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Contribution of Logical Thinking Ability to Students' Achievement in Three Level of Representations in Chemical Dynamic Materials

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Abstract

This research aims to explore information about the profile of the ability of logical thinking of high school students and its effect on student achievement on three levels of representation of chemical dynamics material. This research uses a non-experimental as research design in form of survey. This research involving 242 persons of 11 grade high school students at Ketapang Regency, West Borneo Province. Sampling is done by purposive sampling as a sampling method. There are two instruments in this research, first is Test of Logical Thinking and second is Test of three levels of representations that including 25 multiple choice tests which consist of three levels of representations such as macroscopic, submicroscopic, and symbolic levels. The material raised in this test is chemical dynamics material, including the concepts of reaction rates and chemical equilibrium. The research results is based on the statistically tested findings using the Pearson correlation test, it was found that logical thinking ability had a significant effect on macroscopic, submicroscopic, and symbolic with correlation coefficients of 0.352, 0.684, and 0.564, and significance values is less than 5% each of them.

Keywords: Logical Thinking Ability, Macroscopic Representation, Submicroscopic Representation, Simbolic Representation, Chemical Dynamic

INTRODUCTION

Piaget said that when an educator can understand a child's mental development process, he will know how to do the best teaching (Bunce, 2001). The cognitive development stages of students needs to be developed according to the stages of their age. This is very important to be aware. Therefore curriculum development must continue to be adapted to meet the cognitive development stages of students (Lawson, 1978). Various efforts has also been carried out by many researchers to be able to find out the cognitive development stages of students effectively, efficiently, and accurately (Lawson, 1978).

According to Tobin and Capie (1981) the stages of cognitive development are related to the level of ability to think logically and it can be mapped using tests of cognitive development stages of respondents, namely the Test of Logical Thinking (TOLT). This test was developed by Tobin and Capie (1981) in the form of multiple choice tests with reasoned. TOLT measures logical thinking ability which includes five forms of reasoning as expressed by Lawson (1978), namely proportional reasoning, probabilistic reasoning, controlling variable, correlational reasoning, and combinatorial reasoning.

Piaget's cognitive development stages consists of 4 stages, namely the sensory motor stage until the age of 2 years, the preoperational stage from the ages of 2 until 7 years, the concrete operational stage from ages 7 until 11 years, and the formal operational stage from 11 years until adulthood (Crain, 2014). TOLT measures Piaget's cognitive development stages through three categories of TOLT total scores. If the total score of student is 0-1, then they fall into the concrete development stage category, if the total score of student is 2-3 , then they fall into the transition stage category, and If the total score of student is 4-10, then they fall into the formal development stage category. Furthermore, Valanides (1997) divides the formal development stages by adding more sub-stages, namely the rigorous formal stage, with a score range from 8 until 10. So that the score range from 4 until 7 will falls into the formal development stage.

To be able to adjust the chemistry learning curriculum to the cognitive development stages of the students, Bunce (2001) states that there are two ways that are generally teacher carried out in the teaching process. The first, teaching process is carried out by giving several concepts with low levels of difficulty, meaning concepts that most students are able to understand more easily. The second, to find ways for students to be able to develop abstract thinking that is really needed to understand the chemistry concepts, because chemistry is known to be one of the subject matter that most of the concepts are abstract.

Chemistry is one of the subjects given at the secondary school level which studies about material changes, both chemically and physically (Sunarya, 2007). Chemistry contains many abstract concepts that cannot be represented using the five senses. Many of these chemistry concepts are explained in the form of three levels of representation, namely the representation of macroscopic, submicroscopic, and symbolic.

Chandrasegaran, et al (2007) sees some errors in students' conceptions especially in reflecting between macroscopic levels into submicroscopic levels. Moreover, students still do not understand the use of symbolic level representation to describe reactions that occur at the level of submicroscopic representation.

The macroscopic level of epresentation is a chemistry representation obtained through tangible observations of a phenomenon that can be seen and perceived by the sensory level, both directly and indirectly. These observations can be obtained through daily experience, actual investigations in the laboratory, studies in the field and indirectly through simulations. Thus the macroscopic level of representation relates to everything that can be interact with our five senses.

Submicroscopic level of representation is an aspect of representation that requires the person's mental ability to construct scenarios that might occur from phenomena that cannot be observed. Submicroscopic representations are chemistry representations that explain the structure and processes at the molecular level to the macroscopic phenomena observed (Farida, 2012). Because everything that happen in this submicroscopic level will have an impact to the macroscopic phenomena observed which aim to explain the observed phenomena at the molecular level.

