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High Visual-Spatial Intelligence Students' Creativity in Solving PISA Problems

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ABSTRACT

Creativity is very necessary for learning mathematics, especially when solving geometry problems. This research aims to describe 4th year mathematics education students' creativity in solving geometry problems. Creativity in this research is focused on fluency, flexibility, and originality of student anwer when solving geometry problems. This research is an explorative descriptive research through a qualitative approach. The participants were 7 fourth year mathematics education students of state University in Mataram, who have a high level of visual-spatial intelligence. The data was collected by written test and interview. The test consisted of two open-ended geometry problems about transforming 3-dimensional images into 2-dimensional images and making 2-dimensional images with a predetermined circumference. The problems are modification of the 2006 PISA test. The result showed that subjects with high visual-spatial intelligence levels met all indicators of creativity. In solving problems that meet the aspects of fluency, flexibility and originality, they combine mental rotation and mental visualization abilities and include using their visual experience by modifying the information obtained and the initial problem solving ideas obtained. This also enables them to produce original problem solutions. The results of this research can be used as an illustration and a guideline to assess students' creativity with high visual-spatial intelligence level.

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A. INTRODUCTION

Creativity is an ability to create new and original ideas in manipulating and transforming information (Ayllon et al., 2016; Fauzi et al., 2019) or problem solving processes or problem solving processes (Fauzi et al., 2019; Haddar et al., 2018; Lisa et al., 2018), and is not limited to pragmatic results (always viewed according to their usefulness) (Novitasari et al., 2015). Creativity is a deep, flexible knowledge in content domains; is often associated with long periods of work and reflection rather than rapid, exceptional insight; and is susceptible to instructional and experiential influences (Sternberg, 2006). Creativity is a very important thing in the life of every individual human being (Agustiningsih et al., 2019; NCTM, 2000). With creativity, someone will create ideas that can improve and keep up with the changing times (Triutami et al., 2020). Conversely, without creativity, individuals will be crushed by the wheel of changing times and unable to survive with existing changes (Novitasari et al., 2020;

Purwasih et al., 2019). Therefore, the ability to think creatively is needed by students and become one of the abilities that must be possessed by students (Rohman, 2019; Schoevers, Leseman, Slot, et al., 2019; Velikova & Petkova, 2019; Widiana & Jampel, 2016). So, education in the 21st century emphasizes the importance of fostering student creativity through learning (Agustiningsih et al., 2019; Ayllon et al., 2016; Haddar et al., 2018; Nasution & Sinaga, 2017).

Creativity is important in learning mathematics (Fauzi et al., 2019; Nasution & Sinaga, 2017; Schoevers, Leseman, & Kroesbergen, 2019; Singer et al., 2017). Every student has potency to be creative. Creative thinking can help them to solve abstract material, stimulate students' desire to explore knowledge, help students solve difficult problems, and improve students' autonomy in mathematical learning (Hua et al., 2019; Novitasari et al., 2020). Creative thinking is one of the most important skills students must have to solving mathematical problem (Fauzi et al., 2019; Shoimah et al., 2018), both to find new problem solving and to find relationships with existing problem solving (Novitasari et al., 2015). Formulating, attempting to solve, reformulating, and solving a mathematical problem are activities that require creative thinking processes (Silver, 1997). One of the materials in mathematics that requires creativity in thinking is geometry (NCTM, 2000; Novitasari et al., 2020). Creativity is needed in learning geometry, especially when solving geometry problems (Hua et al., 2019; Schoevers, Leseman, & Kroesbergen, 2019).

There are three indicators that can be used to assess student creativity in solving geometry problems, that is fluency, flexibility and originality (Agustiningsih et al., 2019; Lisa et al., 2018; Purwasih et al., 2019; Silver, 1997). Fluency in problem solving refers to the diversity (variety) of problem answers made correctly by students. Students explore open ended problems, with many interpretations, solution methods, or answers. Flexibility in problem solving refers to the ability of students to solve problems in a variety of different ways. Originality in problem solving refers to the ability of students to answer problems with new or unusual answers made by students at their developmental stage or level of knowledge. In this study, what is meant by originality is the different answers given by students that are unique and different from the answers given by other students and extract unexpected and unconventional solutions.

