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Case Study

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Problems Solving to Develop Higher Order Thinking Skills: An Example for Middle School Mathematics

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Abstract: The current school curriculum in Indonesia emphasizes learning that develops higher-order thinking skills. Higher-order thinking skills are the ability to connect information logically, critically, and creatively to solve problems. These thinking skills can develop through problem-based learning. Problems in problem-based learning have characteristics including appropriateness for students, authentic, and ill-structured. A new math problem example with these characteristics is to count the amount of sesame in onde cake. Secondary school mathematics teaching can use the problem-solving process of this example as a material for fun collaborative analysis by students and teachers.

Keywords: HOTS; Middle school; Mathematics; Sesame Onde; Problems solving

1. Introduction

The current school curriculum in Indonesia emphasizes higher-order thinking skills development and character strengthening to improve the quality of graduates (Ariyana, Pudjiastuti, Bestary, & Zamroni, 2018). The graduates should have the competency of thinking critically, creatively, and innovatively. They also should be able to communicate clearly, work cooperatively, and have self-confident. Graduates with such competencies are appropriate with the needs of human resources in the 21st century to face the challenges of the economy, society, and globalization in work and daily life (Saavedra & Opfer, 2012).

The school curriculum improvement program also responds to the condition of the low competence of Indonesian students compared to students from other countries in international standard assessments in the Program for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) (Ariyana, Pudjiastuti, Bestary, & Zamroni, 2018). The PISA assessment aims to obtain an overview of students' ability to reason mathematically by using mathematical concepts, procedures, facts to explain and predict a phenomenon (OECD, 2018). The low results on the assessment indicate a lack of higher-order thinking skills in students.

Teaching plays a vital role in developing students' higher-order thinking skills (Saavedra & Opfer, 2012; Yen & Halili, 2015). Teachers' ability to apply appropriate teaching methods influences students' thinking skills. Teaching higher-order thinking skills is quite challenging for teachers. Most teachers experienced difficulty constructing higher-order thinking skills assessments (Driana & Ernawati, 2019; Retnawati, Djidu, Kartianom & Anazifa, 2018). They also cannot identify higher-order thinking problems and solve these problems as well (Retnawati, Djidu, Kartianom & Anazifa, 2018; Tanudjaja & Doorman, 2020).

2. Higher-Order Thinking Skills

HOTS is not easy to define but has the characteristics of non-algorithmic, complex, effortful; involves uncertainty, nuanced judgment, application of multiple criteria, self-regulation, imposing meaning; and produces various solutions (Resnick, 1987). Considering the characteristics of HOTS, Lewis & Smith (1993) define HOTS as a group of elaborative mental activities that require careful assessment and analysis of complex and uncertain situations based on several criteria to find possible answers. Brookhart (2010) summarizes HOTS definition as the ability to think logically, critically, creatively, and independently to solve problems. This definition encompasses HOTS categories as a transfer of learning, critical and creative thinking, and problem-solving. These HOTS categories are cognitive processes consisting of thinking activities (Zohar & Barzilai, 2015). Thinking activities include constructing arguments, asking research questions, making comparisons, dealing with controversies, and establishing causal relationships. Zohar & Barzilai (2015) also argues that HOTS are at a cognitive level beyond the stage of recall and comprehension from Bloom's taxonomy. Based on Bloom's taxonomy revision, the cognitive stages beyond understanding are applying, analyzing, evaluating, and creating (Anderson & Krathwohl, 2001). According to Ariyana, Pudjiastuti, Bestary, & Zamroni (2018), the cognitive levels of HOTS are analyzing, evaluating, and creating, whereas the knowledge dimensions are conceptual, procedural, and metacognitive knowledge.

Transfer of learning is an important educational goal to produce meaningful learning (Anderson & Krathwohl, 2001). Transfer occurs when students use their memory or retention of knowledge. According to Brookhart (2010), HOTS as a transfer of learning means the ability to apply knowledge to new contexts. This new context can be within or outside the knowledge domain (Resnick, 1987). De Bruyckere, Kirschner, & Hulshof (2020) and Dixon & Brown (2012) use the term near transfer and far transfer to categorize the context types of learning transfer. Near transfer occurs when students apply their knowledge in similar situations and contexts to those in which the learning occurred. On the other hand, the far transfer occurs in very different situations and contexts. The far transfer is much more difficult because the learner has to analyze the situation to remember the rules or concepts needed to apply his knowledge. According to De Bruyckere, Kirschner, & Hulshof (2020), the two transfer categories are more accurately described as a continuum so that the difficulty level of the transfer is also a range. However, even near transfer does not just happen to students. Dixon & Brown (2012) mentions several factors that influence the transfer of learning are the level of understanding of student knowledge, the time required to study the problem, the frequency of transfer exercises carried out, the meaning of the problem, the conditions of the transfer, as well as the motivation and metacognition of the learner. Teaching strategies such as guidance, scaffolding, interaction, evaluation, and reflection can increase the transfer of learning (Hajian, 2019).