The symbolic level of representation of atoms and molecules can be said to describe an instant recording that is focused only on the reactions that have succeeded. Symbolic representations can be chemical formulas, equations of a reaction, stoichiometry, and mathematical calculations. According to Taber (2009), symbolic representation acts as a language of chemical equations (the language of chemical equation), so that there are rules (grammatical rules) that must be followed (Farida, 2012). According to Taber (2009), symbolic language is a very effective language used by experts in communication. Symbolic language is used as a bridge of communication between macroscopic and submicroscopic representations. According to Nahadi, Firman, and Kurniadi (2018), the national chemistry test at SMA B in the period of 2012/2013 shows that the most elements of chemistry material contains symbolic representation, such as chemical formulas, and equation of reaction, which is 47.5%.

One of the chemistry material that is considered fundamental is the chemical dynamics matter. This is as described in Permendiknas No. 14 year 2007 concerning the standard contents of A, B, and C packages, that chemistry learns everything about composition, structure and properties, changes, dynamics, and energetics of a substances (Republic of Indonesia, 2007). This was also as described in Permendiknas no. 22 year 2006 stating that chemistry lessons in schools learn about substances which include composition, structure and properties, changes, dynamics, and energetics (Republic of Indonesia, 2006). The changes described in the definition are chemical reactions with other substances. In addition, chemistry also studies the state of matter itself, before and after the changes.

Chemistry is a subject matter that involves a lot of experiments. Some processes require logic in chemistry such as collecting and analyzing data to solve problems, formulate hypotheses, controlling variables and define them operationally (Wiji, Liliasari, et al, 2014). So clearly the logic ability is needed in chemistry.

Many researches correlating between the ability to think logically and the chemistry learning achievement, but not many of these researchers correlate this logical thinking ability to the achievements of students in all three levels of chemistry representation. Based on these problems, this research aims to explore information on how the profile of logical thinking skills and the profile of three levels of representation of public high school students in Ketapang District, West Borneo Province in the chemical dynamics matter. Both of these information will be the basis of the findings of the strength level of correlation between both of them. This will be important information related to the importance of efforts to develop a high school chemistry curriculum based on the level of cognitive development of students, especially those that have an impact on students' achievements in their three levels of representation in the chemical dynamics matter.

METHOD

This research uses a quantitative approach with a non-experimental research design. This research using survey as a research method.

This study took the population of all students of elevent grade of the Public High School at Ketapang Regency, West Borneo Province. Purposive sampling method is used for sampling method. We took four schools at Ketapang Regency and then in from each of the school we took one until two class student of elevent grade. In this way finally the sample involved in the research was 242 students.

The instrument used is the Test of Logical Thinking (TOLT) and a test of three levels of chemistry representation (Galevreki Test) with chemical dynamics as a subject matter. The TOLT that used in this research is a test which developed by Tobin and Capie (1981). This TOLT was first translated into Indonesian then language validated by a linguists (a professional who have an expert in translation between english and indonesian language). TOLT consists of 10 items that contain five elements of the ability to think logically. These elements include proportional reasoning in numbers 1 and 2, controlling variables in number 3 and 4, probabilistic reasoning in numbers 5 and 6, correlational reasoning in numbers 7 and 8, and combinatorial reasoning in numbers 9 and 10. This TOLT is given to students by duration of 45 minutes following the procedure of Valanides (1997). Students with a total TOLT score of 0-1 will categorized into concrete stage development category, students with a total TOLT score of 2-4 will categorized into transitional stage development category, students with a total TOTL score of 5-7 will categorized into formal stage development category, and students with a total TOTL score of 8-10 will categorized into rigorous formal stage development category.

The Galevreki test on chemical dynamics matter was developed specially for this research which contained three levels of chemical representation, namely macroscopic, submicroscopic, and symbolic. One item has the same context as the other two. Thus, each context of the problem will be presented in approximately three item in macroscopic, submicroscopic and symbolic representations. This test consists of 25 multiple choice questions by raising the concept of chemical kinetics and chemical equilibrium.