Sternberg stated that creativity is related to six different but related components, one of which is intelligence. Intelligence can indeed be said as a necessary condition of creative ability, creative activity, and creative achievement (Kahveci & Akgul, 2019; Karwowski et al., 2016; Sternberg, 2006). Tyagi also said that there is a mutually (symmetric) relationship between mathematical intelligence and mathematical creativity. Mathematical intelligence is an element in mathematical creativity process and vice-versa (Aini et al., 2020; Hendrik et al., 2019; Tyagi, 2017). Gardner developed a theory of multiple intelligences, one of which is visual-spatial intelligence. Spatial intelligence is a competence to perceive visual word accurately, to transform and to modify someone visual experience even when there is no relevant physical activity (Hatch & Gardner, 1986). Spatial-visual intelligence covered a competence to imagine, to represent idea visual spatially, and to self-orient accurately (Gumilar & Nandi, 2018). Visual-spatial intelligence serves as support of the creative process and innovative idea (Cerrato et al., 2020; Suprapto et al., 2018). Spatial visualization and mental rotation associated with some specific domains from spatial ability positively correlated with creativity (Suh & Cho, 2020). Aini et al (Aini et al., 2020) in their research found that visual-spatial students have better creative thinking skills in learning mathematics, especially in geometry.

Geometry is very important in learning mathematics (Novitasari et al., 2020; Triutami et al., 2020; Wulandari et al., 2020). Geometry is also one of the materials tested in PISA (Programme for International Students Assessment). Geometry is one of the materials in mathematics that can be used as a means to foster student creativity (Aini et al., 2020; Utami et al., 2019). The geometry problem in the PISA test is a non-routine mathematical problem solving, so that, it can be used to support students' creative (Leksmono et al., 2019; Novita & Putra, 2016). One of the non-routine mathematical problems is an open-ended problem. Open-ended problems provide space for students to express their creativity in finding solutions to problems. Therefore, this research focused on student creativity in completing the PISA test, especially open-ended geometry problems. There are various kinds of problems in geometry that can be used to train or determine the level of student creativity, for example draw and construct representations of two- and three-dimensional geometric objects using a variety ways, and visualize three-dimensional objects from different perspectives and analyze their cross sections (NCTM, 2000).

There are several studies about students' creativity in solving geometry problems. Shoimah et al conducted research about elementary student creativity with reflective and impulsive cognitive style in solving geometric problems. In their research, it was found that students with reflective cognitive style were more creative in solving geometry problems (Shoimah et al., 2018). Singer et al conducted research about prospective mathematics teachers' creativity in posing and solving geometry problems (Singer et al., 2017). The differences in creativity in this study are grouped by cognitive type. Lisa et al conducted research about junior high school creativity in solving geometry problems (Lisa et al., 2018). The subjects of their study were three students with high, moderate and low cognitive abilities. Schoevers et al conducted research about effects of the Mathematics, Arts, and Creativity in Education (MACE) program on students' ability in geometry and visual arts in the upper grades of elementary school (Schoevers, Leseman, Slot, et al., 2019). Leksmono et al conducted research about junior high school students' creative thingking process in completing mathematical PISA test corcerning shape and space (Leksmono et al., 2019). Aini et al conducted a research about senior high school student's creative thinking level. The subjects in their research were students who had visual spatial intelligence (Aini et al., 2020).

Research about student creativity, who has a high level of visual-spatial intelligence, in solving geometry problems at the university level is still limited. Research from Aini et al (Aini et al., 2020) and Leksmono et al (Leksmono et al., 2019) are still limited to the subject of high school students. Shoimah et al (Shoimah et al., 2018) and Singer et al (Singer et al., 2017) in their research suggested that there is a need for further research on student creativity in solving geometry problems with variations in the cognitive or intelligence types students have. The creativity of students with various levels of visual-spatial intelligence can be used as a learning resource in solving mathematical problems. Therefore, the aim of this research is to describe the fourth-year mathematics students' creativity in solving geometry problems. We want to focus our research on subjects who have a high level of visual-spatial intelligence because there has been no previous research that focuses on the creativity of students who have a high level of visual-spatial intelligence. In addition, we also want to know how they get creative ideas in solving problems so that we can also direct or guide students who have moderate or even low visual-spatial intelligence to think like them. Creativity in this research is focused on fluency, flexibility, and originality generated by students when solving geometry problems.

