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Students' Prior Knowledge as an Ontogenic Obstacle on the Topic of Ratio and Proportion

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Abstract

This study aims to investigate students' prior knowledge as an obstacle when learning ratio and proportion concept. The study uses an interpretive paradigm which is part of Didactical Design Research. Eighth graders who had learned about ratio and proportion participated in this study. The analysis was carried out qualitatively based on the data from the students' answers and interviews on their answers when solving ratio and proportion problems to identify learning obstacle, especially ontogenic obstacle regarding the students' prior knowledge. The result of this study indicates that prior knowledge is one of the ontogenic obstacle in teaching and learning of ratio and proportion. It can be found from their learning experience in understanding the concept. In conclusion, investigating students' prior knowledge is essential for the effectiveness of teaching and learning of ratio and proportion. It is important to overcome ontogenic obstacles and to understand how to activate students' prior knowledge using the right or appropriate methods when learning ratio and proportion.

Keywords: Prior Knowledge, Ontogenic Obstacle, Ratio and Proportion

Abstrak

Penelitian ini bertujuan untuk menyelidiki pengetahuan awal siswa yang menjadi kendala dalam mempelajari konsep rasio dan proporsi. Penelitian tersebut menggunakan paradigma interpretif yang merupakan bagian dari *Didactical Design Research*. Siswa kelas delapan yang telah mempelajari materi rasio dan proporsi berpartisipasi dalam penelitian ini. Analisis dilakukan secara kualitatif berdasarkan data dari hasil jawaban siswa dan wawancara terhadap jawaban mereka saat menyelesaikan permasalahan rasio dan proporsi untuk mengidentifikasi hambatan belajar, khususnya hambatan ontogenik dari sisi pengetahuan awal siswa. Hasil penelitian ini menunjukkan bahwa pengetahuan awal merupakan salah satu faktor yang mempengaruhi hambatan ontogenik dalam pembelajaran rasio dan proporsi. Hal ini dapat ditemukan dari pengalaman belajar mereka dalam memahami konsep. Kesimpulannya, menyelidiki pengetahuan awal siswa sangat penting untuk keefektifan pengajaran dan pembelajaran rasio dan proporsi. Hal tersebut juga penting untuk mengatasi hambatan ontogenik maupun untuk memahami bagaimana mengaktifkan pengetahuan awal siswa menggunakan cara yang benar atau sesuai saat mempelajari rasio dan proporsi.

Kata kunci: Pengetahuan Awal, Hambatan Ontogenik, Rasio dan Proporsi

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INTRODUCTION

Fundamentally, learning obstacles refer to cognitive obstacles that can be influenced by psychological aspect, instructions in didactical practices and textbooks, and variety of contexts. Those causes are classified by Brousseau (2002) as ontogenic obstacle, didactical obstacle, and epistemological obstacle. Ontogenic obstacle is described as psychological obstacle that emerges due to students' limitations at the time of development or mental readiness (Brousseau, 2002). This obstacle focuses on personal development of students. It is important to identify because the developmental

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limitations can be the primary cause which hinders students' development in understanding more complex mathematics topics (Cortina et al., 2014; Sidik et al., 2021; Wahyuningrum et al., 2019). The development of skills, knowledge, as well as understanding basically depends on motivation, abilities, experience, prior knowledge, or conception. Such factors are categorized as psychological causes (Bingolbali et al., 2011); they affect the development of students' understanding and mathematical skills, as well as their learning outcomes. The factors above need to be investigated for carrying out an effective learning, especially regarding prior knowledge (Ahl, 2019; Ausubel et al., 1978; Bingolbali et al., 2011; Yuksel, 2012).

Dochy and Alexander (1995) define prior knowledge as a person's whole knowledge which is dynamic in nature; available before a certain learning task; structured; can exist in multiple states (declarative, procedural, and conditional knowledge); both explicit and tacit in nature; and contains conceptual and metacognitive knowledge components. Prior knowledge is related to personal development. It is important for students to construct new understanding, new knowledge, or new concept which is useful in more complex domains (Hutapea et al., 2015; Lamon, 1993; Ültanır, 2012). It is also the most important thing for effective learning (Ausubel et al., 1978; Cesaria & Herman, 2019; Glogger-Frey et al., 2018; Yuksel, 2012) because prior knowledge is the most basic aspect, condition, or a need. It is a foundation that must be fulfilled so that the way of thinking becomes systematic and nothing is missed or messy.

