THE DIFFICULTIES OF HIGH SCHOOL STUDENTS IN SOLVING HIGHER-ORDER THINKING SKILLS PROBLEMS

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Abstract

International surveys, such as TIMSS and PISA, frequently put Indonesia in the low ranks. It is an indication that the higher-order thinking skills (HOTS) of students in Indonesia are still low. This research aims to analyze students' difficulties in solving problems that measure HOTS. This is a case study research with a qualitative approach. Participants studied were 93 high school students in grade XI. Data were collected using test instruments that measure HOTS, which was developed based on the standard contents of high school mathematics. The difficulties were analyzed descriptively by observing students' errors in answering HOTS test items. Students' errors were classified based on Newman's Error Procedure (NEP). The result shows that around 8.33% of the students had difficulties in comprehension, 15.59% in transformation, 32.53% in process skills, and 1.34 % in encoding.
Keywords: *HOTS problem in mathematics, students' difficulties*, *case study, Newman's error procedure*.

Introduction

Education nowadays cannot be viewed merely as transferring knowledge from teachers to students. In modern concept, education becomes one of the means for preparing students to encounter every challenge of the modern era. In response to the global challenges, there have been adjustments in the curriculum of education in Indonesia by taking into account the current global challenges. Implementation of the 2013 curriculum in Indonesian education system is now beginning to update the direction of learnings, one of them focusing on the development of high-order thinking skills (HOTS) (Ministry of Education and Culture, 2016). Not only in learning activities, HOTS test items are now also tested in the National Exam (UN), even though in particular, the achievement of the HOTS test items is far from satisfactory (Retnawati, Kartowagiran, Arlinwibowo, & Sulistyaningsih, 2017). This has shown the seriousness of HOTS that it is not only a discourse in the concept of education in Indonesia, but it can be viewed as one of the main goals of the educational process.

Early adaptation of HOTS development in Indonesian education system has demonstrated that HOTS is urgent and relevant to current global needs and challenges (Apino & Retnawati, 2017; Jailani, Sugiman, & Apino, 2017; Yen & Halili, 2015). Operationally it will be easier to define HOTS when referring to cognitive taxonomies. In Indonesia, the cognitive taxonomies which already being used in the formulation of learning objectives are the Revised of Bloom's taxonomy. In the taxonomy, HOTS includes the cognitive dimension of analyzing, evaluating, and creating (Brookhart, 2010; Liu, 2010). In this regard, the use of the revised of Bloom's taxonomy is more relevant to current educational demands, therefore HOTS can be defined as cognitive skills in the analyzing, evaluating and creating levels.

HOTS as a cognitive skill is highly needed by students in every education levels and courses, one of which is mathematics course. HOTS is a skill that must exist in every lesson (Sulaiman, Muniyan, Madhvan, Hasan, Rahim, 2017). The implementation of HOTS in mathematics learning is intended to change the perception that mathematics is a difficult subject, and to attract learners' attention to study mathematics (Abdullah, Mokhtar, Halim, Ali, Tahir, & Kohar, 2017). Moreover, HOTS plays a role in the training of logical and critical thinking, as well as reasoning skills, that are fundamental to everyday life. These skills set are also parts of academic achievement (Marshall & Horton, 2011). It shows that HOTS is an important aspect of the learning process and students' HOTS achievement needs to be evaluated to determine the extent of students' HOTS in the learning process.

Various International studies, such as TIMSS and PISA can be used as a reference to determine the HOTS achievement of the students (Budiman & Jailani, 2014; Jaelani & Retnawati, 2016; Apino & Retnawati 2017). In the TIMSS 2015, for mathematics skills, Indonesia was in the lower ranks and students' skills were still in the 'knowing' and 'applying' domain or in lower order thinking skills. In the 'reasoning' domain, students skill still was very low (Mullis, Martin, Foy, & Hooper, 2016). Similarly, in the PISA 2015, Indonesia was in the 115th position out of 124 participating countries. Indonesian students could only perform in the 1st to 4th levels, while they still had difficulties in the 5th to 6th levels (OECD, 2016). The results of these studies have provided information that students' HOTS in Indonesia is still low.