B. METHODS

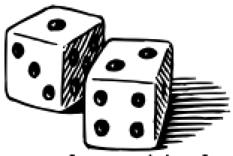
This research is an explorative descriptive research through a qualitative approach. The subjects in this research were selected using purposeful sampling approach. Purposeful sampling in this research is choosing a subject who have a high level of visual-spatial intelligence. First, we conducted a visual-spatial intelligence test to 27 fourth-year students of mathematics study program of a state university in Mataram, Indonesia. The test used is a visual-spatial intelligence test from the research of Dwi et al (Novitasari et al., 2020). The test was carried out only for 15 minutes. The test contained of 18 multiple choice questions arranged based on three components of visual-spatial intelligence, that is the ability to accurately perceive the visual world, transforming visual experience, and modifying visual experience. Of the 27 students who took the visual-spatial intelligence test, 7 students were at a high level and 20 students were at a moderate level. There are no students who have a low visual-spatial intelligence level.

From the results of the visual-spatial intelligence test, 7 students with high levels were selected as research subjects, namely S1, S2, S3, S4, S5, S6, and S7. After that, we conducted a written test and interview on selected subjects. The test is carried out for 60 minutes. The test consisted of two open-ended geometry problems about transforming 3-dimensional images into 2-dimensional images and making 2-dimensional images with a predetermined circumference. The problems in written test are modification of the 2006 PISA test. We choose PISA 2006 test because the questions fit the research indicators we want to achieve. We modified the PISA questions into an open-ended question in Figure 1.

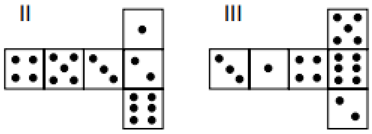
The written test used in this research was first validated by the expert. This validation is intended so that the test questions can be said to be feasible and precisely measure what should be measured or revealed in this research. The experts are two mathematics education lecturers who are also members of the faculty quality assurance group. The experts fill out the validation sheet for the test questions that we have created. The result of the validation is that the questions are suitable for use in this research. The written test can be seen in Figure 1 below.

Problem 1: Numbered dice

Below is a picture of two dice with special number cubes for which the following rule applies: the total number of dots on two opposite face is always seven.

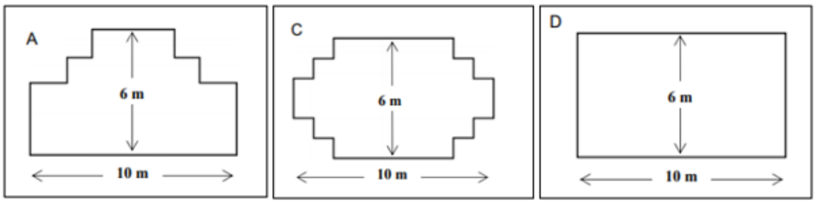


In the picture below, you can see four models of nets to make numbered dice like the picture above.



Problem 2: Carpenter

A carpenter has 32 meters of wooden blocks. With the wooden blocks, he wants to make a fence that surrounds the garden. He made several garden designs as follows.



Make as many other garden designs as possible with the provisions: garden fences should be able to be made using 32 meters of wooden blocks!