Based on the definition of prior knowledge, declarative and procedural knowledge will be focused in this research as the basis to reach conceptual knowledge. Declarative knowledge refers to knowledge of facts and the meaning of symbols, while procedural knowledge is the knowledge of actions which means integration and application of knowledge (Dochy & Alexander, 1995; Hailikari et al., 2008). Therefore, declarative and procedural knowledge are related to "knowing what" and "knowing how", respectively (Anderson, 2015). Students who have declarative knowledge will rely more on memorization because they do not think about how to integrate and apply knowledge. When they achieve procedural knowledge, not only they know facts, they also understand and apply what they already know. Based on the definition and the concept, prior knowledge is very helpful for learning and it is important to develop students' understanding. However, this prior knowledge become an obstacle when it is inaccurate, unadapted, or incomplete (Bingolbali et al., 2011; Brousseau, 2002; Yuksel, 2012). This is called ontogenic obstacle.

Regarding students' prior knowledge as ontogenic obstacle, ratio and proportion are topics that need to be considered. Students are supposed to master the topic (Ojose, 2015) as stated in the Indonesian curriculum (Ministry of Education and Culture, 2014). This understanding will also be used to solve problems in life, in the other disciplines, and even in related mathematics topics (Ojose, 2015; Pişkin-Tunç & Sultan-Gündoğdu, 2022; Valverde & Castro, 2012). Many studies have documented and identified learning obstacles on ratio and proportion, especially in Indonesia. For example, even though students have been taught about ratio, they still do not understand when they should apply (Andini &

Al Jupri, 2017; Wahyuningrum et al., 2017). They just know that there is a multiplicative relationship among quantities, but they never realize it as a ratio or proportion problem. The students apply unit rate and factor of change strategy without representing it with the notation of ratio or even proportion. They always do that for solving the problems given. Even though some of the students use fraction, they just know it as the way to solve that kind of problem, not because they understand the relationship between fraction and ratio (Andini & Al Jupri, 2017; Wahyuningrum et al., 2017). Another research has found that most of students know that it is a problem of direct proportion, but they do not know what strategy should be used (Hardi et al., 2013; Wahyuningrum et al., 2017). It means that their knowledge is only declarative knowledge and their prior knowledge has not been well-conditioned. In addition, there are students who cannot detect the concepts inside and cannot distinguish direct and inverse proportion (Hardi et al., 2013; Karli & Yildiz, 2022; Raharjanti et al., 2016). These conditions happen not only in Indonesia, but also in other countries. Most students do not understand the definition and characteristics of ratio and proportion concept. They cannot distinguish the situation of additive and multiplicative relationship (Bintara & Suhendra, 2021; Karli & Yildiz, 2022; Misailidou & Williams, 2003). They just rely on the procedures and formulas without understanding, such as cross-multiplication as well as the formula of maps and scale drawings and also speed; they just understand the problems that have been exemplified by teachers in the class (Arican, 2016; Cetin & Artekin, 2011; Jiang et al., 2014; Lamon, 1993). This condition needs to be investigated based on the origin of ontogenic obstacle. There must be underlying reasons why the students do not have a good grasp of the topic. One of the reasons is that they probably are not ready yet to learn the material due to the lack of experience or basic concept in a domain, i.e. from previous domains or the domain they have learned (Bock et al., 2015). It can be indicated from the ways they explain the concepts, the ways of thinking in solving the problems, and the ways of using mathematics to represent the situations (Cetin & Artekin, 2011; Rittle-Johnson et al., 2009).