The low students' HOTS skills have proved that students faced difficulties in solving mathematics test items that measure HOTS. Analysis of the students' difficulties in solving HOTS test items is essentially the same as the analysis of students' difficulties in solving mathematics test items in general. In this case, students' difficulties can be identified by analyzing students' errors in solving mathematics test items (Wijaya, van den Heuvel-Panhuizen, Doorman, & Robitzsch, 2014). One of the procedures that can be used to identify students' errors in solving HOTS test items is Newman's Error Analysis (NEA) (Wijaya van den Heuvel-Panhuizen, Doorman, & Robitzsch, 2014; Abdullah, Abidin, & Ali, 2015). Newman (1977) stated that students' errors in solving mathematics test items involve reading errors, comprehension errors, transformation errors, process skills errors, and encoding errors. The data of students' errors can be used to identify students' difficulties in solving test items that measure HOTS in mathematics learning (Abdullah et al., 2015).

Many researches have been carried out to investigate students' difficulties in solving mathematics test items. Jupri and Drijvers (2016) had investigated students' difficulties in solving algebra word (story) problems and the result showed that the student encountered difficulties in formulating the mathematical model, indicated by errors in mathematical equations, schematics or diagrams. Phonapichat, Wongwanich, and Sujiva (2014) had identified students' difficulty in solving mathematics problem, namely difficulty in understanding problems' keywords, finding assumption and key information in the problem, wild guessing when student failed to understand the problem, impatience and reluctance to read the problem thoroughly, and students dislike long word problems. Alhassora, Abu, and Abdullah (2017) found that the difficulty in solving HOTS test items was because the students are not accustomed to reading long word problems and due to the low reading skills of the students. These difficulties are the cause of many errors made by the students in answering HOTS test items.

Prakitipong and Nakamura (2006) studied students' error in solving mathematics test items in Thailand. The result showed the types of students' errors, namely comprehension errors in solving structured questions and transformation errors in solving multiple-choice questions. Abdullah et al. (2015) studied students' error in solving HOTS and found that students' errors consist of encoding, process skills, transformation, and comprehension. Students also had difficulties in relating information and implementation of strategies to solve HOTS test items. Similar findings concluded by Santoso, Farid, and Ulum (2017) showed that students' error type in solving word problems of linear programs are transformation errors and process skill errors.

Research Focus

Based on the background and theoretical studies that have been previously described, it is important to identify the difficulties in solving mathematics problems to measure students' HOTS. Thus, the purpose of this research is to analyze the type of difficulty experienced by students in solving mathematics questions that measure HOTS. The findings of this research can be used as an input for teachers to design the best practices in teaching mathematics to improve students' HOTS.

This research is different from the research on the analysis of students' difficulties in completing the PISA question that have been done by van den Heuvel-Panhuizen, Doorman, & Robitzsch (2014). Their research emphasized the context-based PISA mathematics tasks performed in junior high school. This study emphasizes the difficulties of students in solving the HOTS problems in senior high school, although both of these researches are using NEP.

Methodology of Research

Type of Research

This research is a case study aimed to analyze students' difficulties in solving mathematics problems that can measure HOTS, using quantitative and qualitative approach. It was conducted in May – October 2017. In this research, the researcher identifies the types of difficulties experienced by students when solving mathematics problems that measure HOTS. Classification of student difficulties refers to Newman's Error Procedure (NEP) which consists of reading errors, comprehension errors, transformation errors, process skills errors, and encoding errors.

Participants of Research

The research participants were 93 students (about 77.22% students) of grade XI of Science Program at SMAN 1 Seyegan (Senior High School), Special Region of Yogyakarta, Indonesia. These participants consisted of 30 male and 63 female students with heterogeneous academic skills (low, medium, and high). These subjects were assumed that have learned the tested learning material in the research instruments.