Figure 1. Open-ended Geometry Problems

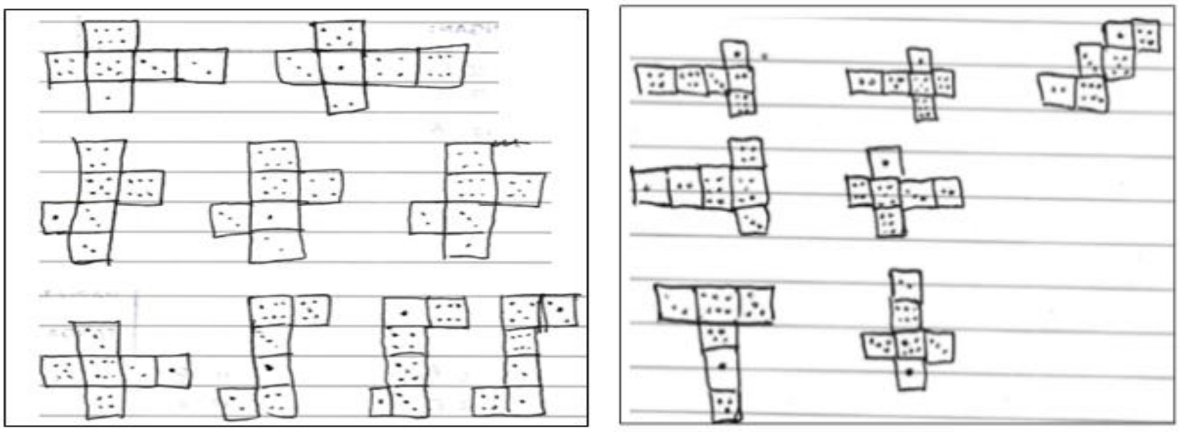
The data in this research were in the form of written test results and interviews of the seven selected subjects. Interviews are conducted after students have finished working on the questions given. Interviews were conducted to obtain data about ideas or strategies used by students to solve each problems. The focus of the interview questions is to explore the thinking process of students in obtaining answers. The collected data were analyzed using transcription, segmentation, coding, categorizing techniques and drawing conclusions (Creswell, 2012). Conclusions drawn related to students' creativity in solving geometry problems. Creativity in this research is focused on fluency, flexibility, and originality of student answers. Fluency refers to the diversity (variety) of problem answers made correctly by students. Flexibility refers to the ability of students to solve problems in a variety of different ways. Originality refers to the ability of students to answer problems with new or unusual answers made by students.

C. RESULT AND DISCUSSION

1. Student Creativity in Solving the First Geometry Problem

a. Creativity in Terms of Fluency

For the fluency indicator, we analyzed the number of correct answers generated by students. Examples of student answers can be seen in Figures 2 (a) and (b).

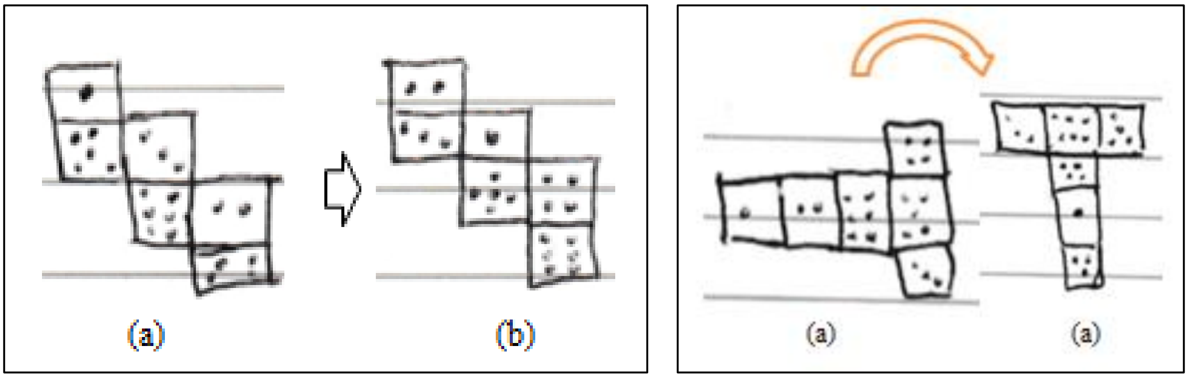


(a) (b)

Figure 2. (a) S3 and (b) S4 Work Results

Creativity in terms of fluency, on average the subjects can give 5 correct answers related to the drawing of cube nets that are suitable for solving the given problem. Most correct answers given by S3 with 9 correct answers and only 1 wrong answer. The answer is wrong because there is two opposite face of cube net which number of dots does not equal to seven. Next in second and third place, S4 can provide 7 correct answers and S6 can provide 5 correct answers. S1, S4, and S7 can provide 4 correct answers. Lastly, S2 only provide 2 correct answers.