HOTS as critical and creative thinking is the ability to express self-reasoning, respond, and make their own decisions (Brookhart, 2010). According to Lai & Viering, 2012, critical thinking and creative thinking are often expressed together because its interaction during making decisions or solving problems. However, critical thinking is not equivalent to creative thinking (Mulnix, 2010; Ülger, 2016). Ülger (2016) argues that critical thinking is related to evaluating ideas, while creative thinking is related to generating ideas. Critical thinking is similar to rational thinking or logical reasoning (Mulnix, 2010), including analyzing and evaluating (Lai & Viering, 2012). Andrews (2015) emphasizes core of critical thinking is argumentation. According to Ennis (2015), critical thinking is logical reflective thinking in determining beliefs or actions. Ennis (2015) further describes that it consists of 18 abilities and 12 attitudes or mindsets. Critical thinking abilities commonly cited in references are interpretation, analysis, evaluation, inference, explanation, and self-regulation (Alsaleh, 2020). Lai & Viering (2012) mentions critical thinking dispositions that are also often cited include open- or fair-mindedness, the tendency to seek reason, curiosity, the desire to be well-informed, flexibility, and respect for others' viewpoints. Hamby (2015) argues that the most basic of all critical thinking dispositions is the desire to think critically. Background knowledge also plays a vital role in critical thinking (Lai & Viering, 2012). Willingham (2019) explains that critical thinking is: novel, not simply concluding from a memory of previous situations; self-regulated, not merely executing other people's instructions; effective, meaning respecting rules that make thinking more likely to generate beneficial conclusions.

Creative thinking definition must include originality and effectiveness of the ideas or products generated (Runco & Jaeger, 2012). Effectiveness can be in the form of usefulness, appropriateness, or value. Kim & Lee (2019) and Ritter & Mostert (2017) define creative thinking as the process of producing something unique and beneficial that can be an innovation. Creative thinking uses complex cognitive abilities. According to Lai & Viering (2012), three general abilities of creative thinking are identifying problems, generating ideas with divergent thinking, and solving problems. Elements of divergent thinking include fluency, flexibility, originality, and elaboration. In addition to divergent thinking, creative thinking also requires convergent thinking. Examples of convergent thinking are searching for and mapping concept combinations (Mumford & McIntosh, 2017). Kim & Lee (2019) propose a creative thinking set involving convergent and divergent thinking. The thinking set consists of inbox thinking, outbox thinking, and newbox thinking. Inbox thinking is the process of mastering basic knowledge and skill using critical thinking that is a form of convergent thinking. Outbox thinking or out-of-the-box imagination is the process of generating multiple solutions and devising unique solutions. This process requires divergent thinking but without the element of elaboration. Newbox thinking or newbox connections combine outbox imagination and critical thinking. This process supports the synthesis and refinement of the selected unique solution. The synthesis is convergent thinking, whereas the refinement as elaboration is a part of divergent thinking. In addition to creative abilities, creative thinking requires creative dispositions. Ülger (2016) emphasizes the imaginative attitude. Lai & Viering (2012) argue that enthusiasm, risk-taking, and self-efficacy are especially important when facing society's natural resistance to new creative ideas or products. Kim & Lee (2019) identify 26 creative attitudes necessary for developing creative thinking skills, such as curiosity, spontaneity, independence, diligence, tenacity, open-mindedness, and reflection.