Teaching and learning of ratio and proportion essentially requires students' understanding of quantity, covariation, multiplicative relationship, notation of fraction, and equivalent fractions which would help the students understand definition and characteristics of ratio. They should understand the relationship between the concept of fraction and ratio because ratio is written as $a:b$ or $\frac{a}{b}$, where $b \neq 0$ (Ben-Chaim et al., 2012). Comparing ratios and being aware of non-proportional and proportional situation would lead them to understand proportion. Furthermore, the conditions of proportion would show them about the characteristics and representation of direct and inverse proportion. Besides, multiplicative schemes and the nature of students' proportional reasoning are knowledge the students should have (Van de Walle, 2008). It indicates that they need to comprehend not only the related mathematical concepts, but also the relationship between knowledge they have just learned and the next ones. However, most of teaching and learning of fraction just encourage the students to know about the procedure and algorithms, without developing their understandings (Shanty et al., 2011; Wijaya, 2017). It affects the understanding on the topic of ratio and proportion. The students do not conceive how to distinguish kinds of proportion and how the strategy, such as cross-multiplication, is created because they are used to knowing the procedures (Arican, 2016; Raharjanti et al., 2016).

Based on those previous studies, this study aims to investigate ontogenic obstacle with regard to students' prior knowledge and how it affects the effectiveness of teaching and learning of ratio and proportion. This research is expected to overcome or minimize the ontogenic obstacle. Furthermore, it can also show that teachers have to create effective learning which is not only goal-oriented, but also decontextualize and depersonalize (Misailidou & Williams, 2003; Ruli et al., 2018; Suryadi, 2013). The two are related to discovery process carried out by students as an effort to obtain new knowledge (Suryadi, 2013) as they need sufficient prior knowledge.

METHODS

The study used an interpretive paradigm of didactical design research. Interpretive paradigm is related to the effort of gaining insight and in-depth information (Kivunja & Kuyini, 2017; Thanh & Thanh, 2015) and becomes the initial stage in didactical design research. This paradigm is used in this study to understand the phenomenon of ontogenic obstacle based on previous didactical design. The comprehensive understanding about the obstacle can be used to develop innovation of didactical design as a critical paradigm, continuation of the previous stage.

The study was conducted at a public junior high school in Bandung, Indonesia. This school was selected based on the diversity of students' abilities and preliminary observations. There were 72 students from grade eight who had learned about ratio and proportion participating in this study. The samples were chosen based on their experience. The students were asked to solve six problems related to ratio and proportion concept. The problems had been validated by two mathematics lecturers as the experts and were designed to identify learning obstacle, especially ontogenic obstacle, which comprises the aspect of understanding ratio concept; applying the notation, rules, or formula; comparing ratios (including proportion concept); and understanding direct and inverse proportion as well as its application. These problems are also based on the types of proportion problems by Lamon (1993), namely part-part-whole (comparing a subset with its complement or with the whole itself); associated sets (relating two quantities with no commonly known connection, but indicating the rate pairs); well-known measures (expressing the relationship between two quantities forming the rate); and growth (stretching and shrinking situations).

Based on students' answers, 23 students were selected for an interview. They had to explain their answers so that the researchers could know more about their ways of thinking and understanding. The selection was based on the strategies the students used (even if the answer is correct or incorrect) or unique explanations. Semi-structured interviews were employed to reveal their prior knowledge based on their learning experience in understanding the concept. The interview questions were developed based on their states of prior knowledge.

Analysis process of qualitative data had been started since the collection of data, namely the data of learning obstacle identification, especially ontogenic obstacle. The students' answers, both on paper or from the interview, were analyzed with regard to their prior knowledge which caused ontogenic obstacle.

RESULTS AND DISCUSSION

Based on students' answers, the researchers found that there are conditions reflecting the ontogenic obstacle regarding prior knowledge. We analyzed it from how the students understand the concept, why their understanding indicates ontogenic obstacle, and how it affects the effectiveness of teaching and learning of ratio and proportion. The results in written test are shown in Table 1. The analysis is based on the definition of prior knowledge by Dochy and Alexander (1995), namely declarative and procedural knowledge to describe conceptual knowledge.