Mostly, students make new cube nets by modifying the initial idea of problem solving given. Modifications made include rotating clockwise or counterclockwise, changing the position of the corresponding dice and shifting the sides of the cube nets that have been made. An example can be seen in Figure 3(a) and (b).



(a) (b)

Figure 3. Modification of Students Work Results

Based on Figure 3(1), using the same idea, S3 modifies the answer by changing the position of the corresponding dice in (a) to (b) so that another answer is obtained. In Figure 3(2), S4 uses another strategy by rotating images of the cube nets they made earlier by 90° counterclockwise (from (a) to (b)).

b. Creativity in Terms of Flexibility

Based on the problem solving given by the seven subjects, there are 6 different strategies or answers produced as shown in Figure 4.

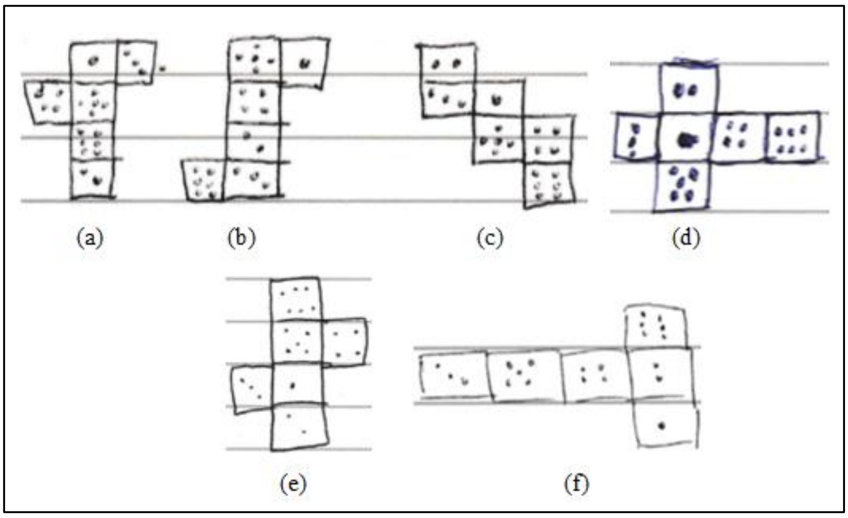


Figure 4. Alternative Answers to The Flexibility Provided by The Seven Subjects

From the results of the analysis and interviews, it was found that the completion strategy carried out by students resulted in the answers as shown in Figure 4, including: (1) imagining that they are opening part by part of the dice to form a net of dice, (2) describing the cube nets formed, (3) determining the corresponding pair of dice eyes, for example 1-6, 2-5, 3-4, (4) placing the position of the eyes of the corresponding dice on each side of the cube facing each other, (5) proving each of the final answers given is correct by re-folding the drawing of the cube nets through the process mentally (in their minds), (6) modified the initial strategy they had obtained to produce various other answers. Strategies 1 to 5 are carried out by students to produce a correct answer, while the 6th strategy is used by students to produce various answers as shown in Figures 4 (a) to (f).

c. Creativity in Terms of Originality

The creativity of problem solving given by the subject in terms of originality can be seen in Figure 5. There are 3 different answers given by subjects that are different from other subjects and are included in the originality category. The difference in these answers compared with the answers of all students as many as 28 people. In general, subjects who have high spatial visual intelligence are able to provide 3 different ideas in solving a given problem compared to students who have moderate spatial visual intelligence.