HOTS as problem solving is the ability to identify and solve a problem independently (Brookhart, 2010; Hmelo-Silver, 2004). This ability is crucial in dealing with a non-routine problem (Funke, Fischer, & Holt, 2018). Non-routine problems are also called ill-defined or ill-structured problems. The early stage of solving an ill-structured problem requires the ability to identify the problem (Hmelo-Silver, 2004). Hmelo-Silver (2004) also explains that the ability to solve the problem shows the ability to transfer reasoning strategies. A person with broad prior knowledge generally uses a data-based reasoning strategy. On the other hand, a person with limited prior knowledge applies a hypothesis-based one. Funke, Fischer, & Holt (2018) argue that a certain amount of prior knowledge is still necessary for problem-solving. In addition to prior knowledge and logical reasoning strategy, problem solving requires creativity, insight, enlightenment, and thinking flexibility (Liljedahl, Santos-Trigo, Malaspina, & Brothers, 2016). Thinking flexibility includes the ability to reduce problems logically to the essential, the ability to reverse the flow of thinking, the ability to consider the relationship aspects of the problem, and the ability to change own thinking. Zhong & Xu (2019) use the term non-recurrent skills for those thinking skills. Non-recurrent skills are used to solve non-routine aspects of a problem. The skills are distinct but related to recurrent skills which simply follow a known problem-solving procedure. The problem solving process consists of stages and strategies. The problem-solving stages by George Polya are understanding the problem, designing the problem solving plan, implementing the plan, and evaluating the solution of problem-solving (Liljedahl, Santos-Trigo, Malaspina, & Brother, 2016). Saygılı (2017) identifies strategies for solving mathematical problems such as making systematic lists, looking for patterns, making models or diagrams, and reasoning logically by deducing solutions from problems using available information.

3. Using Problems to Develop HOTS

Developing HOTS can use problems or questions presented in the teaching (Hmelo-Silver, 2004; Weiss, 2003). In mathematics teaching, problem-solving is the most effective way to transfer operational and basic mathematical knowledge contextually for meaningful and sustainable learning (Căprioară, 2015). According to Weiss (2003), effective HOTS problems should be appropriate, authentic, less-structured, encouraging collaborative learning and lifelong independent learning.

The HOTS problems should be appropriate with curriculum standards, learning objectives, and student characteristics (Hung, 2016). Student characteristics comprise cognitive abilities, learning levels, subject matter knowledge, and context knowledge. Lewis & Smith (1993) argue that intellectual experience determines the challenge level of the problems. Problems requiring higher-order thinking by one student may require only lower-order thinking by another one. Therefore, the HOTS problems should be designed with an appropriate difficulty level and quite challenging so that students are not just repeating their knowledge(Weiss, 2003). These problems must have proximal and tangible goals for students in applying their knowledge (Hmelo-Silver, 2004).

Authentic or real-life problems are problems based on the student experience (Weiss, 2003), related to students' daily lives (Busadee & Laosinchai, 2013), also relevant to the community and social or global contexts (Carvalho, 2015). Weiss (2003) argues that if the problems are not relevant to students' experience, they must be relevant to students' future or careers. In addition to the aspect of meaning and relevance for students, authentic problems should also contain the element of connectedness with other subject matters and contexts outside of textbooks and schools (Tan & Nie, 2015).

Ill-structured problems are closely related to their appropriateness for students (Hung, 2016; Weiss, 2003). Ill-structured problems or ill-defined problems (Roberts et al., 2014) are problems that contain complex, uncertain, or incomplete information. These non-routine problems cannot be solved with a known method or formula, and the results are often unpredictable (Saygılı, 2017). According to Hung (2016), ill-structured problems relate to the aspect of in-transparency (the unknown part of the scope of the problem), interpretation heterogeneity (the number of possible interpretations for understanding or solving the problem), interdisciplinary (the knowledge of various subject matter needed to solve problems), dynamics (the changes in problem characteristics), and legitimacy of competing alternatives (the choices of problem-solving methods). The higher the degree of the five aspects, the more ill-structured the problem is. According to Le, Loll, & Pinkwart (2013), aspects that determine the degree of ill-structuredness of problems are the existence of solution strategies, the application variability for each solution strategy, and the verifiability of solutions. Based on these three aspects, there are five types of problems consisting 1) problems with one solution strategy and one implementation; 2) problems with one solution strategy and alternative implementation variations; 3) problems with some known solution strategies; 4) problems with various possible solution strategies and their solutions can be verified automatically; 5) problems with various possible solution strategies and the solutions cannot be verified automatically (Le, Loll, & Pinkwart, 2013). The more diverse the possible solution strategies, the more ill-structured the problem is. Problem solutions that cannot be verified as true or false automatically determine the highest level of ill-structuredness of the problem.