Instrument and Procedures

Data were collected using multiple-choice test, in which the research subjects were asked to write down the steps of their answers. The test consists of 3 items about probability and statistics, 2 items about limit in function, 4 items about differential, and 5 items about the applications of differential, and the total is 14 items. These items are structured representatively to measure the content of the material in mathematics for one semester in class X of senior high school. It means the test considered logical validity. The reliability of test's score estimated using alpha-Cronbach coefficient, that is 0.833 (high category).

From the 14 items, the researchers have chosen 4 items. The 4 items measure HOTS that are problems 1-4. All of the items are about the application of differential. These problems are presented in the result together with the analysis.

Using students' responses to the tests, the students' difficulties were identified. The identification of the students' difficulty types was observed from the errors made by the students in answering the test items. The types of errors were categorized based on Newman's Error Procedure (NEP), they are reading, comprehension, transformation, process skills, and encoding errors. These errors were identified independently, so in this case, students probably can make any mistakes more than one times.

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To maintain the credibility of the obtained data, the test was done with the exam exercise format. In this format, students finished the test wholeheartedly, so that the answers provided the reflection of the students' true abilities. The researchers also informed that the result of students' difficulties identification would only be used to give feedback of improvement, will not determine the students' positions. To maintain objectivity during checking students' answers, researchers ignored the students' identities.

Data Analysis

Data were analyzed quantitatively and qualitatively. The quantitative analysis was carried out to determine the percentage of each difficulty encountered by the students in solving HOTS test items. The qualitative analysis was carried out to analyze the students' error pattern based on NEP. The analysis of data included the steps of scoring students' answers, classification of error types based on NEP, calculating the percentage of each of the difficulty type, and performing a qualitative analysis to describe each of the students' difficulty.

Using students' responses to the items, researchers check and count the errors done by students. In every item, a student could do more than one error. For example, in Problem 1, a student has done an error in comprehension and transformation. Then, in every kind of error in NEP, the researchers calculating the percentage, how many students that have done in every kind of error divide with the total of research participants.

Results of Research

Data of students' difficulties in solving HOTS test items were identified using Newman's Error Procedure (NEP). Also, identified in this research was the number of students who gave the correct answers and those who did not answer. The summary of students' errors analysis in solving HOTS test items is presented in Table 1.

Table 1. Summary of the results of students' error analysis.

	Problem 1		Problem 2		Problem 3		Problem 4		Average Percentage
	n	%	n	%	n	%	n	%	%
Correct Answer	2	2.15	38	40.86	23	24.73	0	0	16.94
Not Answer	56	60.22	27	29.03	30	32.26	45	48.39	42.47
Reading	0	0	0	0	0	0	0	0	0
Comprehension	10	10.75	5	5.38	13	13.98	3	3.23	8.33
Transformation	11	11.83	11	11.83	26	27.96	10	10.75	15.59
Process Skills	34	36.56	23	24.73	24	25.81	40	43.01	32.53
Encode	0	0	1	1.08	2	2.15	2	2.15	1.34

Table 1 informs that the students were still having difficulties in working on the problems. It is indicated by the low percentage of students with correct answers (an average percentage of 16.94%), and even for Problem 4, there are none who had answered it correctly. In addition, the percentage of students who did not answer questions was also quite high (an average percentage of 42.47%). This is a strong indication that the students had difficulties in solving the given test problems. A graph of students' errors in solving HOTS test items is presented in Figure 1.