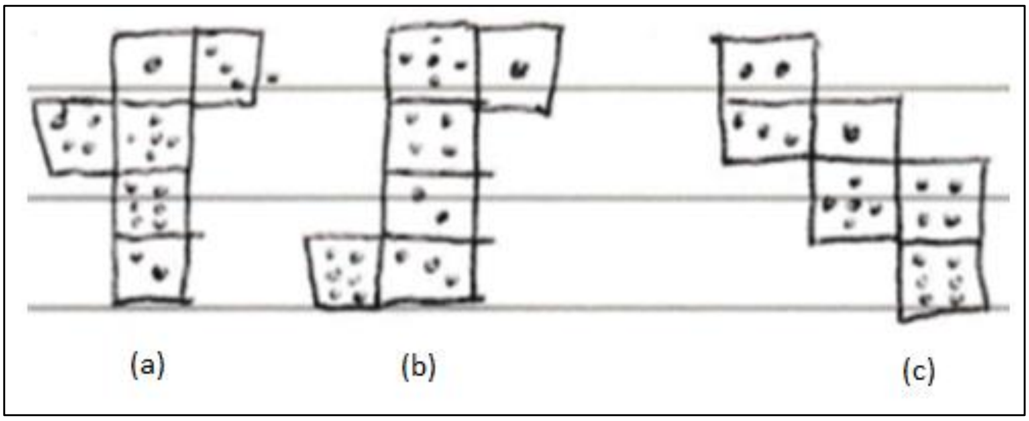


Figure 5. Examples of Alternative Answers Given by S1 are Included in The Originality Category

Figure 5 shows the originality because the three images are not only different from the answers given by other students but also because the students extract the solutions that have been obtained by rotating on several sides of the cube nets that are made so that they produce different new nets that cannot be made by other students.

2. Student Creativity in Solving the Second Geometry Problem

a. Creativity in Terms of Fluency

Based on answer given by the subjects, it is obtained that creativity in terms of fluency, on average the subject can give 5 correct answers. The highest number of answers given by S4, which is as many as 13 models, consisting of 10 correct answers and 3 wrong answers. Examples of subject answers can be seen in Figure 6 below.

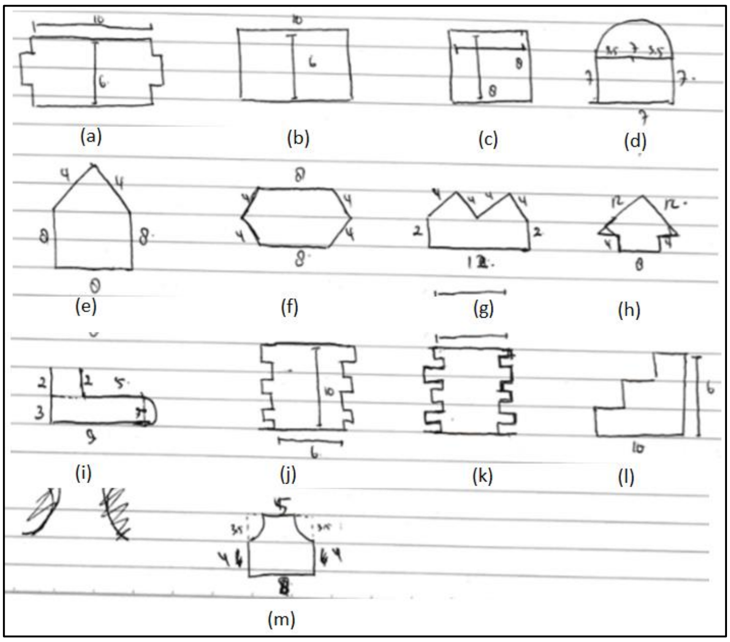
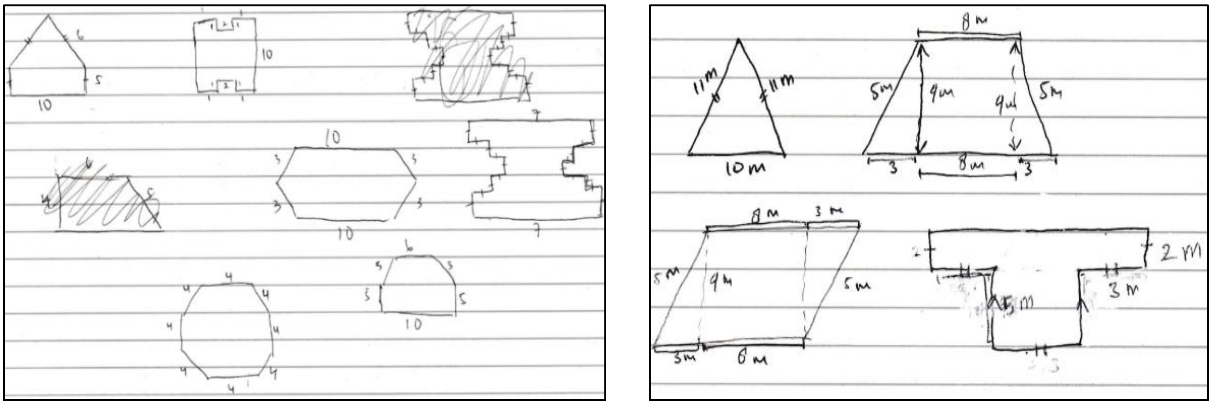


