Students’ understanding of charts: the study of PISA's problem-solving in the content of data

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Abstract. This study aimed to analyze students' ability to interpret data that were presented in charts. The analysis was based on the students' problem-solving of PISA problems regarding charts. The participants were 50 grade-seven students from 3 different schools in Banda Aceh. From the four types of charts namely scatter chart, line chart, bar chart and pie chart, it was found that the students’ tended to understand problems that were presented on only one observational dimension. The students’ explanation about the charts focused solely on either the x-axis or y-axis. The students seemed to find it difficult to understand data which were presented in bar charts and pie charts. Basically, 13-14-year-old students, according to Piaget’s cognitive development theory, are moving towards the stage of formal development so they mainly think of a concept from a single point of view. Therefore, it is necessary for teachers to bridge students’ thinking from informal stage to formal stage. Through the results of this study, we expect to enrich teachers’ references regarding the development of learning materials.

1. Introduction
Program for International Student Assessment (PISA) is an international program to measure the educational success of a country. The survey measures students’ literacy and problem-solving skills. Particularly in mathematics, the PISA test investigates students’ mathematical literacy that can prepare the students to socially involved in a modern society [1]. The purpose of PISA in mathematics is to assess students' knowledge in solving problems in daily life. With the increasing challenges of today’s life, students need to have good understanding and reasoning skills that can be used in their life.

Many of the weaknesses of Indonesian students’ mathematical skills are revealed in PISA results. The weaknesses include inability to reason, lack of reading comprehension, and tend to only "receive" information and then forget about it. This condition indicates that the teaching and learning of mathematics in Indonesian classroom needs improvement in order to promote students thinking [2]. The mathematics topics covered in PISA test were also taught in Indonesian classroom such as uncertainty and data.

The regulation from the Indonesian Education Minister No. 22 Year 2006 asserts that the topic of statistics is one aspect in mathematics subjects that must be taught to students in junior high school level. Even before that, statistics has been introduced to students since the 6th grade of elementary school. This means that statistics is not a new concept for junior high school students. But, the real condition is that many junior high school students consider statistics as a difficult subject, especially data presentation such as pie chart [4]. In addition to that, students still find difficulty in interpreting variables placed horizontally and vertically on histograms [5].
According to Piaget's constructivist theory, cognitive development is a process where learners actively build their understandings using experiences and interactions [6]. This theory explains how children adapt to and interpret objects or events around them. This development follows certain stages from simple to complex. Junior high school students grade 7 are students with the age of 13-14 years old. At this age, students have entered the formal operational stage, which is the top level of cognitive structure development. Adolescent students are able to think logically for all kinds of hypothetical problems and verbal problems, and they can use scientific reasoning and can accept the views of others. They can think flexibly because they can see all the elements and possibilities that exist and can think effectively because they can see which thoughts are suitable for a certain problem. Viewed from biological factors, this stage occurs at puberty (when other major changes occur), marking the entry into the adult world physiologically, cognitively, moral reasoning, psychosexual development, and social development.

Some people do not fully progress until this stage, so they do not have thinking skills like adults and keep using reasoning from the concrete operational stage. Moreover, junior high school students are students who are just starting the stage of cognitive development. In learning mathematics, according to Freudenthal, mathematical process is a key element for two reasons. The first reason is that mathematical process is not only an activity for mathematicians, but also for students through the application of mathematics in everyday-life situations. The second reason is that the final stage of mathematics learning is the formation of axioms. Thus, Freudenthal suggests that mathematics be organized in the process of rediscovery (reinvention) where students construct mathematical concepts through a process that is similar to what experienced by the experts [7]. Similarly, in learning mathematics, students need to be introduced first to the concept of the real world before building his/her personal concept into an abstract formal concept. This is in line with Sari’s [8] remark that learning activity is one of the major supporting elements in a learning process. Without that activity, the teacher will only be transferring knowledge and the students will only be passive recipients without having true understanding. Activities can build a conducive learning atmosphere. Building the learning activities that are relevant to learning materials can be done by creating and applying learning trajectory.

Based on the background above, it is clear that data presentation is not new for junior high school students of age 13-14 years old. However, students still face difficulties in understanding bar charts and pie charts. For this reason, the researchers conducted a study to investigate students’ problem-solving strategies in solving problems related to data presentation. This study aimed to describe students’ abilities in understanding scatter charts and line charts in solving PISA problems.

2. Method
The study was conducted using a qualitative research method based on the phenomenological method. The sample of this study was 50 seventh-grade students (age of 13-14) from three different junior high schools in Banda Aceh. The schools were different in terms of academic ability level according to Banda Aceh Educational Government ranking.

The steps undertook in the study consisted of three stages. The first stage was selecting PISA questions or developing PISA related questions about charts. In the second stage, the selected PISA problems were used to examine students’ strategies for solving problems. In the third stage, interview was conducted to clarify students’ answers. Data analysis was conducted in two ways: analysis of the data related to the students’ answer based on selected PISA problems and analysis of the data related to the interview.

3. Result and discussion
This research was carried out by giving PISA problems to 50 students of grade 7 in three different junior high schools in Banda Aceh. The given questions consisted of scatter plot materials, line charts, bar charts and pie charts. Figure 1 is one of the questions in the test.
Figure 1. A line chart about two kinds of vehicle.

As shown in figure 1, the x-axis showed the days from Monday to Friday. The y-axis showed the time from 0 to 60 minutes. The black line referred to the car and the broken line referred to the motorcycle. The questions related to figure 1 were: (1) On what day is the shortest time for the car and for the motorcycle? and (2) On what day are the two vehicles traveling relatively at the same time?