Table 1. The results of students' answers in solving six problems related to ratio and proportion

Result of answer	Problem					
	1	2	3	4	5	6
Correct (%)	19.44	75	48.61	58.33	5.56	0
Incorrect (%)	80.56	25	51.39	41.67	94.44	100

There are six problems (see Figure 1) to investigate the students' understanding related to ratio and proportion concept. Problem 1 is about comparing ratios (type of part-part-whole), but 80.56% students recognize it as the situation of additive relationship. The students know the quantity between groups and between boys and girls. They know that they must compare quantities. It means that they already have declarative knowledge (Anderson, 2015). However, they were not aware of the multiplicative relationship; so, what the students compared was only limited the quantity among girls. They were not been able to integrate knowledge they already have for solving the problem; they do not even know what notation to represent the problem. Even though some of them represent it with ratio notation, they still considered it as an additive one, as shown in Figure 2. Their declarative knowledge is only limited to recognizing the notation of ratio, but they do not understand its meaning. In addition, the other students solve it correctly using fraction, but they cannot explain why they use it. Sometimes, we have to question when the students have the correct answer because it does not guarantee that they understand the concept of the topic being discussed. All they know is just using fraction, as shown in the following interview.

Teacher : Why did you use fraction to solve this problem?

Student 1 : I don't know. I just know this way.

Teacher : Well, how did you know that it's a fraction problem?

Student 1 : I don't even know what problem it is.

1. *Mrs. Fitri has two teams which are going to participate in science competition. Team A consists of 2 girls and 3 boys, while team B consists of 2 girls and 4 boys. Which team has more girls?*

2. *Aishalina Bakery sells three boxes of brownies for Rp67.000,00. Mommy asks Rania to buy some boxes there for a small event. How much should Rania pay for 12 boxes of brownies?*

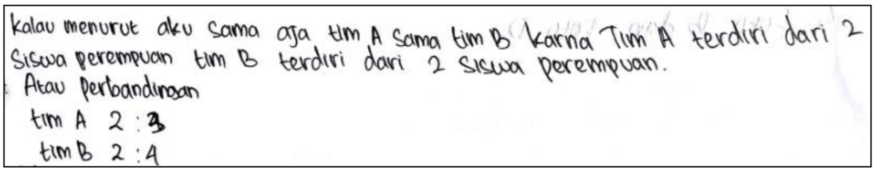
3. *Daddy's car needs 6 litres of fuel to travel 72 km. Can it travel 267 km using 21 litres of fuel?*

4. *A sister and her younger sister went to school in the same track by bike. When the younger one was 800 metres from home, her sister was 200 metres. When her sister was already 600 metres, how far was the younger one from home?*

5. *Daniel calculates that the distance on the map between two places is 7.2 cm. A map scale is 1:5.000.000. He usually went there by motorcycle from 7 a.m. and would arrive at 4 p.m. without calculating the interlude. How much speed does Daniel need to get there within 6 hours?*

6. *Rangga has same photos in different size. He labels each photo as follows:*
   Photo A : 9 cm × 13 cm
   Photo B : 8 cm × 12 cm
   Photo C : 6 cm × 8 cm
   Photo D : 10 cm × 15 cm
   Photo E : 5 cm × 10 cm
   He needs two photos by choosing a photo and one other photo is the enlargement of photo chosen. Which photos are chosen by Rangga?

Figure 1. Problems related to ratio and proportion concept

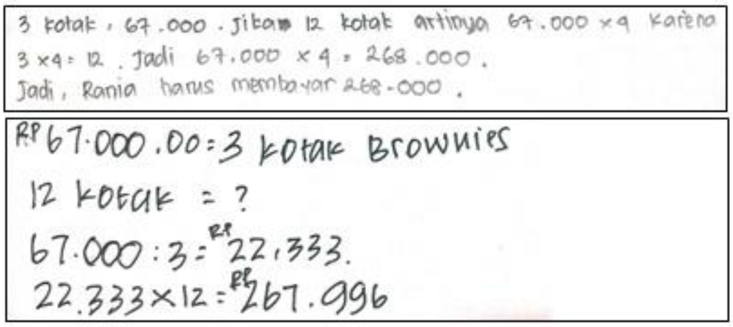


Translated into English:
I think, it's just the same, team A and team B because team A consists of 2 girls, team B also consists of 2 girls. The ratios are
Team A = 2 ÷ 3
Team B = 2 ÷ 4

Figure 2. Strategy of student 2 in solving Problem 1 about comparing ratios (type of part-part-whole)