Figure 6. S4 Work Results on Second Problem

Figure 6 shows that the correct answers are (a), (b), (c), (e), (f), (g), (i), (j), (l) and (m), while the answers that are wrong are (d), (h) and (k). Answers (d) and (h) are wrong because the circumference of the shape drawn exceeds the size that should be a maximum of 32 meters. Meanwhile, the answer (k) is wrong because the size in the image is not clear.

b. Creativity in Terms of Flexibility

Figure 7 below is an example of students' answers in terms of flexibility when solving the second problem.



(a) (b)

Figure 7. (a) S5 and (b) S3 Work Results

S5 can provide 6 different ideas/strategies to solve problems, meanwhile S3 can provide 4 different ideas/strategies to solve problems. Based on Figure 7, it can be concluded that subjects who have high spatial visual intelligence are able to provide 10 different correct answers to solve the second problem. The 2-dimensional image forms used by subjects in solving problems, namely: rectangle, square, isosceles triangle, trapezoid isosceles, parallelogram, irregular hexagons, regular octahedron, kite, circle (but the subject did not write the size correctly) and the combination of more than one 2-dimensional images. Subjects generally have 2 different ideas/strategies for resolving, that is, using one 2-dimensional images and a combination of several 2-dimensional images. The more complete strategies used by students can be seen in Table 1.

Table 1. Student Creativity in Terms of Flexibility in Solving Problems 2

Types of 2-dimensional images drawn	**Number of subjects answered**	
	True	**False**
Rectangle	4	0
Square	3	0
Isosceles Triangle	1	0
Isosceles Trapezoid	1	0
Parallelogram	1	0
Irregular Hexagons	2	0
Regular Octahedron	1	0
Kite	1	0
Circle	0	1
Combination of more than one 2-dimensional images	5	2

Through interviews, it is known that the problem solving strategies undertaken by the subject are: (1) gathering information from the questions (the garden should not be more than 32 meters), (2) imagining the design/shape of the park (in the form of 2-dimensional images) which will be created by mentally visualizing it, (3) determining the size of each side of the 2-dimensional images that will be made to conform to the provisions by doing mathematical calculations, (4) describing the design/shape of the garden that has been previously imagined by adjusting it to the size has been calculated, (5) prove the answer that has been made whether it is correct or not.

c. Creativity in Terms of Originality

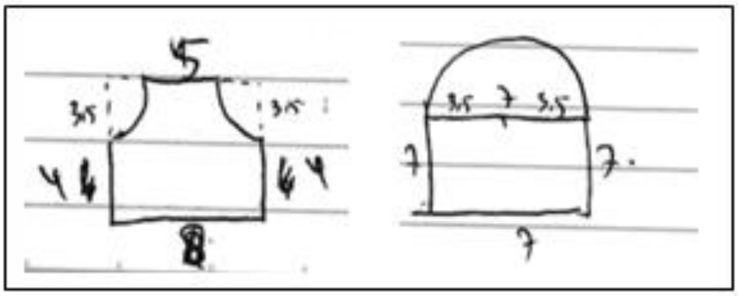


Figure 8. Examples of Alternative Answers Given by S1 Included in The Originality Category

Based on Figure 8, there are 2 answers from subjects who have high visual-spatial intelligence that belongs to the originality category. Only subjects with high spatial visual intelligence categories which extract unexpected solutions by combining two types of shapes which make designs using a combination of circles and rectangles. Other subjects (students with moderate spatial visual intelligence) do not use circles because of the difficulty in determining their size to match the provisions of the questions.