The test that was developed then validated by a number of experts by adopting the Content Validity Ratio (CVR) as validity method from Lawshe (1975). The CVR method involved five panel experts in the subject matter (Subject Matter Experts), consist of chemistry lecturers. The items that used in the research must have a CVR value greater than the critical value that has been set. In the validation process, the critical value that used to validated the instrument was the table of critical values from Wilson (2012). With a number of panelists of 5 people ($\alpha = 0.05$), so that the critical value used was 0.877. This Wilson critical value table illustrates that the more experts are involved as panelists (subject matter experts), the easier the validity of the items will be.

RESULTS AND DISCUSSION

The first findings in this research, is in the form of a TOLT score profile obtained from 242 students that can be seen on Table 1.

Table 1. TOLT score profile of student

N	Minimum	Maximum	Average	SD
242	0	10	2,53	2.224

Table 1 informs us that the range of total TOLT data score looks very wide, ranging from students who get the minimum total TOLT score of zero, until the students who get the maximum total TOLT score of 10. Zero score indicates that none of all the TOLT items answered correctly by students. A score of 10 means that all 10 items in the TOLT are answered correctly. However, it appears that the average total TOLT score of students is 2.53 (SD = 2.224). This shows that there are still many students whose total TOLT scores are small. Based on Valanides (1997), the 2.53 TOLT score categorized into transitional stage development category and has not fall into the formal stage development category. This shows that many students have TOLT scores below 2.53 or in the range of concrete stage and transition stages categories, compared with the formal stage category.

This can be seen if you look at the frequency distribution of students in their respective cognitive development categories based on the TOLT score obtained. This can be shown in the graph like Figure 1.

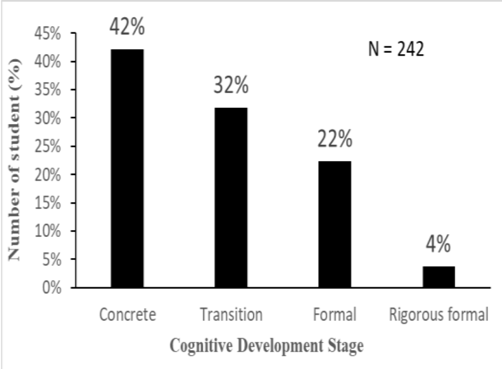

Figure 1. Cognitive development stage of student

Figure 1 shows that the most cognitive development stage of students is at the concrete stage which is as much as 42.00% (102 students), while the rigorous formal stage of students' cognitive development is only 4.00% (9 students), whereas at the first formal stage there were as many as 22% (53 students). Thus, total number of students whose cognitive development stage has entered the formal stage is 26% (63 students).

According to Piaget's theory (Crain, 2014), a student after the age of 11 years, his cognitive development should have reached the formal stage. In this research, it is known that the sample of the research was eleven grade high school student, which the range of their age was estimated between 16-18 years. At this range of age, the cognitive development of students should have entered the formal stage, but in reality there are still many students whose cognitive development is still in the concrete stage, and it almost half of them. Only 4% of students whose cognitive development has reached final formal and 22% reach the initial formal stage. This means that almost three-quarters of the total students still haven't reached the stage of formal development as they should have. Though chemical material is material that requires abstract thinking to be able to understand it. This abstract thinking is characteristic of individuals whose cognitive development have reached the formal operational stage.

Before looking at the correlation of each variable, the distribution of data obtained needs to be tested for its normality. The normality test is done using the skewness of normal data curve using the SPSS version 20. The results of the normality test by looking at the skewness of the curve can be seen in Table 2.

Table 2 shows that there are several variables whose data is not normally distributed according to the rules of Morgan, et al. (2004: 72). This is based on the indication that if the skewness value is between -1 to +1, then the data distribution of a variable is categorized as normal. So beyond that range, the distribution of the data is categorized as abnormal. Thus, some variables whose data are normally distributed include proportional reasoning variables, combinatorial reasoning variables, and macroscopic, submicroscopic, and symbolic representation variables. Whereas some variables whose data are not normally distributed include variable controlling variable, probabilistic reasoning, and correlational reasoning. The total TOLT score itself has a skewness value of 1.044, this value is still in the range of the normal curve slope. Thus, we can consider this total TOLT score to be normally distributed.

Thus, for variables whose data is normally distributed, the correlation test uses the parametric correlation test, such as Pearson Correlation. The data that will be correlated each other are TOLT score data with student scores at the three levels of chemistry representation, namely macroscopic representation, submicroscopic representation, and symbolic representation.

