Indonesian junior high school students’ higher order thinking skills in solving mathematics problems

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Abstract. Higher order thinking skills are important for students to help them solve various problems faced over time. Several previous studies on higher order thinking skills have been conducted, but no one focuses on higher order thinking skills at junior high school level in the regions where the average of computer-based national exam results are relatively low in Indonesia. The purpose of this study is to find out categories of and describe students’ higher order thinking skills in solving PISA problems based on determined indicators. This study used a descriptive qualitative methodology. The instruments used in this study were the PISA test and interview guide. The participants were students in the age range of 15 years randomly selected from several junior high schools in Banda Aceh. At this age, the students’ knowledge and abilities could be assessed. Data were collected from the test, interview and documentation that involved 40 participants. This study found that, generally, students had low level of higher order thinking skills, and there were no students who achieved a high level. Therefore, it is recommended to address this issue by developing and improving the students’ abilities that require higher order thinking skills so that the students are able to apply their knowledge and skills to solve new problems and implement them in real life situations.

1. Introduction
Indonesia’s participation in Programme for International Student Assessment (PISA) aims to examine to what extent the development of educational achievement in Indonesia compared to other countries. PISA, an international study made by the Organization for Economic Cooperation and Development (OECD), analyzes thinking ability of students in the age range of 15 years and has been participated in by several countries. This program is developed to find out whether students in this age range are able to master knowledge and skills that should have been able to be achieved, and find out if students are able to apply them in real life situations.

PISA problems not only require the ability to apply concepts, but also how the concepts can be applied in various problems. Solving PISA problems require reasoning and problem-solving skills, analysis, evaluation and innovation [1,2]. Based on the results of PISA survey in 2009, 2012 and 2015, Indonesia ranked lower than other participating countries. Student outcomes in Indonesia are still lower than those in Southeast Asian countries [3]. It is evident that Indonesian students are at lower level and no one reaches to the highest levels of higher order thinking [4]. These results indicate that higher order thinking of Indonesian students in problem solving is still relatively low.
Higher-order thinking requires logical and reasoning skills, creation, analysis, evaluation, problem solving, and decision making [5,6]. Analytical skills are the skills to determine elements that contribute to the problems and examine how those relate to one another, and identify the causes of the mathematical problems [7]. Evaluation ability is an ability to find ideas and methods in a mathematical problem [8]. Creative thinking is the ability to put parts together to form new ideas, design and find the answers with multiple solutions [6]. Anyone need this ability in thinking prose and take a knowledge conclusion.

There are some indicators needed to measure an individual's higher order thinking. Brookhart [6] states that the indicators of analytical skills focus on the main idea; that is, the ability to make decisions or choose strategies aligned with the objectives. Meanwhile, the indicators of creativity include solving problems with multiple solutions, designing strategies, and creating new things. Lastly, the indicators of logical and reasoning skills consist of content and proof with clear and correct explanation.

Moreover, the renewal and improvement in education is needed to produce students with highly qualified human resources in order to be able to face challenges in the new era. By regularly giving problems oriented to higher order thinking process, students are able to practice to develop their creativity and logical thinking in finding solutions for those problems [9,10]. Therefore, it is important to know and recognize students’ abilities in a certain field to help them develop their abilities easier. Recognizing students’ abilities thoroughly means knowing students’ higher order thinking skills (HOTS) and lower order thinking skills (LOTS). Those wide ranges of thinking skills should be traced directly to students with a broad range of research subjects in order to obtain accurate and detailed data.

Students who have higher order thinking skills will be determined, active, creative and able to interact effectively with others, to compete and to solve complex problems. Moreover, higher order thinking skills occur when students obtain new knowledge and memorize it in order to achieve certain goals and the skills include reasoning and logical skills, analysis, creation, and evaluation, which is the highest levels in Bloom’s cognitive taxonomy [11]. Therefore, issues related to higher order thinking skills should be addressed immediately because it will affect students’ success [5].

In fact, a lot of students still meet difficulties in solving non-routine problems, and also are not able to develop their concepts of knowledge. Referring to the results of TIMSS and PISA studies [3], Indonesian students still performed below average on advanced mathematics problems. In addition, a study by Kurniati, Harimuki and Jamil [12] showed that even though students in Jember had a higher average score on computer-based national exam mathematics results than those in Aceh, there were no students who scored high on HOTS in Jember. Moreover, another study found that the quality of education in Indonesia was still considered low because in its implementation a lot of learning materials are provided to achieve curriculum target, but these materials do not optimize students’ HOTS [13,14]. As there has been no previous studies on higher order thinking skills at junior high schools in the regions where the average of national exam results is still relatively low. The researchers investigate mathematical HOTS of students in junior high schools in Banda Aceh.