Figure 2 shows that the students' prior knowledge is just about the facts of quantity and notation. It has not been well-integrated to achieve the understanding about the existence of quantities, its relationships, and the related concepts. When the students do not have an understanding of quantity and relationship between quantities, it means that they have insufficient understanding about the ratio concept. Ratio is related to comparing quantities, and its relationship characterizes whether the problem is the ratio. The understanding should help the students to recognize the problems which refer to multiplicative or additive relationship (Van de Walle, 2008). Then, they will develop their understanding about covariation and know when using the ratio is appropriate for solving the problems. Moreover, this understanding is a basic thing in learning proportional relationships (Arican, 2016). Unfortunately, the students just have a part of declarative knowledge. They know about the facts without understanding them.

The students also know the notation or procedure they used to get. The effort of putting the quantities into notation reflects their understanding of a concept. An understanding of fraction concept is required because the ratio can be written as fraction, but the facts that the students cannot explain why they use fraction or equivalent ratios in solving the problems show the gap between fraction and ratio concept. Their understanding about those concepts is also incomplete. Fraction concept should be their prior knowledge here. When the students understand fraction, it means that they have to carry out the rule of fraction and equivalent fractions, which are used to find equivalent ratios (Ben-Chaim et al., 2012; Lamon, 1993). This understanding should make them realize about related mathematical concepts and how fraction works in the ratio which eventually leads the students to understand the proportion concept. They will understand that proportion can be written as equivalent fractions, and then it is used for solving the problems (Solomon, 1987; Yee, 2007). When the students' understanding does not achieve it, showing that they just have declarative knowledge, it reflects the quality of prior knowledge. The incompleteness of their prior knowledge affects their conceptual knowledge so that it causes the emergence of ontogenic obstacle.



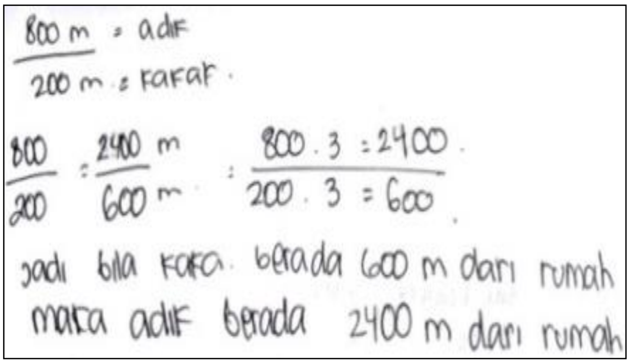
Translated into English:
First strategy
3 boxes, 67.000. If there are 12 boxes, it means 67.000 × 4 because
3 × 4=12. Therefore, 67.000 × 4 = 268.000.
So, Rania should pay 268.000.

Translated into English:
Second strategy
Rp67.000, 00 ÷ 3 boxes of brownies
12 boxes = ?
67.000 ÷ 3 = Rp22.333.
22.333 × 12 = Rp267.996

Figure 3. Strategy of student 3 and 4 in solving Problem 2 about proportion (type of associated sets)

Ontogenic obstacle is also depicted by how they solved problem 2 about simple proportion problem (type of associated sets). There are 25% students who have incorrect answer just because they do not know how to operate those quantities. They do not even realize how to solve that simple problem with any prior knowledge. The other results the researchers found are all about the correct answers. Their declarative knowledge just explains how they realize the fact of quantities without knowing how to apply the facts they already have. The answers show that almost no one uses the notation of proportion; only two students try to represent it using the notation of proportion. The students actually have applied unit rate or factor of change strategy, but they do not understand the problem as proportion problem (Figure 3). The concept they have already learned is not useful for them here because they do not even remember how to solve it using equivalent ratios or proportion. As the students were aware about quantity for solving Problem 1, it reveals here that they actually never know how it relates to each other. They do not realize the fact of the topic and it affects how they achieve procedural knowledge and conceptual one. This condition proves that there is something that has not been emphasized to students when learning the concept of ratio and proportion whereas the understanding will become another prior knowledge (Ahl, 2019; Thurn et al., 2022) or the readiness for students to face another problems or topics.