4. Calculating the Number of *Onde* Sesame Seeds as an Example of a HOTS Problem

Onde is a famous street food cake in Indonesia. Onde is round in shape made of glutinous rice flour, stuffed inside with green beans paste, and sprinkled on the surface with sesame seeds (Picture 1). These onde sesame seeds caught the attention of many people. For example, people jokingly ask how many sesame seeds are on the onde. Others often answers also jokingly that if someone wants a delicious onde, choose the one with an odd number of sesame seeds on it.

Problems similar to questioning the number of onde sesame seeds are often found in everyday life. A simple example of problems like that is asking the number of tiles in the floor area. This problem is not challenging because it has been discussed many times in the textbook. Uncommon but similar problems can be presented to students to develop their thinking. Examples of the problems are: "How many grasses are in a field? How many hairs are on the head? How many people attend a demonstration in the area? How is the audience capacity in the room?"

Figure 1. Onde

4.1. Method of Calculating the Number of Onde Sesame Seeds

An onde is a sphere in shape. Sesame seeds stick on the surface of the onde. To calculate the number of onde sesame seeds requires an understanding of the surface area of onde and the location area of a sesame seed. The calculation can apply the whole or the sampling method.

Surface area of a sphere = 4 x area of a circle

Area of a circle = area of a rectangle (which the width = radius of the circle;

the length = half the circle circumference (**Figure 2**)

$= \pi R \times R = \pi R^2$

Surface area of onde $= 4\pi R^2$

The location area of a sesame seed is the outer rectangle area of a sesame seed.

Location area of a sesame seed $= d^2$ (**Figure 3**)

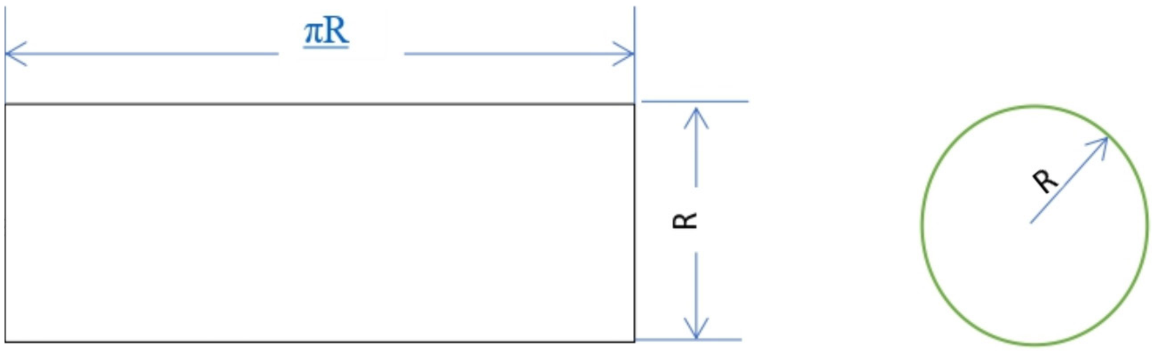

Figure 2. A circle

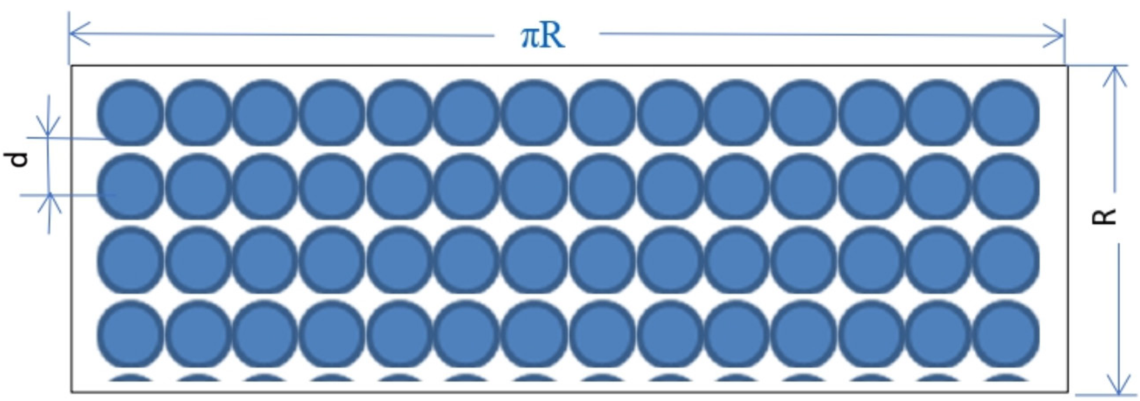

Figure 3. Location area of a sesame seeds d (scale 7 : 1)

This method is applied when the sesame seeds are equal in shape and size and sprinkled orderly on the onde. The number of sesame seeds on the onde can be calculated by dividing the surface area of the onde with the location area of a sesame seed. The formula and its simplified version are as follows.