This present study was conducted to investigate higher order thinking skills of junior high school students in the age range of 15 years towards given PISA problems. The results of this study were expected to provide information about students’ mathematical higher order thinking skills, so that it can assist educators in developing students’ HOTS in order to improve not only the quality of mathematical skills of Indonesian students, but also the quality of the Indonesian educational system.

2. Method
Based on the previous explanation, the aim of this study is to investigate category of and to describe higher order thinking skills of junior high school students in the age range of 15 years in solving the PISA problems, because higher order thinking skills can help students to think deeply of a subject [15]. Thus, students will be easier to apply their knowledge and skills to solve new problems and implement them in real life situations.
This study used descriptive qualitative method. According to Creswell [16], a descriptive qualitative methodology is a research method used to identify and comprehend the meaning of the objects of study. This study also went through the following procedures: 1) introduction; 2) determination of research subjects; 3) instrument design, 4) instrument validation, 5) analysis of validation results, 6) data collection, 7) data analysis; and 8) conclusions.

Further, the researchers determined several junior high schools in Banda Aceh that is consists of two State schools. The total all of students from this school is 382 and 321 student an average of 25 students each class. That would be studied and then decided the research subject. In this study, 40 junior high school students aged 15 years were randomly selected from several of those schools in Banda Aceh.

The instruments utilized in this study were the PISA standard-based test and interview. Because the question of PISA form international standard problem than replacement to Indonesian, this research just validation of language by validator. Then, the researchers analyzed the results of the validation in order to determine the level of its validation. Then, those valid instruments were used to collect data. The data was collected on the 20th to the 24th of May 2019 by giving the PISA test in Indonesian language. The test consists of three questions, to find out high order thinking skills of students, specifically, in the aspects of logical and reasoning skills and analysis. Afterwards, interviews were conducted to six students, three of low ability and three of medium ability based on test score, to obtain data for creation and evaluation aspects.

The data were analysed using an inductive approach and the results of this study emphasized on the generalization of the actual data. The results of students' answers on the PISA test and interviews with students were analyzed to get a description of higher order thinking skills of 15-year-old students, based on the assessments of logic and reasoning and the assessments of analysis, evaluation, and creation. Furthermore, the categorization of low, medium and high for HOTS levels was adapted from Kurniati, Harimukti and Jamil [12]. To find the minimum value, the number of questions on the PISA test was multiplied by the lowest score on the HOTS assessment rubric. On the one hand, to get the maximum value, the number of questions on the PISA test was multiplied by the highest score on the HOTS assessment rubric. The lowest score of rubrics is 0 and 3 question of PISA questions test. The minimum value is 0 from multiplication of 0 by 3, student will get minimum value that 0. While the highest score of rubrics is 4 and 3 question of PISA questions test too. The maximum value is 12 from multiplication of 4 by 3, 12 is the maximum value student obtained.

Additionally, to score students’ answers, the researchers referred to the assessment rubric modified from Suprihatin, Maya and Senjayawati [17] as follows.

| Score | Description |
|-------|-------------|
| 4     | Correct answer with complete clear and precise solutions steps or strategies |
| 3     | Correct answer with partial clear and precise solutions steps or strategies/ incorrect answer with complete clear and precise solutions steps or strategies |
| 2     | Correct answer without solutions steps or strategies |
| 1     | Incorrect answer with complete solutions steps or strategies |
| 0     | Incorrect answer without complete solutions steps or strategies/ no answers without complete solutions steps or strategies |

The results, strategies and the reasons of students for completing 3 PISA standard test questions will assessed and scored according based on scoring guidelines rubric. Students get the highest score if they explain step by step on distinct and precise.

