Combinatorial thinking and creativity skills in solving a colored-square paving decoration problem

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Abstract. Nowadays, Higher Education (HE) 4.0 demands students to have the top ten skills which are seeked by the businessmen in 2020, such as creativity. One of the fields in mathematics which has many applications for everyday life and can give a chance for students to gain their creative ideas is mathematics discrete, especially on combinatorics topic. The objective of this study was to describe the students' combinatorial thinking and creativity skills in solving a colored-square paving decoration problem. This research was conducted in University of Jember, Indonesia. The subjects of this study were 4 students of Mathematics Education Department, The Faculty of Teacher Training and Education, University of Jember. The research subjects were chosen based on their learning abilities. This study used qualitative approach. The researchers gave open-ended problem test about colored-square paving decoration problem and conducted interview to the subjects of the research on discreate mathematics issues. The test results were analyzed based on the process to find some alternative solutions that were in accordance with the creative thinking indicators. The creative thinking indicators used in this research were fluency, flexibility and originality. The results of this research showed that the creativity level achievement was classified into creative category and the combinatorial thinking achievement was on level 4 in which the students were able to change the problem into another combinatorial problem.

1. Introduction

The changing of industrial revolution 4.0. has direct impact on the process, demand, and goal of our higher educational system. One of the instructional goals of our education today is to ensure the teaching quality through learning system and to enable students to gain new knowledge through exploration activity. Higher Education (HE) 4.0 also demands the students to have the top ten skills covering problem solving, creativity, critical thinking, emotional intelligence, cognitive flexibility, people management, coordinating with others, judgement and decision making, service orientation, negotiation, which are seeked by the businessmen in [1]. However, there are still many students who come up with the rote learning system. They have a great and deep foundation on their major study, but they are lack of the real application knowledge or creative skills. They do not know how to develop the materials they have so that it will be easier to be learned. To fulfill the demands of HE 4.0, the educators, especially mathematics teachers are required to deliver the meaningful learning and to provide the situation or condition which gains the creativity for solving the complex problems. There are many mathematics teachers who find it difficult to teach the students on how to solve the complex or even the simple problem.

The difficulty faced by teachers are mostly caused by the mindset of the mathematics teachers who claim that the final answer of the problem is the main goal of learning. The process of solving the problems done by students are not really noticed by the teachers because the teachers only focus on the correctness of the final answer. Besides, it is not easy for the teachers to create the unique problem that only has one correct answer. Unfortunately, we have to realize that the development of HE 4.0 today gives more priorities on the process of solving the problems that now becomes the main objective of mathematics learning. HE 4.0 focuses more on how the students solve the open-ended problems, but not the close-ended ones.

Open-ended problems are problems that can be solved in many ways, strategies, or even has many answers. When the students are given open-ended problems, the main goal is not in the final answers, but the emphasize is on the way how the students get the final answers. By the time the students are investigating or analyzing some strategies or ways that they believe will fit to be elaborated with the problems, the mental activity, especially on creative thinking will arise and develop at the maximum level. Foong states that through open-ended problems, students will have opportunities to demonstrate knowledge, skills, and their math understandings; gives challenge to the students to think and to do what they are expecting to do by applying some approaches and solutions, so that it encourages the students to think creatively [2] . Creativity is the key part in advanced education [3]. The previous study conducted by Walia showed that there was an effect of creativity on the students' mathematics achievement, which means the students who had high creativity level got better mathematics achievement than those who had low creativity level [4]. Creativity can be interpreted as the ability to bring something new, whether a new solution, method or strategy, device, art or object [5]. The components of creativity consist of fluency, flexibility, originality, and the ability to make, develop, or improve certain idea [6]. In this research, the creativity components measured were fluency, flexibility and originality.

It will be better if problems that provide opportunities for the students to gain their creative ideas are realistic problems. There are some benefits the students can get from realistic problems. Students will learn mathematical concepts based on reality or the environment around them [7]. They will draw on the same content, situations, or information but there will be a possibility where the students can investigate themselves that will bring them into the better understanding of the concept as the results of their own thinking. They will also produce class interactions in the form of various ideas because every student has their own result or solution that they already found by themselves [8].

One of the fields in mathematics which has many applications in daily life and gives a chance for the students to gain their creative ideas is mathematics discrete, especially on combinatorics topic. Combinatorics provides connections between people's experiences in their daily life with their professional expertise that linked to various fields of mathematics subject and other subjects like computer, communication, genetic, and statistic [9] .