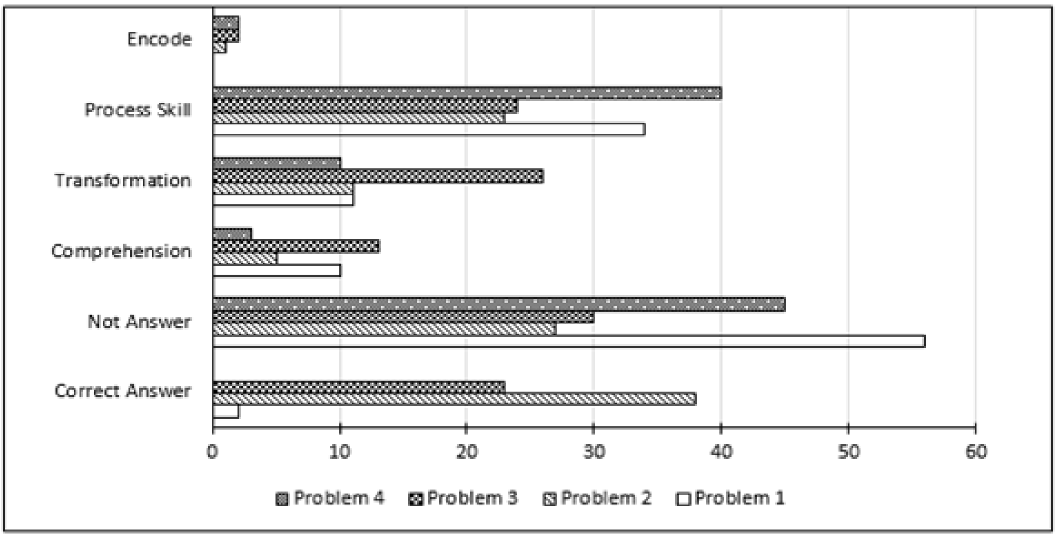


Figure 1. Error distribution of the students in solving HOTS test items.

Based on Figure 1, Problem 2 is the most correctly answered problem whereas, for Problem 4, none of the students could answer it correctly. The number of students who did not answer was quite high, in which Problem 1 was the most unanswered test item. Comprehension errors were experienced mostly in solving Problem 3, and so were the transformation errors. Process skill errors were the most common error experienced by the students compared with other error types and mostly found in Problem 4. In addition, encoding errors were the least experienced errors by the students and commonly encountered in working on problem 3 and 4. The next section will describe the error types experienced by the students in solving HOTS test items.

Comprehension Errors

Comprehension errors are marked by students' errors in the identification of "what is asked" and "what is given" from the test items. This error also can be marked by students' inability to write down important and relevant information of the test item. Figure 2 shows an example of students' comprehension errors. As seen in Figure 2, students comprehend the test sentence "the product of the squares of the two numbers" as $y = x^2 : y^2$ (the one being circled), which should have been written as $x^2 \cdot y^2 = 0$. Another example of students' comprehension error is presented in Figure 3. Student's answer in Figure 3 indicates that the student was having difficulty in comprehension of the test item. The written answer did not represent what was asked and what was given in the test item, it did not even lead to the correct answer. This is a strong indication of the student's difficulty in comprehension of the test item.

Question: Problem 3

The sum of two numbers is 8. In the event that the product of the squares of the two numbers reaches the maximum value, the difference between the largest and the smallest numbers is … (Answer = 0)

Student response:

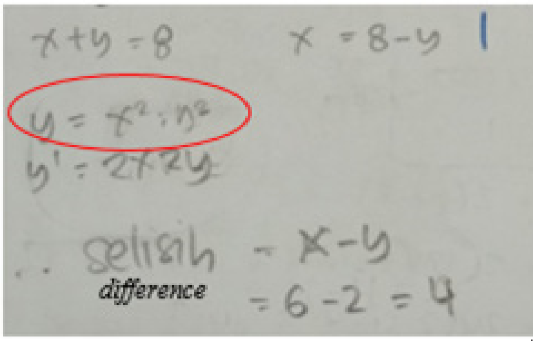
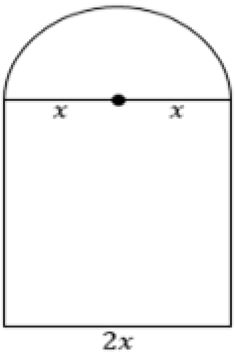


Figure 2. Example of comprehension error.

Question: Problem 4

A door has a similar geometry to the figure below.



