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Analyzing Mathematical Creative Thinking Processes in Higher Education: A Learning Style Perspective in Graph Problem Solving

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Abstract

This study aims to determine the process of mathematical creative thinking in solving graph problems based on students' learning styles. This research method uses descriptive qualitative. This study was conducted on 5th semester students of the Mathematics Education Study Program, Universitas PGRI Semarang in the 2024/2025 Academic Year. Subjects were taken by purposive sampling. The research instruments were in the form of mathematical creative thinking tests, learning style questionnaires and interview guidelines. Data analysis techniques included validity, reliability, discriminatory power and difficulty level tests. Furthermore, data validity tests were carried out using the technical triangulation method and qualitative data analysis using an interactive analysis model. The results of the study showed that the mathematical creative thinking process of the average of the four students' learning styles at the preparation stage did not meet the indicators of flexibility and originality. The incubation and illumination stages still need assistance to bring up the originality indicators. While the verification stage has met the four indicators of mathematical creative thinking ability completely. Thus, the findings of this study can be used as a consideration for lecturers in understanding the differences in students' learning styles. Lecturers can provide appropriate scaffolding to make it easier for students to solve graph problems.

Keywords: mathematical creative thinking process, learning styles, graph

INTRODUCTION

One of the goals of 21st century education is to foster creative thinking skills in solving problems, so it is important for teachers to know how someone applies the creative thinking process (Paz-Baruch et al., 2025). The rapid development of the digital world has given birth to new professions that require creative skills so that each individual is required to develop creative thinking skills (Liljedahl et al., 2016). Creative thinking skills are seen at the stage when someone seeks information to generate new ideas and solutions in the context of everyday problems (Chavula et al., 2022). The existence of

different mathematical creative thinking processes when students solve problems, so a lecturer must pay attention to the character of each stage of thinking in order to produce creativity in compiling assignments (Zamzam et al., 2023).

The difference in creative thinking process is influenced by the character of students with theoretical learning styles and pragmatic learning styles in building ideas to implement ideas (Ferdiani & Harianto, 2024). Students with active learning styles tend to rush through problems and get ideas based on everyday experiences (Dwi Ferdiani et al., 2022).One of the causes of difficulties in developing creative thinking processes is different learning styles (Hadi et al., 2023; Jagom et al., 2021). Differences in learning styles have a significant influence on students' creative thinking abilities. Subjects with Visual, Aural and Reading-Writing learning styles are classified as very creative while subjects with Kinesthetic learning styles are classified as less creative (Restanto & Mampouw, 2018). Students with a dominant learning style of one type do not show a very creative level category, students with a dominant learning style of two types of learning styles are also unable to show a very creative level category, and students with a combined learning style of 3 or 4 types of learning styles have reached a very creative level category. The mathematical creative thinking ability of students with a combined learning style shows a better average value than students who are only dominant in one type of learning style (Restanto et al., 2023).

Student learning style is one of the factors that need to be considered in preparing teaching materials. Learning that is adjusted to learning styles will help students understand concepts and solve problems (El-Sabagh, 2021; Shamsuddin & Kaur, 2020). Learning styles are important in a college environment because they can prepare students to face the world of work (Amir & Jelas, 2010). A popular learning style model is Visual, Auditory, Reading-writing and Kinesthetic (VARK). The VARK model was created by an educator named Dr. Neil Fleming providing more dynamic functionality and more profitable results (Hawk & Shah, 2007). The learning style in this study uses Neil Fleming's Theory, namely the VARK Model (Visual, Auditory, Reading-writing and Kinesthetic). The characteristics of the learning styles possessed by students can be seen in table 1.

Table 1. Characteristics of Learning Styles

Types of Learning Styles	Characteristics
Visual (V)	Visual preferences include depicting information in maps, diagrams, charts, graphs, flow charts, and all symbolic arrows.
Auditory (A)	Preference for information that is heard or spoken. They learn best from lectures, group discussions, and talking things through.
Read/Write (R)	Read/Write preference is information presented in the form of words. This preference emphasizes text-based input and output reading and writing in all its forms, especially manuals, reports, essays, and assignments.
Kinesthetic (K)	Kinesthetic preference is information that is presented based on experience and practice (simulated or real). This includes demonstrations, simulations, and videos of “real” things, as well as case studies, practices, and applications.

(Amaniyan et al., 2020; Fleming, 2020)

The characteristics of different student learning styles cause different ways of thinking in processing information. This causes students to lack understanding of graph problems. They still make mistakes when modeling mathematics and do not generate enough ideas to solve problems. Thinking skills can be developed through a learning process that involves students in solving open-ended problems to stimulate problem-solving ideas. Students will be able to analyze and reason information, express mathematical ideas, and have flexibility in solving problems (Prayitno et al., 2022).