Combinatorics is an essential component of discrete mathematics that has an important role in mathematics subject [10], [11]. Combinatorial has a role to provide the students with the opportunity to think deeply about mathematics idea that are complex but accessible [12]. Besides, Jones says that combinatorial problem also facilitates the development of enumeration process, as well as conjecture, generalizations, and systematic thinking [13]. Combinatorics problems that are related to the realistic problems will be meaningful to be solved by some solutions. The students will have a good chance to calculate by using certain formula (the calculation is correct) and the formula will be meaningful for them [14]. Today, the higher education development requires us to develop our thinking ability, especially on mathematics thinking ability to face the challenge in daily life. Thus, this research was conducted to know and describe about combinatorial thinking and creativity skills in solving a colored-square paving decoration problem for the students to face Higher Education (HE) 4.0.

Based on the explanation above, the researcher wants to bring up some formulation of the problem including 1) What is the description of students' combinatorial thinking in solving the problem of colored paving decorations and 2) What are the creativity skills in solving the problem of colored paving decorations.

2. Research Methods

This research uses a mix method research approach (quantitative and qualitative). For quantitative data, the researcher will look for the correlation beetwen creativity level and combinatorics thinking level. In addition, this research was descriptive research which means it described the the students' combinatorial thinking based on their creativity in solving open-ended problems that consisted of combinatorial operations and procedures. Combinatorial operations in this research was by making the formula or pattern while combinatorial procedures in this research means algebraic and numerical procedures which included the generation of functions [13] . The participants of this research were 110 students of Mathematic Education Department batch 2016 who had already taken Discrete Mathematics course. The researcher gave one open-ended problem to the participants individually to be done in 120 minutes. After that, the researcher collected the results based on the indicators of creativity. The indicators were based on its fluency, flexibility, and originality. The participants fulfilled the criteria of fluency if their answers contained minimally 3 color square paving decorations. The participants whose answers formed arithmetic rows for each square size with the arrangement of different colored-square paving that needed were categorized into flexibility. The participants were into originality category if their answers were different from others and were able to determine the pattern to decide the numbers of colored paving that were needed for all square size n x n for any n. Then, the data were categorized based on the creativity category adapted from Khutobah [15] as shown in the Table 1.

Table 1. The Classification of Students' Creativity Level

Level	Characteristics of the creativity level
Level 4 (Very creative)	The students' answers fulfill the aspects of fluency, flexibility and originality
Level 3 (Creative)	The students' answers fulfill the aspects of fluency and originality or flexibility and originality
Level 2 (Fairly creative)	The students' answers fulfill the aspects of fluency and flexibility
Level 1 (Less Creative)	The students' answers fulfill the aspects of fluency or flexibility

Based on the Table 1, the researchers chose one participant from every category to conduct the in-depth interview. The selection was based on the unique answers which were different from others but still at the same creativity level and were able to communicate well. The results of the interview were used to describe the students' combinatorial thinking based on the 4 levels of combinatorial thinking in solving combinatorics problems.

3. Result and Discussion

Mathematics activity refers to concrete objects (something that is interesting to oneself) [16]. Discrete Mathematics problems allow the students to solve the problems by using many ways or perhaps many answers (correct answers). The existence of these possibilities guide the intellectual potential of the students and the students' experiences in finding the new ideas, so that the meaningful learning happens. Finally, the instructional goal is to develop the students' mathematics thinking maximally and at the same time, the creative activities of the students delivered through the teaching and learning process.

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The problems used in this study were open-ended combinatorics problems by determining the colored paving decorations that consisted of combinatorial operations and procedures. The problems in this study were formulated as follows:
"The backyard of the house has a square land with n x n size. The land is planned to be paved with 2 colors of paving that have the same size. Make various decorations of the paving in such a way that the numbers of colored paving meets the size n x n of the square land under the condition that the arrangements of the colored-square paving form an arithmetic sequence and make the formula or pattern to determine the numbers of colored paving that are needed."
In this study, the researcher used the correlation Test with SPSS for quantitative data, to determine whether there is a correlation beetwen creativity level and combinatorial thinking level and the level of closeness of the relationship. The concept of decision making is as follows:

Basis for a decision:
1) If the value of significance (2-tailed) $< 0{,}05$ then correlates
2) If the value of significance (2-tailed) $> 0{,}05$ then do not correlate