If the circumference of the door is p, the value to make the area of the door at maximum is … . (Answer = $\frac{p}{4+\pi}$)

Student response:

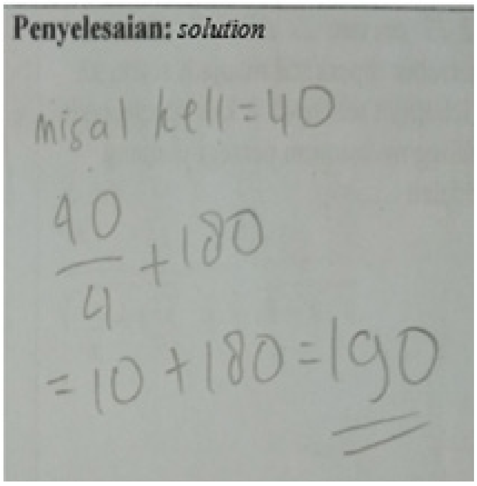


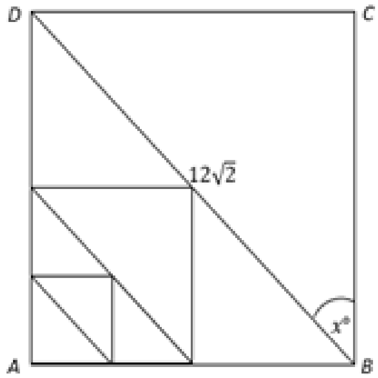
Figure 3. Example of comprehension error.

Transformation Errors

Transformation errors are marked by students' error in developing a mathematical model from the information given, error in selecting the formula to be used, and error in the completion of the test item. An example of students' transformation error is presented in the Figure 4. Figure 4 shows a fraction of student's answer in solving Problem 1. The figure shows that the student used a formula of $\frac{1}{16}\times$ circumference of the big square to find the solution. The solution plan was wrong; the student should directly calculate the circumference of the small square because the diagonal of the small square can be determined. Because of the error in choosing the solution plan, the student was unable to find the final solution for the test item. This indicates that the student made an error in planning the solution of the test item, and thus indicates that the student was still encountered difficulty in the transformation of the test item.

Question: Problem 1

Consider the following figure.



A square ABCD has diagonal BD = $12\sqrt{2}$ cm and $\angle$ CBD = $x°$. If the square is scaled into half the length and half the width, twice, as shown in the figure, then the maximum circumference of the smallest square is … . (Answer = 12 cm)

Student response:

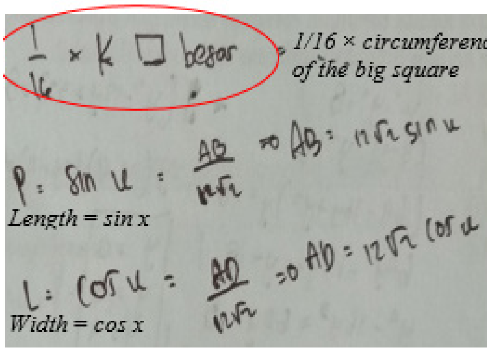


Figure 4. Example of transformation error.

One more example of students' transformation error is presented Figure 5. Figure 5 shows that student made a mistake in determining the formula of a rectangle's circumference. In Figure 5 (the circled portion) it is seen that to determine the circumference of the rectangle the student used a formula of $p \times l$ (length times width), which in fact this formula should only be used to calculate the area of a rectangle. Due to this error, the student failed to find the solution to the given problem. This strongly indicates that there were students who still encountered difficulties in transforming the test item.