Surface area of onde $= 4\pi R^2 = \pi D^2$

Location area of a sesame seed $= d^2$

The number of sesame seeds on the onde:

$$n = \frac{\pi D^2}{d^2}$$

If the onde has a diameter of D mm and the sesame seed has a diameter of d = 1 mm, then the formula can be simplified using these steps.

$$n = \pi D^2 \text{ mm}$$

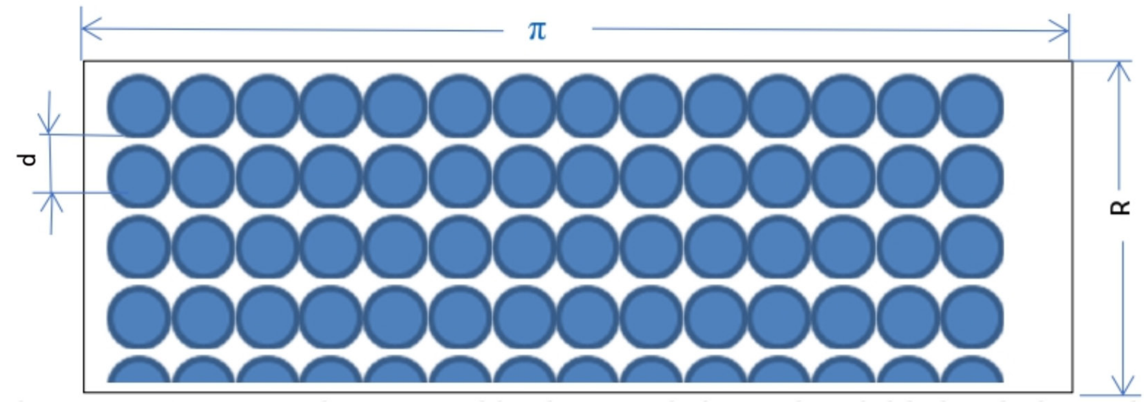

Figure 4. Sesame seeds are equal in shape and size and sprinkled orderly on the onde surface

Problem example

Suppose an onde has a diameter of 36 mm. Sesame seeds have diameter of 1 mm. If sesame seeds are sprinkled orderly to the surface area of the onde, how many sesame seeds are on the onde?

Answer:

The number of sesame seeds on the onde:

$$n = \frac{\pi D^2}{d^2}$$

$$n = \frac{3,14x36^2}{1}$$

$$n = 4073$$

4.2. Calculation using the sampling method

The sampling method is used when the sesame seeds have unequal shape or size, and are sprinkled unorderly on the onde surface. The number of sesame seeds is calculated using the sample area with the following steps: 1) Cut two parts of the onde as samples, either at top-bottom, front-back, or right-left. For example, an onde with a diameter of 4 cm, cut two samples of 1 cm2 each; 2) Count the number of sesame seeds in each sample; 3) Calculate the average number of sesame seeds of the two samples; 4) Calculate the number of onde sesame seeds by multiplying the average number of sesame seeds with the onde surface area and then dividing by the sample area.The formula is as follow.

Surface area of onde = πD^2

Area of sesame seed location = d^2

Area of samples = a^2

Average number of sesame seeds on samples = n_r

The number of sesame seeds on the onde (n):