Guideline for relationship degrees
- Pearson Correlation Value $0{,}00 - 0{,}20$, it means there is no correlation
- Pearson Correlation Value $0{,}21 - 0{,}40$, it means the correlation is weak
- Pearson Correlation Value $0{,}41 - 0{,}60$, it means moderate correlation
- Pearson Correlation Value $0{,}61 - 0{,}80$, it means strong correlation
- Pearson Correlation Value $0{,}81 - 1{,}00$, it means perfect correlation

The researcher categorizes the values for creativity levels, as follows:
- Students in the first of creativity level are categorized by S1 with the value of 1
- Students in the second of creativity level are categorized by S2 with the value of 2
- Students in the third of creativity level are categorized by S3 with the value of 3
- Students in the forth of creativity level are categorized by S4 with the value of 4

The researcher also categorizes the values for combinatorial thinking levels, as follows:
- Students with 1 level of combinatorial thinking namely level 1 are categorized by the value of 1
- Student with 2 levels of combinatorial thinking, level 1 and level 2 are categorized with a value of 2
- Students with 3 levels of combinatorial thinking namely level 1, 2, and 3 are categorized by the value of 3
- Students with 4 levels of combinatorial thinking, namely levels 1,2,3, and 4 are categorized by the value of 4

[DataSet0]

One-Sample Kolmogorov-Smirnov Test

		Creativity Level	Combinatoric Thinking Level
N		110	110
Normal Parameters[a,,b]	Mean	3.2091	3.1727
	Std. Deviation	.88924	1.21050
Most Extreme Differences	Absolute	.286	.362
	Positive	.187	.247
	Negative	-.286	-.362
Kolmogorov-Smirnov Z		2.998	3.796
Asymp. Sig. (2-tailed)		.000	.000

a. Test distribution is Normal.

b. Calculated from data.

Figure 1. The results of Normality Test

Correlations

[DataSet0]

Correlations

		Creativity Level	Combinatoric Thinking Level
Creativity Level	Pearson Correlation	1	.878**
	Sig. (2-tailed)		.000
	N	110	110
Combinatoric Thinking Level	Pearson Correlation	.878**	1
	Sig. (2-tailed)	.000	
	N	110	110

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 2. The results of Correlation Test

Based on the results of correlation, it can be seen that the value sigifikansi $0{,}000$ (2-tailed). Because the value is smaller than $0{,}05$, it can be said that there is a relationship between students' Creativity Level and Combinatoric Thinking Level students. Then, for the Pearson Correlation value, the value is equal to $0{,}878$ (positive) which means that the level of relationship between Creativity Level of students with Combinatoric Thinking Level of students is included in the perfect category with positive direction.

Based on the creativity level category of 110 the students' answers of Mathematics Education Department batch 2016, the results obtained as in Figure 1 below.

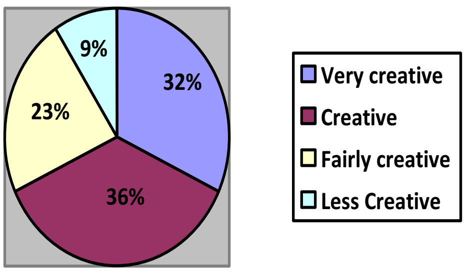
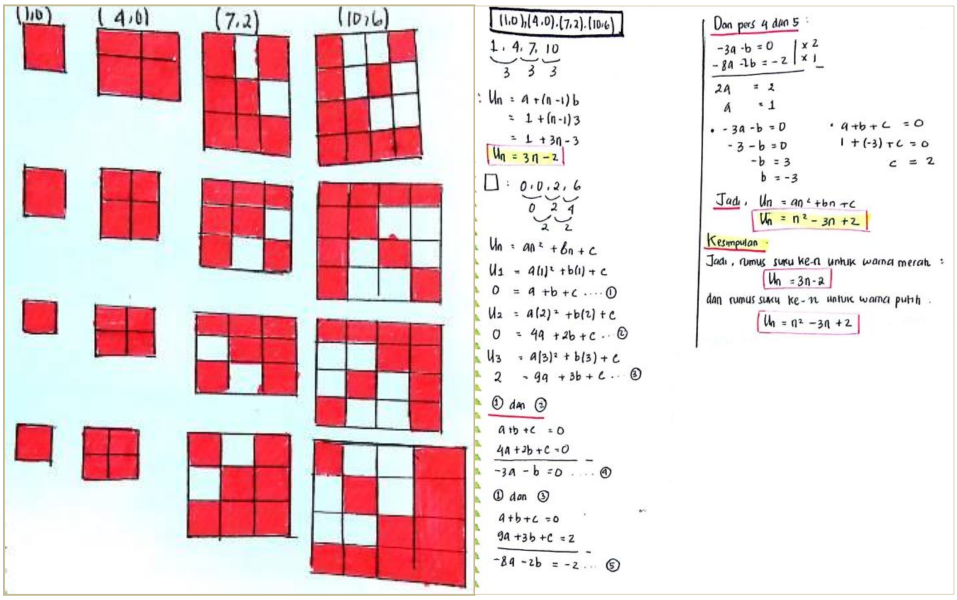