The stages of the creative thinking process include the following: (1) problem discovery; (2) information search, absorption, assessment; (3) concept combination; (4) idea generation; (5) development of solution approaches; (6) idea evaluation; (7) adaptation and realization; (8) communication and implementation (Görlich, 2023). The creative thinking process reflects a mental model that guides a person's behavior in showing their performance through the stages of information search, incubation, idea generation and idea validation (Lucas & Mai, 2022). According to Wallas' theory, there are four stages of the creative process, namely preparation, incubation, illumination, and verification. Based on several opinions related to the stages of the mathematical creative thinking process, this study uses Wallas' theory because it is more appropriate to the stages of thinking of students in higher education. The description of the stages of the creative thinking process according to Wallas' theory can be seen in table 2.

Table 2. Stages of the Creative Thinking Process According to Wallas' Theory

No	Stages	Description
1	Preparation	How students collect information related to the given problem.
2	Incubation	How students connect ideas that emerge and are organized in their minds.
3	Illumination	The stage of the emergence of ideas from students on the problems received. Students begin to understand and find solutions to the problems.
4	Verification	The solution obtained at the illumination stage will be re-identified, checked and developed if the solution found is not appropriate, then the student must repeat the initial stage. Re-checking process.

(Gunawan et al., 2023; Pitta-Pantazi et al., 2018)

With these stages, students can understand the problem by collecting information, connecting ideas that arise in their minds, finding solutions and re-examining the solutions. Thus, it is expected that through the stages of the creative thinking process according to Wallas' theory, students can improve their mathematical creative thinking skills in solving graph problems.

METHODS

This study uses a qualitative approach. This approach is carried out to collect in-depth data on the characteristics of the mathematical creative thinking process in solving graph problems. This study was conducted on 5th semester students of the Mathematics Education Study Program, Universitas PGRI Semarang. The study was conducted in the

odd semester of the 2024/2025 Academic Year for the Discrete Mathematics course. The research subjects were selected by purposive sampling. The instruments used were mathematical creative thinking tests, learning style questionnaires and interview guidelines. Data analysis techniques consisted of validity, reliability, discriminatory power, difficulty level, data validity and interactive analysis. Determination of subjects was based on the results of filling out the learning style questionnaire with visual, auditory, read/write or kinesthetic categories. Each learning style category was taken by one student each. The selected research subjects were asked to work on mathematical creative thinking ability test questions on graph material. Furthermore, the researcher conducted in-depth interviews to determine the obstacles to students' mathematical creative thinking processes.

RESULTS AND DISCUSSION

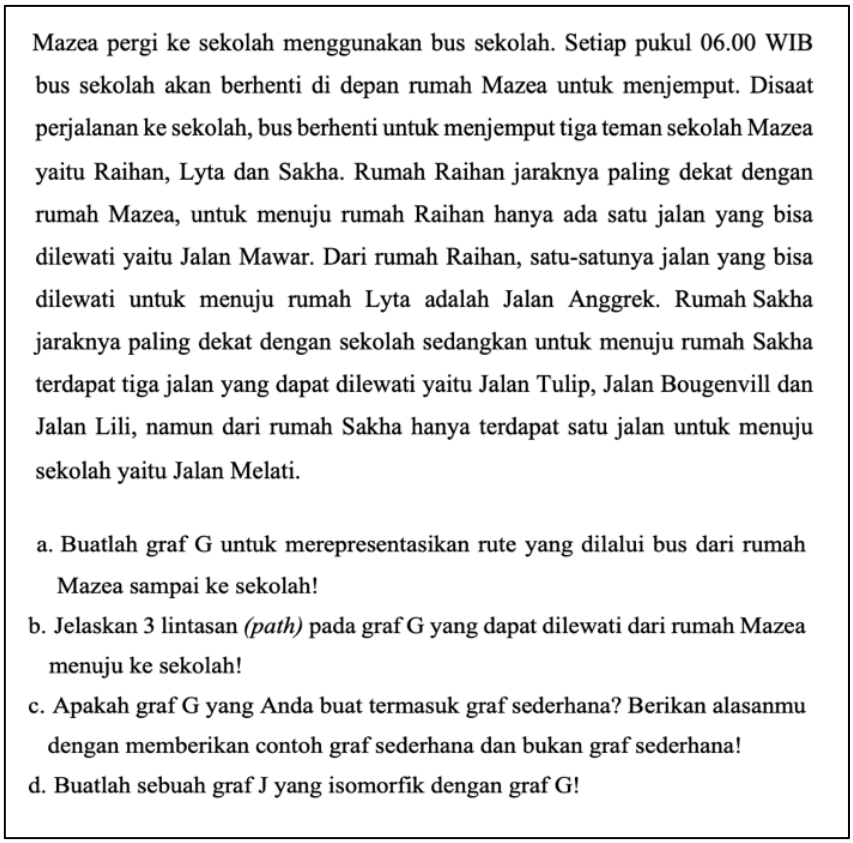
Analysis Results of Mathematical Creative Thinking Process Characteristics