Table 3 informs us the relationship between the total TOLT score variables correlated with the three levels of student representation variables, namely macroscopic, submicroscopic, and symbolic representations. The degree of correlation of the two variables connected is measured through the correlation coefficient and p value (Sig). It is seen that the largest level of correlation is in the relationship between total TOLT scores on the submicroscopic achievements of students with a correlation coefficient of

0.684 (p = 0.000). The lowest degree of correlation was in the relationship between total TOLT scores on the macroscopic achievements of students with a correlation coefficient of 0.352 (p = 0.000). The degree of correlation can be said to be significant if the p value <0.000. Based on that we can conclude that the total TOLT score has a significance correlation on students' abilities at all three levels of representation, especially for the submicroscopic and symbolic representation. Submicroscopic achievement is the most variable which influenced by the total TOLT score. Students who have a high ability to think logically tend to have high ability to represent at submicroscopic and symbolic levels. Thus, students whose cognitive development has reached the formal stages and rigorous formal stages are students who are better able to solve problems related to abstract things in chemistry. These abstract things mean covering objects that cannot be seen with a normal view, and also a problems around symbols, formulas, and reaction equations.

In line with the findings of Nilawati, et al (2016) that so many students experience difficulties in quantitative and symbolic aspects of chemistry. So if it is associated with the profile of students' logical thinking abilities in this study, then this would make sense. Based on the data of the research, it is known that there are still many students and about 75% of those who have not reached the formal stage of cognitive development. This also implies that there are still many students who find it difficult to use symbolic languages such as chemical symbols, chemical formulas, and reaction equations. Whereas according to Taber (2009), symbolic language is a bridge to understanding the macroscopic and submicroscopic representations. So that in order to understand the interrelationship between macroscopic and submicroscopic in chemistry, students must be able to understand the language of chemical symbols well.

The submicroscopic representation level according to Johnstone (1993) is the most difficult representation. It because when the macroscopic and symbolic level of representation can be visualized using models, but it different with the submicroscopic level of representations that we can't make its' model accurately. For students whose cognitive development stage is still in the concrete stage, this submicroscopic level will be the most difficult representation. Students must build mental models, construct abstract objects to be more concrete. Therefore, students will be able to understand submicroscopic levels well, the cognitive development of students must be able to reach the formal or rigorous formal stage of cognitive development.

Macroscopic representations and submicroscopic representations according to Gilbert and Treagust (2009) can be categorized into group A curriculum, while symbolic representation and quantitative aspects can be categorized into group B curriculum. Both of these curriculum relationships are expected to become a basic and integrated model in chemical education especially to be able to support understanding chemistry. Gilbert and Treagust themselves stated that symbolic languages in the group B curriculum were abstract languages but were simple, concise and appropriate communication methods to describe the macroscopic and submicroscopic aspects. It is this abstract nature that can be understood if the cognitive development of students has reached the formal and rigorous formal stages.

Table 2. Result of normality test using skewness

Component	Skewness Statistic	Std. Error
Proporsional reasoning	0.575	0,176
Controlling variable	1.286	0,176
Probabilistic reasoning	2.806	0,176
Correlational reasoning	1.312	0,176
Combinatorial reasoning	0.511	0,176
Total TOLT score	1.044	0,176
Macroscopic representation	-0.241	0,168
Submicroscopic representation	0.290	0,168
Simbolic representation	-0.283	0,168
Total chemistry achievement score	-0.091	0,168

Table 3. Result of correlation test using Pearson correlation

Component	Aspect	Total TOLT score Pearson Correlation
Macroscopic representation	Correlation coefficient	0,352
	pvalue	0,001
Submicroscopic representation	Correlation coefficient	0,684
	Pvalue	0,000
Simbolic representation	Correlation coefficient	0,564
	Pvalue	0,000

CONCLUSION

Through this research, we can concluded that the stage of cognitive development of students is still far from ideal conditions at the age they should be. Students who are supposed to be in their age have entered the stage of formal development, but in reality only 26.00% of them who have entered the formal development stage. This implies that there are still many students who feel difficulties in understanding at the level of submicroscopic and symbolic representation. This is because between TOLT scores towards symbolic representation, especially submicroscopic representation, it has high degree of correlation. Therefore, to understand chemistry as a whole, students are required to be able to improve their logical thinking skills so that they can understand the level of submicroscopic and symbolic representation well. In addition, teachers are also required to be able to provide learning that is able to help improve students' logical thinking skills.

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