Figure 3. The results of the students' categorization on the level of creativity

As shown in Figure 1, it could be seen that most of the students were at the creative level. 40 students were at the 36% creative level. 32% of very creative level consisted of 35 students. 23% of fairly creative consisted of 25 students and 9% of less creative consisted for 10 students. The result of each subject selected from each creativity level would be described. The selection was based on the unique and different answers from each subject who was at the same level of creativity and able to communicate well. Each subject representative at the less-creative level was named as S1, fairly creative category was coded as S2, creative level category was called as S3 and S4 was for a subject at very-creative level category. The output from each subject at creativity levels was described as follows:

3.1. The process of combinatorial thinking of the less-creative students

As described above, S1 fulfilled the fluency aspect at the level of creativity. S1 was able to compose as many as 4 different colored-square paving with the same pattern. According to the interview done by the researcher, S1 realized that the decoration he made was actually the same, but he was not brave enough to arrange the different decoration of coloured-square paving between one to another. Hence, S1 felt that he already put the maximum efforts on the decoration so that the aspect of flexibility was not fulfilled. Moreover, S1 also did not meet the originality aspect as S1 created the pattern of colored-square paving arrangement as same as what others research subject made. Those statements were in line with Lee and Olatoye who cites that taking a risk is one of the factors who affects a person's level of creativity [5], [17].



There is one coloring pattern

- Red : $u_n = 3n - 2$ (using the formula of the first degree arithmetic sequence)
- White : $u_n = n^2 - 3n + 2$ (using the formula of the second degree arithmetic sequence)

So the coloring pattern formula that formed is :

$(red, white) = (3n - 2, n^2 - 3n + 2)$

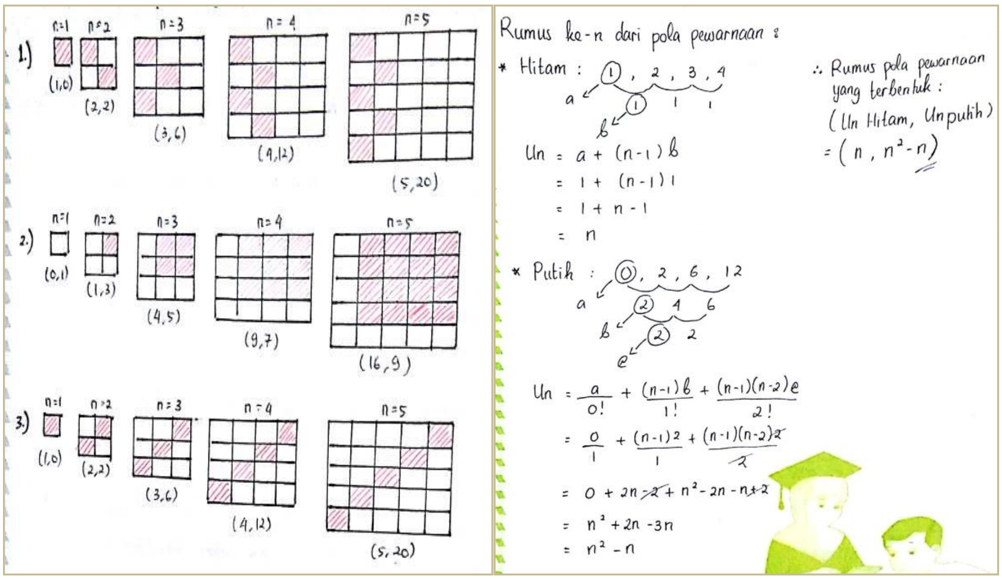
Figure 4. One of the answers of the less-creative students (S1)

Based on the combinatorial thinking process, S1 only did the permutation based on the combinatorial thinking process. It was shown on Figure 2 in which S1 only arranged 4 different coloured square paving but the patterns was the same for 1x1, 2x2, 3x3, 4x,4 land sizes, however they had pattern color arrangement that referred to (1,0), (4,0), (7,2), (10,6) with 1 for red coloured square paving and 0 for white coloured square paving for 1x1 land size and so forth. As gathered from Figure 2 and in-depth interview, s1 arranged the coloured square paving with 4 same color arrangements without even realizing that he did the permutation concept in which several coloured-square paving needed were the same. In determining the number of coloured-square paving, the first thing to do was registering the coloured square paving arrangement starting from the 1x1 land size to the expansion ones which was 4x4 land size.