$$n = \frac{n_r x \pi D^2}{a^2}$$

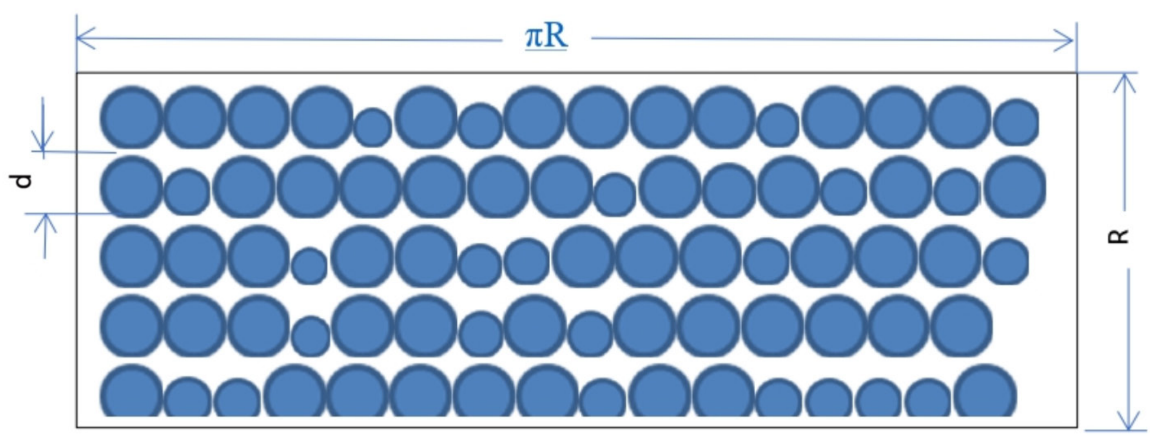

Figure 5. Sesame seeds have unequal shape or size, and are sprinkled unorderly on the onde surface area

Problem example

Suppose an onde has a diameter of 36 mm. If sesame seeds with diameters of 1 mm are sprinkled unorderly to the surface area of the onde, how many sesame seeds are on the onde?

Answer

Since sesame seeds are sprinkled irregularly on the onde, it is necessary to take samples of the surface area of the onde. Two square samples with sides of 4 mm are cut at the top and bottom of the onde. Suppose the number of sesame seeds counted on the sample from the top and bottom of the onde is 16 (n_1) and 14 (n_2), respectively.

Area of sampel (a^2) = 16 mm^2

Average number of sesame seeds (n_r) = 15

Surface area of onde = πD^2

The number of sesame seeds on the onde

$$n = \frac{n_r x \pi D^2}{a^2}$$

$$= \frac{15x(3{,}14\,x\,36^2)}{16}$$

$$= 3818$$

So, in calculating the number of onde sesame seeds can be searched in more than one way and the result is more than one correct answer. Method 1 calculation, namely: calculating the Surface area of onde = 4πR2, calculating the location area of a sesame seed = d2,, dividing the area of onde by the area of sesame seeds. Method 2 calculation, namely: calculating the area of the ball, cutting two or 3 samples from the surface area of the ball, calculating the number of sesame seeds for each sample/piece, calculating the average number of sesame from the sample, dividing the area of the ball by the sample area multiplied by the average number of sesame seeds of the sample.

5. Discussion

In calculating the number of onde sesame seeds can be searched in more than one way and the result is more than one correct answer. The way to solve more than one way is one of the characteristics of HOTS. According Resnick (1987) HOTS is not easy to define but has the characteristics of non-algorithmic, complex, effortful; involves uncertainty, nuanced judgment, application of multiple criteria, self-regulation, imposing meaning; and produces various solutions. Lewis & Smith (1993) define HOTS as a group of elaborative mental activities that require careful assessment and analysis of complex and uncertain situations based on several criteria to find possible answers.

In solving the problem of calculating the number of onde sesame seeds, students are required to transfer from the ability to count the number of things in the area of a square shape to a sphere, for example the ability to calculate the number of ceramics in the area of the floor to the ability to calculate sesame in the area of a sphere. According to Anderson & Krathwohl (2001) transfer of learning is an important educational goal to produce meaningful learning. Brookhart (2010) to explaned HOTS as a transfer of learning means the ability to apply knowledge to new contexts. This new context can be within or outside the knowledge domain (Resnick, 1987). In the activity of counting the number of onde sesame seeds, knowledge transfer, reasoning, and even creation are needed. Brookhart (2010) summarizes HOTS definition as the ability to think logically, critically, creatively, and independently to solve problems. This definition encompasses HOTS categories as a transfer of learning, critical and creative thinking, and problem-solving. These HOTS categories are cognitive processes consisting of thinking activities (Zohar & Barzilai, 2015). Thinking activities include constructing arguments, asking research questions, making comparisons, dealing with controversies, and establishing causal relationships.