The students' understanding in solving Problem 2 tends to be used in solving Problem 3 (type of well-known measures) about proving if two ratios are proportional. The percentage of correct answers (see Table 1) does not reflect that the students solve the problem correctly. No one uses the concept of direct proportion. The students just work on numbers, guess, and answer the problem with "yes, he can" or "no, he can't," but there is no right explanation. Again, they have the knowledge of facts, such as quantities, but they still do not see the relationship among quantities. They do not have any idea as well how to represent it. It means that their declarative knowledge is still unadapted. Although they are given a clue if it is a proportion problem, they still have no idea what proportion is. Moreover, they still do not understand why it is denoted as a proportion problem. This condition shows that the students do not understand because there are limitations of the development of knowledge they should achieve so that it becomes ontogenic obstacle for them.



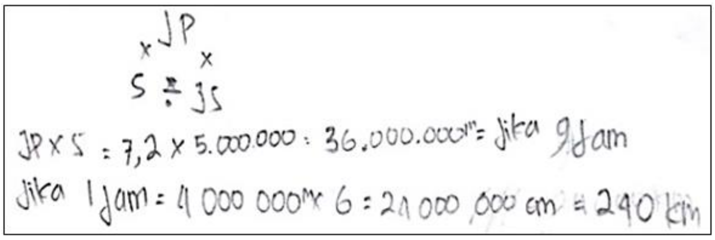
Translated into English:
800 m = younger sister
200 m = sister

$$\frac{800}{200} = \frac{2400\text{ m}}{600\text{ m}} \rightarrow \frac{800 \times 3}{200 \times 3} = \frac{2400}{600}$$

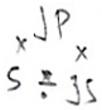
So, if a sister is already 600 meters away from home,
Then her younger sister is 2400 meters away from home.

Figure 4. Strategy of student 5 in solving Problem 4 about additive relationship

Different condition emerged when the students solve Problem 4 which is not a proportion problem. The results reveal that some of the students (58.33%) recognize additive change in the problem and solve it correctly. Unfortunately, they still do not know why they use that strategy while some students think of direct proportion concept, as shown in Figure 4. It really indicates that the students do not recognize the difference between additive and multiplicative change at all. The students just recognize the quantity. Their declarative knowledge is they remember the formula after finding out the problem has just the same type as what they ever get in the class so that they use it. Their understanding about proportion is actually limited to the procedures which the teacher usually emphasized in the class involving missing value. The students just know that if three values are known, they can always find a missing value using proportion. They do not know whether proportion is the appropriate concept. It shows that their knowledge has not been integrated when a procedure can be used or when the concept can be applied. This inaccurate knowledge causes the emergence of ontogenic obstacle.



Translated into English:



JP	= map distance
S	= scale
JS	= actual distance

$$\text{JP} \times \text{S} = 7{,}2 \times 5.000.000 = 36.000.000 \text{ m} = \text{if 9 hours}$$
$$\text{If 1 hour} = 4.000.000 \text{ m} \times 6 = 24.000.000 \text{ cm} = 240 \text{ km}$$

Figure 5. Strategy of student 6 in solving Problem 5 about application of proportion concept (scale and speed)

Another fact is the students do not recognize situations in which applying the proportion concept is reasonable, as shown in Figure 5. It shows their strategy in solving Problem 5 as the application of proportion concept. The problem is about direct proportion (scale and speed) and/or inverse proportion. The students do not have any idea to explain the kinds of proportion they learned in grade 7. Most of them (94.44%) just work on information or try to memorize the formulas without understanding as shown by the illustration in Figure 5. Thus, when they forget the formula, they create the wrong ones. Some students are not sure as well when they illustrate the way they memorize the formula as revealed in the following interview.

Teacher : Can you explain how you solve this Problem 5?

Student 7 : Firstly, I have to draw the formula which is illustrated in triangle.

Teacher : How is it?

Student 7 : It is like this (Fig. 6)), if I'm not mistaken. I don't know whether it's true or not.