Then, the researchers determined the range of the data and divided it in three levels. The highest, medium, and lowest data intervals showed the categories of high, medium, and low. HOTS levels for students, as presented in Table 2.
Table 2. HOTS Level Categorization

| NO. | Score     | Category |
|-----|-----------|----------|
| 1   | 0 ≤ score ≤ 4 | Low      |
| 2   | 4 < score ≤ 8 | Medium  |
| 3   | 8 < score ≤12 | High    |

3. Results and Discussion

The results of those instruments were used to determine the levels of students’ higher order thinking. From the results of the test and interview on the aspects of logic, reasoning, analysis, evaluation and creation, the highest and the lowest scores were obtained, which are 6 and 0 respectively. From those scores, the categories of students’ HOTS level would be made. For the example a student gets a score 4 on the question number 1 and gets a score 1 on the question number 2 and gets score 1 on the question number 3, so the overall value of students is 6. Based on the categorization of HOTS scores, these students classified as a medium level HOTS ability category. For the example a student gets a score four on the question number one and gets a score one on the question number two and gets score one on the question number three, so the overall value of students is six. Based on the categorization of HOTS scores, these students classified as a medium level HOTS ability category.

Data obtained from 40 participants are presented in the following table 3.

Table 3. Data of the Number of Students Obtaining Scores on Each Question

| Score | Question 1 | Question 2 | Question 3 |
|-------|------------|------------|------------|
| 0     | 8          | 7          | 10         |
| 1     | 25         | 33         | 22         |
| 2     | -          | -          | -          |
| 3     | -          | -          | 8          |
| 4     | 7          | -          | -          |

The results obtained from 40 students showed that none of them were considered at high level of HOTS, but 15 students were at medium level, and 25 students were at lower level. Students with medium level of HOTS did not do well on logical thinking and reasoning, analysis, evaluation, and creation aspects in some questions. Meanwhile, students with lower level were unable to do analysis, creation, evaluation, reasoning and logical thinking in all questions. On the other hand, students having high level of HOTS had deep understanding of the concepts, so that it was easier for them to apply their knowledge to solve new problems [18].

The following will present the answers of several students representing students with medium and low level of HOTS.
3.1 HOTS Medium Level

SMH is the code for student who had a HOTS medium level. The student’s solutions are given in Figure 1.

![Figure 1](https://via.placeholder.com/150)

 Translate figure 1:

3) Known: Every year, Anak Krakatau's mountain is 20 feet taller. Right now, the height of Anak Krakatau's mountain reaches 230 meters above the water surface while the height of Krakatau's mountain reaches 813 meters above the water surface before it erupts.

Question: in what year the Anak Krakatau's mountain will be the same height as the Krakatau's mountain before eruption?

Answer:

\[
\begin{align*}
&= 813 - 230 = 583 \text{ m} \\
&= 583: 20 = 24 \text{ years} \\
&= 24 + 1,883 \text{ years} = 1,907 \text{ years}
\end{align*}
\]

Therefore, in 1,907 the Anak Krakatau's mountain will be the same height as the Krakatau's mountain before eruption.

2) It is known that a rectangular field measuring 100 meters long and 50 meters wide is prepared for concert goers.

Question: how many viewers are there?

Answer:

\[
\begin{align*}
&= 100 \times 50 = 5,000 \text{ m}^2
\end{align*}
\]

Therefore, many of these viewers are 5,000 meters/answer is B. 5,000

1) Known: there are three different height towers consisting of rectangles and hexagons.

height of the first tower = 21 meters
second tower height = 19 meters

Question: third tower height?

Answer:

Height of the first tower = 3 rectangle and 3 hexagons
Second tower height = 2 rectangles and 3 hexagons

so,

\[
\begin{align*}
3 \text{ rectangles} + 3 \text{ hexagons} &= 21 \text{ m} \\
2 \text{ rectangles} + 3 \text{ hexagons} &= 19 \text{ m} \\
3 \text{ rectangles} + 0 \text{ hexagons} &= 2 \text{ m} \\
1 \text{ rectangle} &= 2 \text{ m}
\end{align*}
\]

Because,

\[
\begin{align*}
\text{rectangles} &= 2 \times 3 \text{ rectangles} = 6 \text{ m} \\
&= 21 \text{ meters} - 6 \text{ meters} = 15 \text{ meters} \\
15 \text{ meters} &= 3 \text{ hexagons} = \frac{15}{3} = 5 \text{ meters} \\
1 \text{ hexagon} &= 5 \text{ meters}
\end{align*}
\]