3.2. Combinatorial thinking process on the fairly-creative students

Figure 3 showed that S2 were capable in arranging as many as 3 different coloured square paving although there was a similar decoration in which it referred to the first and third ones. Besides, S2 brought up the differences in the number of coloured square paving needed. Therefore, the fluency and flexibility indicators were successfully achieved on the level of creativity. There was no renewal on the arrangement of coloured square paving made by S2 compared to other subjects' answers, hence, they missed the originality indicator. S2 felt challenged to finish the problem he faced by arranging different coloured-square paving according to the interview carried out by the researchers. Thus, S2 was able to arrange 2 different coloured-square paving or more.

Based on combinatorial thinking process, S2 was capable to arrange three coloured-square paving decorations in which two of them were similar. Both patterns created by S2 were for the 1x1, 2x2, 3x3, 4x4, 5x5 land sizes. If they were put systematically, they had pattern (1,0), (2,2), (3,6), (4,12), (5,20). Other patterns in which S2 created were (0,1), (1,3), (4,5), (9,7), (16,9). The data shown on Figure 2 and obtained from the in-depth interview revealed that S2 made three different coloured-square paving decorations although the first and third decorations were similar to each other. To determine the number of needed coloured -square paving, S2 had to register the coloured paving arrangement starting from 1x1 to 5 x 5 land sizes.



The n term formula of the coloring pattern :

- Black : $u_n = n$ (using the formula of the second degree arithmetic sequence)
- White : $u_n = n^2 - n$ (using the formula of the third degree arithmetic sequence)

So the coloring pattern formula that formed is :

$(black, white) = (n, n^2 - n)$

Figure 5. One of the Answers of the fairly-creative students (S2)

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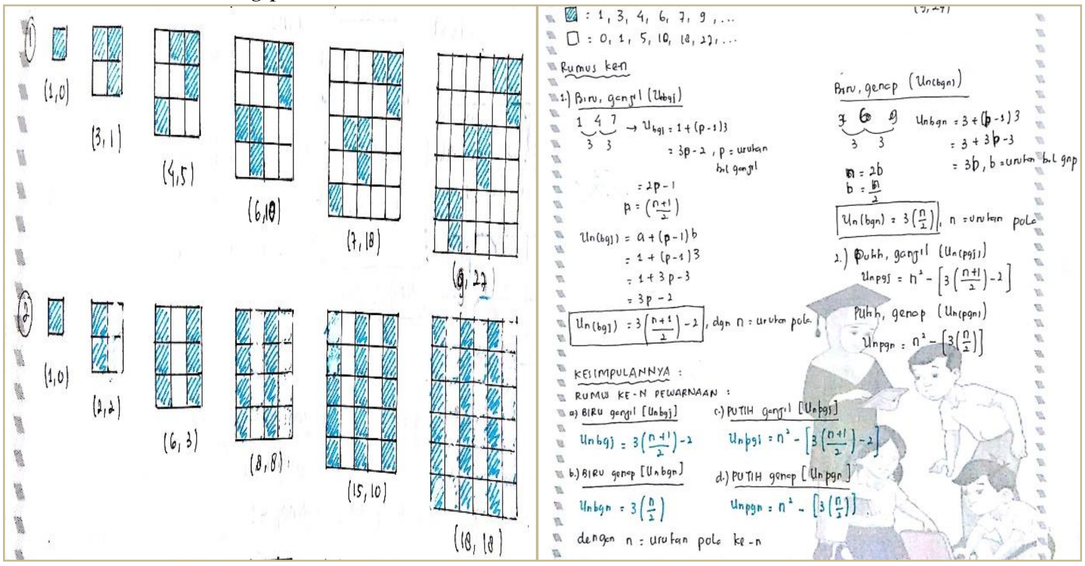
3.3. The combinatorial thinking process on creative students



$$u_{nbgj} = 3\left(\frac{n+1}{2}\right) - 2$$ (The n term of the odd blue paving)

$$u_{nbgn} = 3\left(\frac{n}{2}\right)$$ (The n term of the even blue paving)

$$u_{npgj} = n^2 - \left[3\left(\frac{n+1}{2}\right) - 2\right]$$ (The n term of the odd white paving)

$$u_{npgn} = n^2 - \left[3\left(\frac{n}{2}\right)\right]$$ (The n term of the even white paving)