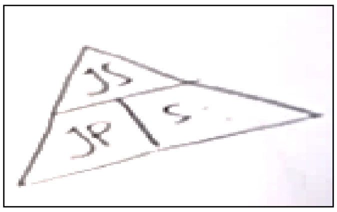
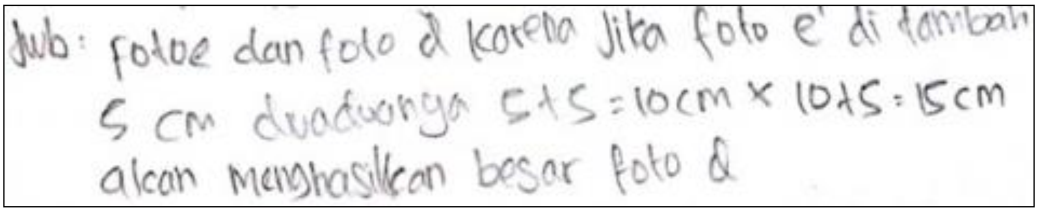


Figure 6. The illustration of formula drawn by student when solving scale problem

The students should know that proportion is classified as direct and inverse proportion, at least they understand the differences. They need to recognize the difference between those kinds of proportion through the characteristics and representations before applying the notation of proportion. The students need to see it clearly so that there is no gap to understand direct and inverse proportion (Arican, 2016; Van de Walle, 2008). They should find the formula themselves as representation of each proportion and find how proportion related to cross-multiplication (Solomon, 1987), for instance, how $\frac{3}{8}=\frac{x}{24}$ is related to $3\cdot 24=8\cdot x$. Furthermore, they can use their understanding to the application of proportion, such as map and scale drawing, as well as speed. When the students just revolve around "knowing the topic, getting the formula and examples, and solving the problems which are almost same with the examples," it does not construct their understanding in the right ways. Their prior knowledge solely brings up the obstacle.



Translated into English:
Photo E and photo D because if the length and width of photo E are both plus 5 cm,
$5+5=10$ cm $\times$ $10+5=15$ cm, it will be the size of photo D.

Figure 7. Strategy of student 6 in solving Problem 6 about photograph-enlargement problem (type of growth)

The last problem is photograph-enlargement problem (type of growth) using proportion or scale factor. No one solves it correctly. Some of the students think of enlargement as additive change (Figure 7), some apply the concept of area, and some just pick the given numbers. It shows that they do not understand about stretching (enlarging) and shrinking (reducing) which ratio and proportion concept applied.

The conditions above reveal that the students know the quantities, formulas or procedures, but without understanding. Their prior knowledge has not reached a conceptual knowledge. They miss things they should have for constructing new understanding about ratio and proportion concept, and then it has an impact on the emergence of ontogenic obstacle. Hence, prior knowledge is a factor when there is a gap between their prior knowledge and new knowledge or when their prior knowledge is inaccurate, unadapted, or incomplete (Bingolbali et al., 2011; Brousseau, 2002). It affects their mental readiness (Brousseau, 2002) because the students think that there are always new things they have to memorize. They do not see the relationship among mathematical domains. They just know that a concept is not related to another concept. They do not find the importance of their prior knowledge. Therefore, it surely affects the effectiveness of teaching and learning of ratio and proportion.

CONCLUSION

The results of this study imply that the students' prior knowledge is essential for the effectiveness of teaching and learning of ratio and proportion and reveal the importance of activating prior knowledge through the right ways. Investigating their prior knowledge will show what the students have known about ratio and proportion, their ways of thinking and understanding, things which have been missed, and description of previous didactical design. Declarative or procedural is like a journey towards conceptual knowledge. So far the studies of ratio and proportion are only about the obstacles without understanding the factors of those obstacles as well as the things should be considered and achieved. In addition, the other studies discuss alternative strategies without knowing what things need to be considered. Therefore, this study is expected to provide an insight into ontogenic obstacle, to describe the aspects in activating students' prior knowledge on ratio and proportion, and to be guidance for designing didactical situation in teaching and learning of ratio and proportion. One notable thing is that the students' prior knowledge should help them learn, not hinder learning. It is therefore suggested that future research should broaden the investigation into didactical practices and teachers' knowledge in improving students' learning strategies. This aims to identify the reasons for insufficient prior knowledge.

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