Question: *See Problem 4*

Student response:

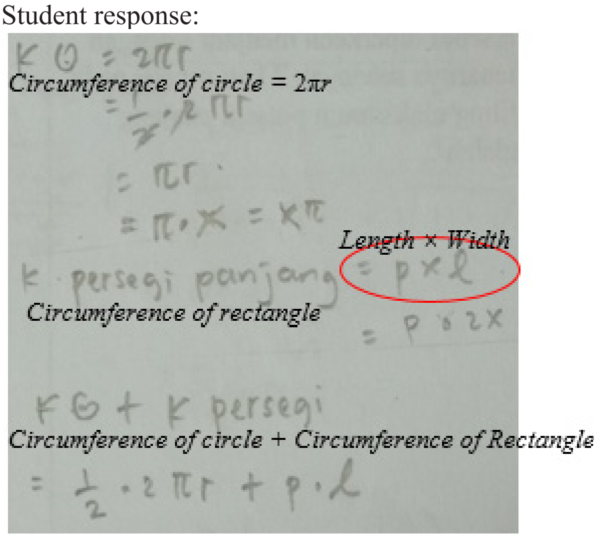


Figure 5. Example of transformation error.

Process Skill Errors

Process skills errors are marked by students' error in implementing a formula, error in math calculation, error in algebraic manipulation, and error in implementing mathematical process in solving a problem. This research found that process skill error is the most common error made by the students and it happened in the entire test items. Figure 6 describes an example of student's process skill errors. The First error is the error in algebraic operation, in which the function $3x - 900 + \frac{120}{x}$ (step 1) should be multiplied by the x variable, which would produce $3x^2 - 900x + 120$, but the student's process (as can be seen in step 2) resulted in $\frac{3x^2-900x+120}{x}$. It is obviously erroneous and indicates that the student was having difficulty in the algebraic multiplication operation. Furthermore, looking closely at step 3 in Figure 6, the factorization performed by the student still resulted an error. It can be concluded that students' process skill in algebraic operation is still very low. These findings indicate that student still encountered difficulties in mathematical process skill, especially in algebraic operation.

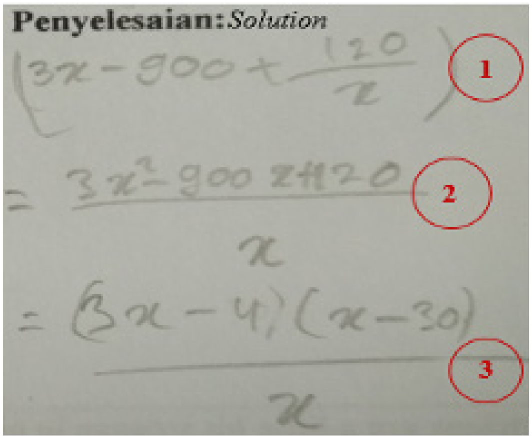
Question: Problem 2	Student response:
Construction project of a school building can be completed in x days, with project cost per day as $\left(3x - 900 + \frac{120}{x}\right)$ in hundred thousand rupiahs. In order to make the cost at minimum, the project should be completed in ... days. (Answer = 150)	

Figure 6. Example of process skill error.

Here in after, another example of process skill error is presented in Figure 7.

Question: *See Problem 3*
Student response:

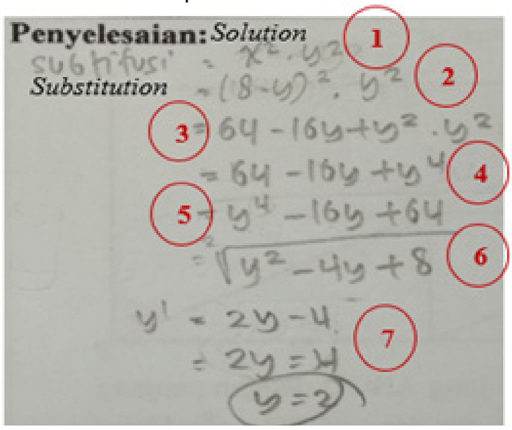


Figure 7. Example of process skill errors.

Students' error shown in Figure 7 happened in step 3 and 4, in which the student made an error in performing the algebraic multiplication operation. Furthermore, it can also be seen that the student made an error in the manipulation of algebraic form, as shown in step 6. The student also managed to make another error in the derivation of the algebraic manipulation (step 7). This indicates that students were still having difficulties in process skill related to an algebraic manipulation operation.