So the coloring pattern formula that formed are :

For odd pattern : $$(blue, white) = \left(3\left(\frac{n+1}{2}\right) - 2,\ n^2 - \left[3\left(\frac{n+1}{2}\right) - 2\right]\right)$$

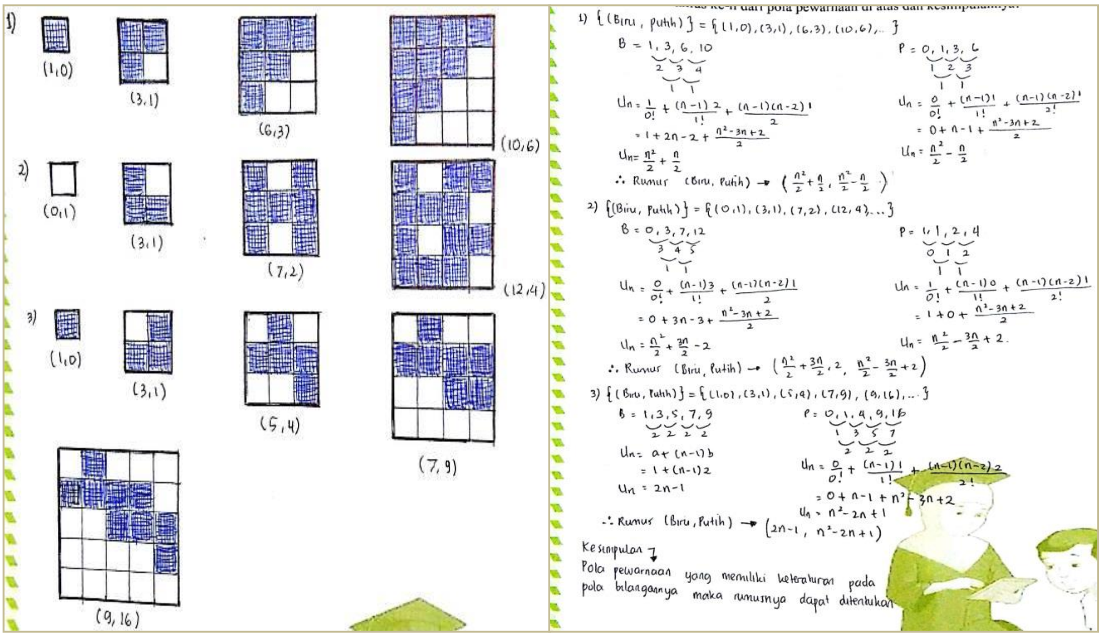
For even pattern : $$(blue, white) = \left(3\left(\frac{n}{2}\right),\ n^2 - \left[3\left(\frac{n}{2}\right)\right]\right)$$

Figure 6. One of the answers from creative student (S3)

S3 did not meet the fluency indicator as he only arrange as many as 2 different coloured-square paving. In contrast, the number of needed coloured-square paving between the first and third pattern were different. so that he reached the flexibility indicator. The originality indicator was also reached since there was no students could make the decorations which S3 made. S3 said that the problem given was challenging in which he was required to make the different coloured-square paving decorations. It can be said that S2 was adequate in constructing more then 2 different coloured-square paving. On the other hand, S3 also stated that the time required to arrange the decorations was not enough, it resulted the less efforts they put in making coloured-square paving decorations from the problem given. This was parallel with what Bruce states that a student who is not given enough time is not capable in asking or answering the question correctly and effectively [18].

Based on combinatorial thinking process, S3 was capable in arranging two coloured-square paving in which it had different patterns. Registering coloured-square paving arrangement on 1x1 to 6x6 land sizes was needed in determining the number of coloured-square paving pattern needed. The first decoration created by S3 had (1,0), (3,1), (4,5), (6,10), (7,18), (9,27) coloured patterns. Meanwhile, in the second decoration, the color patterns were (1,0), (2,2), (6,3), (8,8), (15,10), (18,18).

