0,3	32
4	0,04	0,2	27

Berdasarkan data di atas, tentukan nilai k (konstanta) dari data di atas!

Fig. 15. Test Item with the lowest score on Mathematic level

Figure 15 represents an information about the test item of mathematic level with the lowest score achieved. Pursuant to the analysis result, the conclusion drawn was that test item 27 became the hardest problem since most of the students found it difficult to determine the reaction order by looking through one of similar concentrations in the table of observation result. On the table of observation result, test item 27 was not delivering the same concentration so that majority of students were confused in determining the order of reaction. Reaction order in test item 27 can be obtained by determining 2 quadratic equation x and y. If the equations has been found, the equations were then eliminated and subtituted. Mathematical quadratic equation such depicted on test item 27 had already been taught in Junior High School level. If the students have good skill in organizing numbers in periodic table appropriately, test item 27 will be much easier to do.

This research result is closely aligned with a research by Hafsah et al. (2014) stating that Chemistry concepts understood by students have not been able to be resolved appropriately if the students are not skillful in mathematical calculation. In accordance with the research result, it can be concluded that Chemistry teaching and learning at school should implement multiple representation model which combines every level of macroscopic, microscopic, symbolic, and mathematic. Chemistry teaching and learning this way is expected to organize students' knowledge thoroughly.

Conclusion

According to the research result, it can be concluded that student's chemical representation skill was categorized low, averaging in score of 64.69. The highest percentage of students' achievement was on macroscopic level and the lowest percentage was on microscopic level. The distribution of achievement percentage of students' multiple representation was as follow: macroscopic level by 89% percentage in points, microscopic 29%, symbolic 49%, and mathematic 38%. The order of students' representation on the material of chemical reaction rate from the highest was macroscopic, symbolic, mathematic, and then microscopic.

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