The analysis of the characteristics of the mathematical creative thinking process in this study began with filling out a learning style questionnaire based on Neil Fleming's Theory, namely the VARK Model (Visual, Auditory, Reading-writing and Kinesthetic). The questions consisted of 16 questions that had met the content validity based on expert assessment. Based on the results of the questionnaire analysis, 4 research subjects were obtained who had different learning styles, namely students with a visual learning style (M18), students with a learning style (M23), students with a Read/write learning style (M6), students with a Kinesthetic learning style (M36).

The four research subjects were given mathematical creative thinking ability test questions. The questions were arranged by considering the indicators of creative thinking ability according to Munandar's theory, namely fluency, flexibility, originality and elaboration (Lince, 2016). From one question that was arranged, it had met the validity, reliability, discriminatory power and level of difficulty tests so that the question could be used to measure mathematical creative thinking ability. The mathematical creative thinking ability questions are shown in Figure 1.

Question number 1a meets the fluency indicator because it asks students to be able to present a graph correctly based on what is known in the question. Question number 1b meets the flexibility indicator because students are asked to be able to mention several alternative answers about the path. While question number 1c meets the elaboration indicator because students associate a new concept in detail and question number 1d meets the originality indicator because students are asked to create a new graph based on their own thinking.

The test results from the four research subjects were then analyzed based on the characteristics of each stage of the mathematical creative thinking process. In the next stage, the researcher conducted interviews with the research subjects to obtain in-depth information related to indicators of mathematical creative thinking skills for each stage of the process. Thus, data triangulation can be carried out on test and interview data.



Mazea pergi ke sekolah menggunakan bus sekolah. Setiap pukul 06.00 WIB bus sekolah akan berhenti di depan rumah Mazea untuk menjemput. Disaat perjalanan ke sekolah, bus berhenti untuk menjemput tiga teman sekolah Mazea yaitu Raihan, Lyta dan Sakha. Rumah Raihan jaraknya paling dekat dengan rumah Mazea, untuk menuju rumah Raihan hanya ada satu jalan yang bisa dilewati yaitu Jalan Mawar. Dari rumah Raihan, satu-satunya jalan yang bisa dilewati untuk menuju rumah Lyta adalah Jalan Anggrek. Rumah Sakha jaraknya paling dekat dengan sekolah sedangkan untuk menuju rumah Sakha terdapat tiga jalan yang dapat dilewati yaitu Jalan Tulip, Jalan Bougenvill dan Jalan Lili, namun dari rumah Sakha hanya terdapat satu jalan untuk menuju sekolah yaitu Jalan Melati.

a. Buatlah graf G untuk merepresentasikan rute yang dilalui bus dari rumah Mazea sampai ke sekolah!
b. Jelaskan 3 lintasan *(path)* pada graf G yang dapat dilewati dari rumah Mazea menuju ke sekolah!
c. Apakah graf G yang Anda buat termasuk graf sederhana? Berikan alasanmu dengan memberikan contoh graf sederhana dan bukan graf sederhana!
d. Buatlah sebuah graf J yang isomorfik dengan graf G!

Figure 1. Mathematical Creative Thinking Ability Questions

Description of Mathematical Creative Thinking Process Characteristics of Students with Visual Learning Style (Subject M18)

In the preparation stage, subject M18 was able to understand the information in the problem by describing the graph according to what was known and what was asked. The writing of the symbols for sides and points and the shape of the graph were different from those exemplified in class so that they met the indicators of mathematical creative thinking, fluency and originality. The next stage of the creative thinking process is the incubation stage.

In the incubation stage, subject M18 was able to think of strategies to solve the problem. The strategy used was to prepare paper to express thoughts related to the existing information, so that it met the fluency indicator. The subject was able to think of new concepts related to simple graphs and provide examples so that it met the elaboration indicator. This is supported by the results of the interview between the researcher (P) and the student (M18) below.