3. Discussion

The results showed that in solving problems related to transforming 3-dimensional images into 2-dimensional images and making 2-dimensional images with a predetermined circumference, subjects with high visual-spatial intelligence were able to meet all aspects of creativity, that is fluency, flexibility and originality. Each subject is able to provide more than 2 different solutions and methods or strategies correctly to solve the problem. These results are in line with the results of research conducted by Kontoyianni et al (Kontoyianni et al., 2011) which shows that gifted students, where creativity is one of the supporting aspects, are able to provide better problem-solving solutions in terms of fluency, flexibility and originality compared to non-talented students (Pitta-Pantazi, 2017). In Renzulli's model of the three rings (Piske et al., 2016; Renzulli, 1986), there are 3 aspects that are present in the gifted child, namely above average ability, task commitment and creativity. However, in this study, researchers did not explore these three things but emphasized more on student creativity with high level of visual-spatial intelligence, especially how they produce creative answers in solving problems.

The results of this study are also in line with research conducted by Suh and Cho (Suh & Cho, 2020) that spatial ability has a positive correlation with creativity. Someone with high spatial ability also has high creativity in generating ideas/strategies for solving problems. Individuals with higher intelligence scores allocate more cognitive resources at their disposal to creative tasks (Ojha et al., 2017). Visual-spatial students have better creative thinking skills in learning geometry (Aini et al., 2020). Visual-spatial intelligence serves as support of the creative process and innovative idea when solving problems (Cerrato et al., 2020; Suprapto et al., 2018). However, in several previous studies, it has not been explained how they generate these creative ideas, especially for students with high-visual spatial intelligence. From the results of this study, it is known that students with high visual spatial intelligence use creative ideas by manipulating and developing problem-solving ideas that they have previously obtained to produce new problem solutions, including by combining mental rotation and mental visualization.

Subjects with high visual-spatial intelligence in this study also involved their intelligence in generating creative ideas to solve the given problems. This can be seen from the mental visualization process carried out by the subject in understanding the problem and gathering information in the problem. The subject also performs mental rotation and modifies the visual experience they have to produce various problem-solving strategies. This is in line with the theory of multiple intelligences which states that a person uses various intelligence capabilities he has to produce relevant problem solving (Gardner & Hatch, 1989; Hatch & Gardner, 1986). Intelligence also plays a role in producing originality of problem-solving ideas (Benedek et al., 2012). Spatial-visual intelligence as one of the predictors of significant creativity (Ahvan et al., 2016; Piaw et al., 2014). Therefore, subjects with high visual spatial intelligence can provide many answers and creative ideas, especially by using more of their spatial and visualization abilities in understanding, gathering information and finding solutions to solve problems.

D. CONCLUSION AND SUGGESTIONS

The result in this research showed that subject with high visual-spatial intelligence level met all indicators of creativity, that is fluency, flexibility, and originality. In term of fluency, subject can make an average more than four correct answers. In term of flexibility, subject can make an average more than two different ideas to solved the problems. In term of originality, subject can make new ideas and ways to solved the problems. The ideas were different from the origin and have never been used before. They use creative ideas by manipulating and developing problem-solving ideas that they have obtained previously in generating new problem solutions. This is done by combining mental rotation and mental visualization and even the visual experiences they have (in everyday life).

The suggestions based on this research are lecturers can provide challenges, open-ended problems, and ask students to solve problems with various kinds of solutions, so that students will be trained to improve their creativity in solving mathematical problems, especially in geometry. Lecturers should make a lesson plan and implemented a comfortable learning where students dare to convey their mathematical ideas. The results of this research can be used as an illustration and a guideline to assess students' creativity with high visual-spatial intelligence level.

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