3.4. Combinatorial thinking skill on a very-creative student



1) {(blue,white)}={(1,0),(3,1),(6,3),(10,6), ...} » formula : $\left\{\left(\frac{n^2}{2}+\frac{n}{2}\right),\left(\frac{n^2}{2}-\frac{n}{2}\right)\right\}$

2) {(blue,white)}={(0,1),(3,1),(7,2),(12,4), ...} » formula : $\left\{\left(\frac{n^2}{2}+\frac{3n}{2}-2\right),\left(\frac{n^2}{2}-\frac{3n}{2}+2\right)\right\}$

3) {(blue,white)}={(1,0),(3,1),(5,4),(7,9), ...} » formula : $\{2n-1, n^2-2n+1\}$

The conclusion : we can find the formula for the coloring pattern, if the numbers pattern has regularity

Figure 7. One of the answers from very-creative student (S4)

S4 was adequate to make three different compositions of coloured-square paving decorations. Based on his composition, S4 met the indicators of fluency dan flexibility. Since his decoration was different compared to others subjects, the originality indicator was reached. During the interview, S4 did not only feel challenged in arranging different coloured-square paving, but also felt eager to be able to make the coloured-square different from one to another. He was dared to take a risk without paying attention to whether or not his decoration was considered correct. It corresponded to Khutobah who mentions that a student who is brave in taking a risk will arise his creative ideas better whether or not his idea was acceptable [15].

Based on combinatorial thinking process, the different patterns of coloured-square paving decorations were successfully arranged by S4. In deciding the number of needed patterns of coloured-square paving on the first and second decorations, S4 should register the coloured-square paving arrangement starting from 1x1 to 4x4 land sizes sequentially. The pattern of the first decorations were (1,0), (3,1), (6,3), (10,6). On the other hand, the second decorations had (0,1), (3,1), (7,2), (12,4) coloured pattern arrangements. In determining the number of pattern needed on the third decoration, S4 registered his decoration starting from 1x1 land size, then it was expanded to 5x5 (1,0), (3,1), (5,4), (7,9), (9,16) arrangements. After the interview section was carried out, it was revealed that S4 wanted to make sure to expand the decoration he made, S4 was not really sure as he had no idea how coloured-square paving would be if it only reached 4x4 land size. Therefore, S4 needed to clarify that any coloured-square paving should have pattern, not only the needed coloured-pattern. According to Rezaie M. & Gooya Z. there are 4 levels on combinatorial thinking comprehension [19].

Level 1: Investigating "Some cases".
The first student's effort in resolving this problem was to find "Some colored-square paving decoration arrangement they had thought" by using "Permutation or combination principle". The student that used permutation concept acknowledged their solution by arranging the colored-square paving with different position although it had the same amount of paving patterns needed. However, this decoration arrangement was not satisfying for those who used combination concept. They assumed that different paving arrangement locating as the same decoration form as long as the amount paving patterns needed used was the same. Therefore, they started to arrange flexible thought by creating an actual different decoration, which was different in the arrangement of colored-squared paving and the number of the paving needed.
Level 2: "How am I sure that I have counted all the cases?".
In this level, the students arranged paving decoration one by one starting from n=1 up to n=3/4 by believing that the decoration they made had an orderliness and aesthetic so that it can be expanded up to n x n square size. They summarized the problem and thought it in a systematical way. All students tried to show some various colored-square paving arrangement decorations as the result form their systematical approach. They believed that when the decoration had a pattern, they just need to make the formula for that pattern without arranging more decoration.
Level 3: Generating All Cases Systematically.
Some students felt satisfied on the decorations they had made and believed that the decorations had certain patterns so that it can be expanded. However, all the students felt that this guarantee was just the first step into the real complex and abstract situation. The students did not estimate the calculation for the whole n because it was really difficult to do. This is in line with the research result done by Eizenberg M., & Zaslavsky O. who stated that the verification activity by evaluating the reasonability of the answer was not frequently used [9]. In this case, they used some strategies as follows:

- How to make myself find the pattern from the colored-square paving I have made for all n in which n>1.
- Is that the decoration I have made has the same or similarly same between each other.

Level 4: Changing the problem into another combinatorial problem.
In this level, students solved the problem by finding the relationship between each decoration size starting from n=1 up to n=3 or certain n. They had to find the relationship from their own decorations. The results of the research showed that generally, the relationship found by the students related to arithmetic, odd-even function or modulo concept. The research results also showed that all the subject of the research passed the fourth levels.