Encoding Errors

Encoding errors are marked by students' error in defining conclusion. Encoding error is the least error type made, in which only 1.34% of the students were experiencing this error type. An example of student's encoding errors in solving Problem 3 is presented in Figure 8.

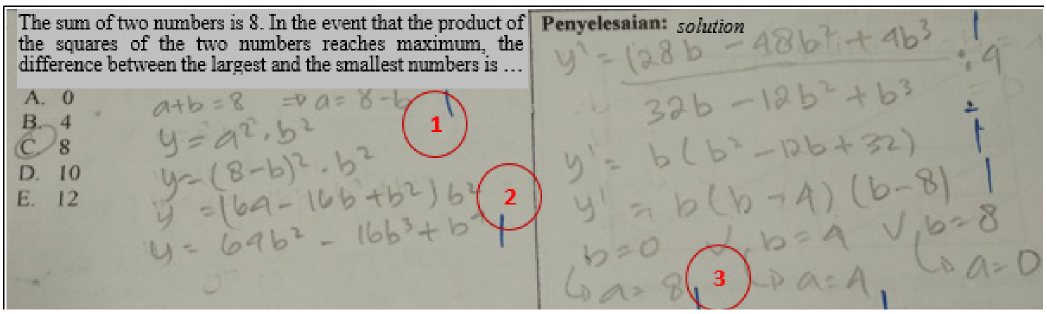


Figure 8. Example of encoding error.

Figure 8 shows a process done by the student in solving Problem 3. In step 1 the student developed a mathematical model from the given information, and in step 2 the student substituted one of the mathematical models into the other mathematical model to form a function. In step 3 the student determined the derivative of the function and determined the variable's value that satisfies the function when the derivative equals zero. In this case, the student's error happened when determining the difference between the largest and smallest values, which led to the multiplication of the numbers' square at its maximum. From the obtained variable values (a = 0, then b = 8; a = 4, then b = 4; and a = 8, then b = 0), the student should have tested first the multiplication that will lead to a maximum value. In this case, the student only looked at the value that was maximum, which was 8, and opted for option C.

Discussion

Results of data analysis show that the errors done by the students in solving HOTS test items are comprehension error, transformation error, process skill error and encoding error. The research findings are in line with the results obtained by Abdullah et al. (2015) and Santoso et al. (2017). These two researches both stated that errors experienced by students in solving mathematics problems are comprehension error, transformation error, process skill error, and encoding error. These errors serve as an indicator that students are still having difficulties in solving mathematics problems that measure HOTS. From the errors type stated by Newman (1977), the data analysis result shows that there is one type of errors which was not encountered by the student in solving the test problems, namely reading error. This finding is also in line with the result of Abdullah et al. (2015) and Santoso et al. (2017). Their researches both show that none of the test subjects had difficulty in reading the test problems. It occurs because the subjects were grade XI junior high school students, who already have good reading skills. In addition, the type of test problems came with figures or illustrations, so that the information in the test problems could be understood almost instantly just by looking at those figures or illustrations.

The crucial difficulties experienced by the students in solving test problems were process skills and transformation difficulties. Difficulty in mathematical process skills in this research mostly happened when students performed an algebraic operation and manipulated algebraic forms. This is due to their low understanding of the concept of algebraic operations and the manipulation of algebraic forms, and lack of ability in mathematical connections. The lack of students' conceptual understanding becomes one of the constraints in solving HOTS test items (Alhassora et al., 2017). Likewise, in performing transformation, there were still a few students' made errors in determining the formula to answer test problems. This is a concrete proof that not all of the students have a good understanding of the concept. In addition, students' error in determining the mathematical model of a problem only proved that their transformation skills were still low. Rachmawati (2016), Jupri and Drijvers (2016) stated that one of the constraints the students experienced in solving mathematics is the difficulty in developing the mathematical model. This should be used as a reflection for math teachers to improve the forthcoming math teaching. In this case, there are two pivotal points that should be the focus of math teachers, which are strengthening the conceptual understanding for students, especially in algebra, and training the students in developing the mathematical model.