The problem shows data presented in two dimensions of time and day involving two objects, a motorcycle and a car. Thus, this chart has 4 dimensions of observation. Nevertheless, this problem is still relatively easy and requires simple reasoning.

Out of 50 students who answered these questions, 18 students answered both questions correctly: Tuesday for the car and Thursday for the motorcycle. 10 of the students answered the first question correctly and the second question incorrectly. Their answers were: 20 minutes for both vehicles. Six students answered the first question incorrectly and the second question correctly, and 16 students answered the second question incorrectly. That means 22 students or 44% had incorrect answers for the first question and 26 students or 52% of students had incorrect answers for the second question.

During interview with the students who had incorrect answers, it was discovered that the students misinterpreted the line chart. For the first question, they only looked at the bottom of the horizontal line without paying attention to which vehicle had the shortest time. As for the second question, the students raised the number 25 for every aspect of motorcycle and car observations, which showed a 25-minute travel time. This implies that in this case the students paid attention only to the information displayed from the y-axis or horizontal line so they did not realize the integration with the vertical line which indicated the time. This means that majority of the students only looked at the presentation of the data from one dimension only.

The second problem was related to line charts, where students were asked to make statements and reasons based on figure 2. The students were asked whether they agreed if firm A was the company that offered the cheapest transportation service than firm B and firm C. The chart gave two dimensions of observation: the cost of car rental and the number of passengers.

From 50 students who answered this question, 37 students answered correctly and 13 students answered incorrectly. Two of the students who answered correctly used answers that matched the manipulation of numbers and mathematical formulas to find the right number of rents for each passenger. Interestingly, 39 students reasoned this problem based on their observations of the horizontal line. Since firm A had the longest line with the highest point, they assumed that firm A had the most expensive cost of car rental.

In figure 2, the x-axis showed the number of passengers and the y-axis showed the rate of the rent starting from 0 to 16 thousand rupiahs.
Apart from that, 8 students disagreed with the statement in the question. They reasoned that although the price was in the highest position, the number of passengers was also many, this was based on observations from the vertical line so they assumed that the more passengers, the rent would be cheaper. The other 3 students who answered wrongly did not give reasons for their answers.

In the third and fourth questions, the students were asked to create bar charts and pie charts based on previous questions in tabular form. For this session, the students were asked to work in groups of four so that they could collaborate by sharing ideas and get feedback from their friends.

Out of 15 groups of the students who participated in the study, only one group could make a bar chart with information from the vertical and horizontal sides. For the pie chart problem, no group answered correctly. This showed that the students were still using observations from only one dimension. Table 1 shows students’ answers to the PISA questions.

Table 1. The number of students’ responses based on the answer types.

| Number of Problem | Answer Type 1<sup>a</sup> | Answer Type 2<sup>b</sup> | Answer Type 3<sup>c</sup> | Answer Type 4<sup>d</sup> |
|-------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| 1.a               | 7                         | 21                        | 0                         | 22                        |
| 1.b               | 7                         | 17                        | 0                         | 26                        |
| 2                 | 7                         | 30                        | 0                         | 13                        |

<sup>a</sup>True answer and Two-dimensional viewpoint.
<sup>b</sup>True answer and One-dimension viewpoint.
<sup>c</sup>Wrong answer and Two-dimensional viewpoint.
<sup>d</sup>Wrong answer and One-dimensional viewpoint.

According to the Piaget’s theory of cognitive development, the students have entered the formal operational stage. This means that the students should have been able to build their own mathematical concepts through the principles of hypothesis and deductive reasoning. In the further development, students aged 13-14 years old begin to develop abstraction skills using symbols or notation [12].
However, this study indicated that some students aged 13-14 years old in Banda Aceh had not reached the appropriate cognitive development.

Whereas, the ability of students who only observed an event through a single point of view according to Piaget’s Theory was a cognitive development of level 2 which was the pre-operational stage. This level was actually a stage of cognitive development of children aged 2-7 years old. According to Piaget, children’s perceptions in this stage of development were generally restricted to one aspect or dimension of an object. Piaget tested the concept of conservation by pouring the same amount of liquid into two similar containers. When the liquid from one container was poured into a third, wider container, the level was lower and children thought there was less liquid in the third container. Thus, the children were using one dimension, height, as the basis for their judgment of volume.

This was the same case as the findings of this study. When the students were given a problem involving two dimensions, they only paid attention to one dimension. This indicated that in considering two interrelated things, the students tended to look at one side only. This finding was confirmed through the interview. 37 out of 50 students, or equal to 74%, exhibited that they consciously and repeatedly interpreted the line chart on one dimension only. The students’ errors in interpreting the scatter chart and line chart made them faced difficulties in interpreting or presenting data in the form of bar charts because the three types of the diagrams were actually the same, just different in shapes. Pie chart was even more challenging for the students because of its shape. It required the students to be able to convert data into degrees. It meant that mathematical problem-solving in junior high schools in Banda Aceh still needed attention from teachers or educators [13].

4. Conclusions
Students aged 13-14 at some junior high schools in Banda Aceh had not reached the suitable cognitive development stage yet. Students in grade 7 should have entered the formal operational stage, but this study found that the students were still at the pre-operational stage according to Piaget's theory. A pre-operational stage is a condition for children aged 2-7 years old. It means that some junior high schools in Banda Aceh fall behind two stages from the normal stage. This can be seen from the students’ perception in interpreting problems of presenting data in the form of a chart where they only paid attention to one dimension, either the x-axis or y-axis. This condition must be improved otherwise the curriculum content will always be difficult for the students. This also explains why Indonesian students’ achievement in PISA survey has not improved.

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