Therefore, third tower height:

\[
\begin{align*}
&= 2 \text{ rectangles} + 1 \text{ hexagon} \\
&= 2 \times 2 + 5 = 9 \text{ meter}
\end{align*}
\]

Figure 1. Solutions of a Student with HOTS Medium Level
Question 1 is an open ended question. This question has change and relationships content, occupational contexts, and formulate process. In this contextual question, students are required to use their higher order thinking skills. First, students have to be able to convey mathematical ideas embedded in that question, if not, students will find difficulties to start solving the problem [1]. Then, students should be able to change and find connections with one another, and able to determine the formula to gain the solution. Students with HOTS medium level comprehend the application of algebra in daily lives. Based on the answers and the interview results, the student was able to recognize what is known and asked. The student was also able to design the solution strategies and re-examine the answers.

Question 2 requires a short answer. The question has space and shape content, occupational context, and formulate process. Solving this contextual problem actually does not require difficult mathematical calculations or formulas, but needs imagination and creativity so that high level of thinking skills is needed in solving this problem [19]. HOTS medium level students did not really understand the application of the area and perimeter of plane shapes in everyday life. Students have to understand a complex situation, starting from the size of the field, understanding the situation that occurs because tickets are sold out so that many audiences stand up. Students are also required to imagine the situation in the question. Finally, students are required to evaluate possible choices with known facts in the question. Also, students were also able to identify what the problems ask correctly.

Question 3 requires limited open descriptions. This question has change and relationships content, personal context, and formulate process. In this contextual problem, students have to change and look for relationships with one another, and generate formulas to find answers. Students’ mistakes in solving this question are in basic mathematical abilities [20]. HOTS medium level students had not fully mastered the content of unit and measurement and changed it to other forms. However, the students could write what is known and asked from the question.

3.2 HOTS Lower Level
SSA is the code for student who had a HOTS low level. The student’s solutions are given in Figure 2.
Translate figure 2:

1) 2 meters
   Known tower length 1 = 21 meters
   Known tower length 2 = 19 meters
   Question: Known tower length?
   So, the number of tower 1 is reduced by the number of tower 2 = 21 - 19 = 2 meters

2) 5,000
   Long known = 100 meters
   Wide known = 50 meters
   Question: How many concert goers?
   So, the length of the field multiplied by the width of the field = 100 x 50 = 5,000 meters

3) Krakatau mountain height = 230 meters (after erupting)
   Krakatau mountain height = 813 meters (before it erupts)
   Question: What year is the height of the Krakatau the same as its parent?
   So, the high number of Krakatau volcano after eruption is reduced by the high amount of
   Krakatau volcano before erupting = 230 - 813 = 573

Figure 2. Solution of Students with HOTS’ Low Level

In Question 1, the HOTS low level student did not understand the application of algebra in daily life. Based on the answers and interview results, the student was able to determine what is known and asked from the questions.

In Question 2, the HOTS low level student did not understand the application of the area and perimeter of plane shapes in daily life. However, the student was able to identify what is known and asked from the questions correctly.

In Question 3, the HOTS low level student did not understand the unit and measurement and how to convert variables into each other. However, the student was able to identify what is known and asked from the questions correctly.

4. Conclusion

The findings showed that, in general, higher order thinking skills of students were still relatively low and there were no students who achieved a high level of HOTS due to not understanding of some topics and their applications in daily life. Further, out of 40 students from several junior high schools in Banda Aceh, only 15 students were at medium level of HOTS and 25 students were considered at low level.

HOTS medium level students had not been able to fully determine the main ideas, solutions and methods used. Yet, these students could determine what is known and asked correctly, re-examine the answers to several questions so that they were able to analyze and evaluate their solutions fairly well. In logical and reasoning skills, the students wrote clear, effective, good, and logical answers in the PISA test, demonstrating good logical and reasoning skills, analysis, evaluation, and creation.

HOTS low level students had not been able to fully determine the main ideas, solutions and methods used. Also, these students could determine what is known and asked correctly, did not re-examine the answers to several questions so that they were not able to analyze and evaluate their solutions well. Regarding logical and reasoning skills, the students did not write clear, effective, good, and logical answers and reasons, demonstrating a lack of good logical and reasoning skills, analysis, evaluation, and creation.

The implication of this study suggested to conduct future research on how to improve students’ HOTS. Suggestions for further researchers need to do research to improve students' HOTS abilities as well as research on how to improve students' HOTS abilities.
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