Comprehension of the problem is another difficulty experienced by students in answering HOTS test items. An indication of this difficulty can be seen from students' error in writing down what is given and what is asked on the test items. In addition, students still often made errors in selecting and writing down important information and relevant facts from the problem. It can be identified from the students' answer sheets that one of the causes of difficulty in comprehension is that students were not accustomed to tests items that led them to an in-depth analysis. For the comprehension of the problem's context, students preferred short questions and explicitly written problems. Therefore, when presented test items that required in-depth analysis, students tended to experience difficulties. This finding is supported by the results of Phonapichat et al. (2014) research, which found that students are often impatient and do not like to read the passage of the test items.

The high percentage of students who were not answering was also an evidence of students' low interest in HOTS test items. This also indicates that the students were not challenged by HOTS test problems. It happened because they were not accustomed to HOTS model test items. Because students were not accustomed to HOTS model test items, they were confused when working on the answers. They were not even capable to determine what is given and what is asked on the test items. Other than that, the low perseverance of the students really affects how they answered. Students with low perseverance tended to work on less challenging problems and the ones that had a clear workaround. If a problem is deemed as difficult by the students, there is a high chance that it will not be answered. Students' literacy also plays a role on whether a problem will or will not be answered. Phonapichat et al. (2014) stated that students dislike long word problems. Therefore, when presented with test items that encourage them to use literacy skills, students tend to be reluctant in solving them.

Many efforts can be implemented to overcome the difficulties experienced by students. Teachers can strengthen the understanding of mathematical concepts during math lessons (Retnawati, Kartowagiran, Arlinwibowo, Sulistyaningsih, 2017), make improvements in teaching and learning process (Retnawati, Munadi, Arlinwibowo, Wulandari, Sulistyaningsih, 2017), utilize various media and technology in teaching and learning (Retnawati, 2015), also utilize the right learning trajectory during the learning process (Retnawati, 2017; Retnawati, Arlinwibowo, Wulandari, Pradani, 2018) and use HOTS problem in assessment (Retnawati, Hadi, Nugraha, 2016). Improving teacher qualification in mathematics teaching and learning (Retnawati, Djidu, Apino, Kartianom, Anazifa, 2018) is also an attempt to make students' achievements better.

Conclusions

The most common difficulty for students in solving test items that measure HOTS is math process skills. This difficulty is indicated by errors in implementing the formula, errors in mathematics calculation, and errors in algebraic operation and manipulation. Next in line is the difficulty in the transformation of the problem, which was indicated by students' error in developing a mathematical model, errors in determining the formula to solve the problem, and difficulty in planning to solve the problem. Other difficulties experienced by the students are difficulties in comprehension of the test item, which was indicated by students' error in determining what is given and what is asked on the test items. Encoding is also one of the difficulties experienced by students. This can be indicated by errors in interpretation of the result obtained. The difficulties mentioned earlier which are experienced by the students are caused by many factors. First, students are not familiar with the tests that measure HOTS. Second, the low perseverance of the students in solving HOTS test items. Third, there is a tendency for students to dislike long word problems. Teachers' role is very important to improve students' capability in solving HOTS test items. In this case, teachers need to train their students so that they will be familiar in solving HOTS test items.

Other researches related to student difficulties in solving the HOTS problem in mathematics can be done. The students' habits to solve the HOTS problem need to be established along with the development of appropriate mathematical teaching and learning strategies or methods. This teaching and learning process needs to be supported by the development of HOTS media or teaching aids. Supporting students' abilities to resolve mathematics problems, such as conceptual understanding, mathematical connections, and mathematical representations abilities also need to be identified.

Acknowledgements

Special thanks and appreciation researchers convey to SMA (Senior High School) Negeri (State) 1 Seyegan, Special Region of Yogyakarta, Indonesia, especially to students of grade XI who have been willing to be the participants of research.

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Received: *May 03, 2018* Accepted: *August 03, 2018*

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