The data analysis showed that the students could emerge their creative ideas in arranging colored-square paving decoration by using some various concepts and combinatorial technique. The interview result showed that many students faced no difficulty in solving the problem. However, by looking at their creativity, some students were not aware that each other decoration has similarity in terms of pattern although it almost looked different. In the final level, the students re-checked or tried to add number for the n which was relatively small to prove that the formula they had made was correct, and then they matched it with listing activity into their determined n. The formula checking was a strategy and an essential activity in solving the problem. By looking back into a certain solution, there was an opportunity to identify the connection within and between the problems [9]. Therefore, the students became surer about the answers and reduce mistakes when doing this. In addition, re-checking was also gave opportunity to find solution, strategy, or development of a new method from the given problem.

Based on the research results, when the subject showed their creativity, they also showed their combinatorial thinking process. The combinatorial thinking process could not be separated from students' creativities in solving combinatorial problem given. The combinatorial thinking process in solving colored-square paving decorations problem can be explained in a schema which can be seen in the following Figure 6.

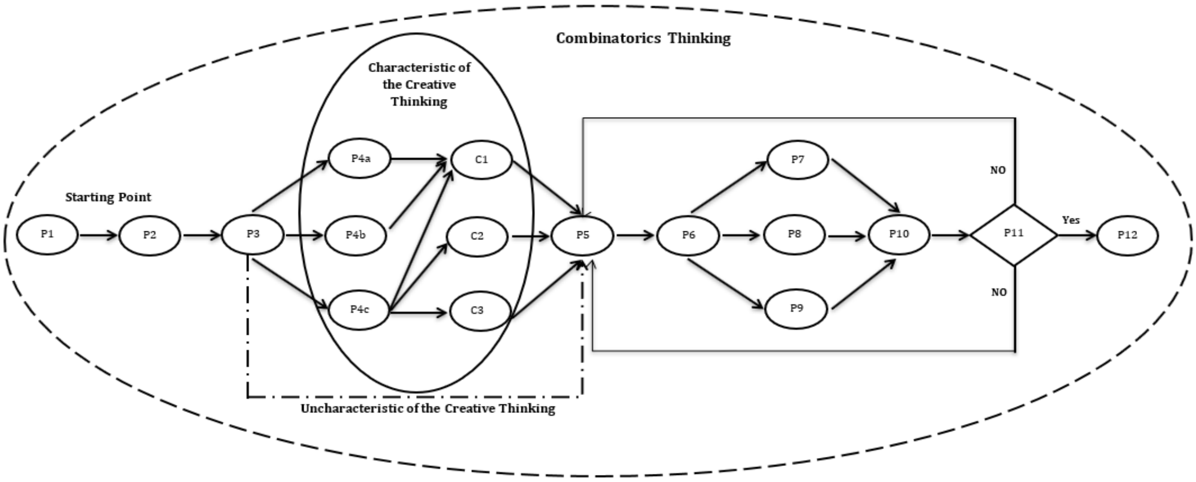


Figure 8. Schema of combinatorial thinking process in solving colored-square paving decorations problem.

Notes:

P1	Determining paving's color
P2	Arranging square size paving in 1x1 up to nxn
P3	Determining paving decoration under consideration that it has orderliness and the number of colored-square paving create an arithmetic pattern
P4a	Developing colored-square paving arrangement from the former paving arrangement by using permutation concept so that the number of the needed paving is same.
P4b	Developing colored-square paving arrangement which is different from the former paving arrangement by considering the number of the needed paving still same.
P4c	Developing colored-square paving arrangement which is different from the former paving arrangement so that the number of the needed paving become different
C1	Indicator category of fluent creative thinking
C2	Indicator category of flexible creative thinking
C3	Indicator category of original creative thinking
P5	Deciding the relationship between each colored-square paving pattern to form a certain arithmetic pattern
P6	Determining the formula of nth term from the arithmetic pattern by using deviation concept from each term
P7	Identifying formed arithmetic pattern according to arithmetic concept of degree of one, two, and so on.
P8	Identifying formed arithmetic pattern according to odd and even term concept
P9	Identifying formed arithmetic pattern according to modulo concept
P10	Determining function according to the relationship between each formed arithmetic pattern
P11	Rechecking the function or the formula that has been determined.
P12	The result of the answered problem

4. Conclusion

Based on the research result and discussion, the students, generally, had been in the creative stage. Flexibility indicator has an essential role in the creativity component because it is an aspect of divergent thinking. Moreover, some factors that affect students' creativity are the sense of challenge, the time given and the decision to take risk to solve problem. Students' combinatoric thinking had reached the fourth level that was changing problem into another combinatorial problem. Reviewed from the creativity and combinatory thinking and seen from the made schemata, in solving combinatoric problem, the students also need their creative ideas. This revealed that students' creative ideas are essential in solving combinatoric problem.

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