To complete the calculation of the number of onde sesame seeds, prerequisite knowledge is required. Funke, Fischer, & Holt (2018) argue that a certain amount of prior knowledge is still necessary for problem-solving. Completing the calculation of the number of sesame seeds also requires creativity because this problem is classified as non-routine. In addition to prior knowledge and logical reasoning strategy, problem solving requires creativity, insight, enlightenment, and thinking flexibility (Liljedahl, Santos-Trigo, Malaspina, & Brothers, 2016). Non-routine problems are also called ill-defined or ill-structured problems. The early stage of solving an ill-structured problem requires the ability to identify the problem (Hmelo-Silver, 2004). Hmelo-Silver (2004) also explains that the ability to solve the problem shows the ability to transfer reasoning strategies. These non-routine problems cannot be solved with a known method or formula, and the results are often unpredictable (Saygılı, 2017). HOTS as critical and creative thinking is the ability to express self-reasoning, respond, and make their own decisions (Brookhart, 2010). HOTS as problem solving is the ability to identify and solve a problem independently (Brookhart, 2010; Hmelo-Silver, 2004). This ability is crucial in dealing with a non-routine problem (Funke, Fischer, & Holt, 2018).

Thinking flexibility includes the ability to reduce problems logically to the essential, the ability to reverse the flow of thinking, the ability to consider the relationship aspects of the problem, and the ability to change own thinking. Zhong & Xu (2019) use the term non-recurrent skills for those thinking skills. Non-recurrent skills are used to solve non-routine aspects of a problem. The skills are distinct but related to recurrent skills which simply follow a known problem-solving procedure. The problem solving process consists of stages and strategies. The problem-solving stages by George Polya are understanding the problem, designing the problem solving plan, implementing the plan, and evaluating the solution of problem-solving (Liljedahl, Santos-Trigo, Malaspina, & Brother, 2016). Saygılı (2017) identifies strategies for solving mathematical problems such as making systematic lists, looking for patterns, making models or diagrams, and reasoning logically by deducing solutions from problems using available information.

To calculate the number of onde sesame seeds in method 1, the ability to calculate: 1) the area of the surface of the sphere, 2) the area of the sesame location (not the surface area of the sesame) and the reason, and 3) the method of division. These three abilities are in the junior high school curriculum. According to Weiss (2003), effective HOTS problems should be appropriate, authentic, less-structured, encouraging collaborative learning and lifelong independent learning. The HOTS problems should be appropriate with curriculum standards, learning objectives, and student characteristics (Hung, 2016). Therefore, the HOTS problems should be designed with an appropriate difficulty level and quite challenging so that students are not just repeating their knowledge (Weiss, 2003). These problems must have proximal and tangible goals for students in applying their knowledge (Hmelo-Silver, 2004). Authentic or real-life problems are problems based on the student experience (Weiss, 2003), related to students' daily lives (Busadee & Laosinchai, 2013), also relevant to the community and social or global contexts (Carvalho, 2015). Weiss (2003) argues that if the problems are not relevant to students' experience, they must be relevant to students' future or careers. In addition to the aspect of meaning and relevance for students, authentic problems should also contain the element of connectedness with other subject matters and contexts outside of textbooks and schools (Tan & Nie, 2015).

The characteristic of HOTS questions in mathematics is that there is not only one correct answer or only one correct answer with different solutions and is a new problem for students. No matter how difficult the question is, if the question has been discussed in class, or is already in a book, then the question is not categorized as a HOT. To answer the question of counting the number of onde sesame seeds, learners must be able to remember, understand, and apply factual, conceptual, and procedural knowledge and have high logic and reasoning because the problem is classified as non-routine and contextual. Thus, calculating the number of onde sesame seeds is eligible as a HOTS question.

6. Conclusion

The completion of calculating the number of onde sesame seeds can be used as an example of a HOTS question item. In the number of onde sesame seeds solving problems, learners are required to be able to use reasoning to determine how to solve them), predict and reflect, the ability to develop new strategies to solve contextual and non-routine problems, and the ability to transfer concepts from one concept to another. Therefore, the answers to the HOTS questions are not explicitly stated in the stimulus. There are 2 formulas that can be used to calculate onde sesame, namely the whole method and the sample method. The formula for calculating the number of onde sesame in the whole way is $n = \frac{\pi D^2}{d^2}$, The formula for calculating the sample way is $n = \frac{n_r x \pi D^2}{a^2}$. In addition, the results of the calculation also have more than one correct answer because the sample selected is different.

7. Recommendations

The way to solve counting the number of onde sesame seeds can be transferred in calculating the number of grass in the field, the number of hairs on the head, the number of hairs on the arms, the number of crowds of people who are somewhere, and the like. This is in accordance with one of the characteristics of the HOTS question item is that the questions tested have never been discussed.

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