P : Before working on question 1a, what do you think about in making a route?

M18 : For me, it's just an idea, so later the bus will pass approximately where, then after that I first determine if it can pass 2 routes, meaning the estimate from the second route can be connected to which other route, then I using another paper and then move it to the answer sheet.

At the illumination stage, Subject M18 was able to create a graph depicting the route taken by the bus from Mazea's house to school so that it met the fluency indicator. Subject M18 was able to write three alternative answers so that it met the flexibility indicator. Subject M18 was able to identify simple graphs and provide examples so that it met the elaboration indicator. Subject M18 was able to create an isomorphic graph with a different graph shape from graph G so that it met the originality indicator. The next stage of the creative thinking process is the verification stage.

At the verification stage, Subject M18 has rechecked the results of his answers so that at the verification stage it has met the indicators of fluency, flexibility, elaboration and originality. The results of the interview related to the verification stage are as follows.

P : Did you also have time to re-check the answer to question number 1?
M18 : Yes, I did.
P : What findings? When you checked again?
M18 : It turns out there is a code that does not comply with the rules for writing graphs but I have changed it.

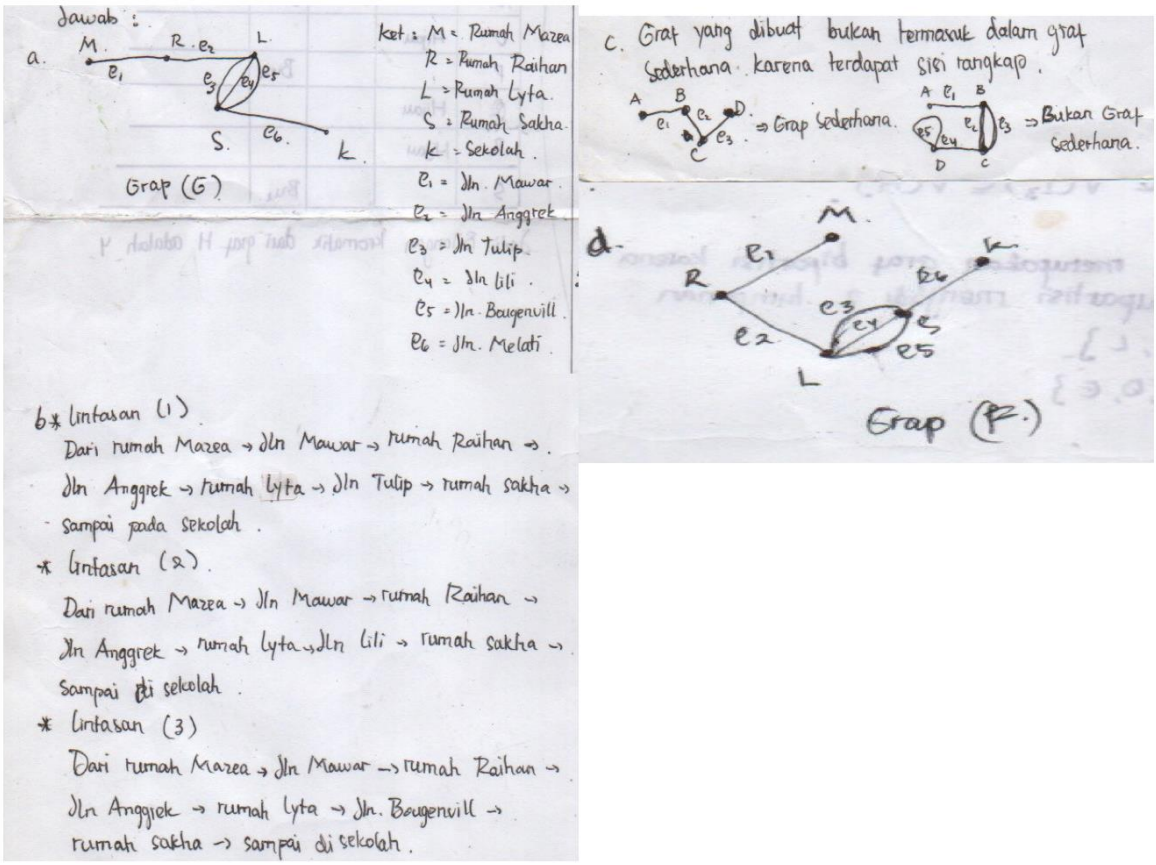


Figure 2. Subject M18's Answer Results

Description of the Characteristics of the Mathematical Creative Thinking Process of Students with Auditory Learning Style (Subject M23)

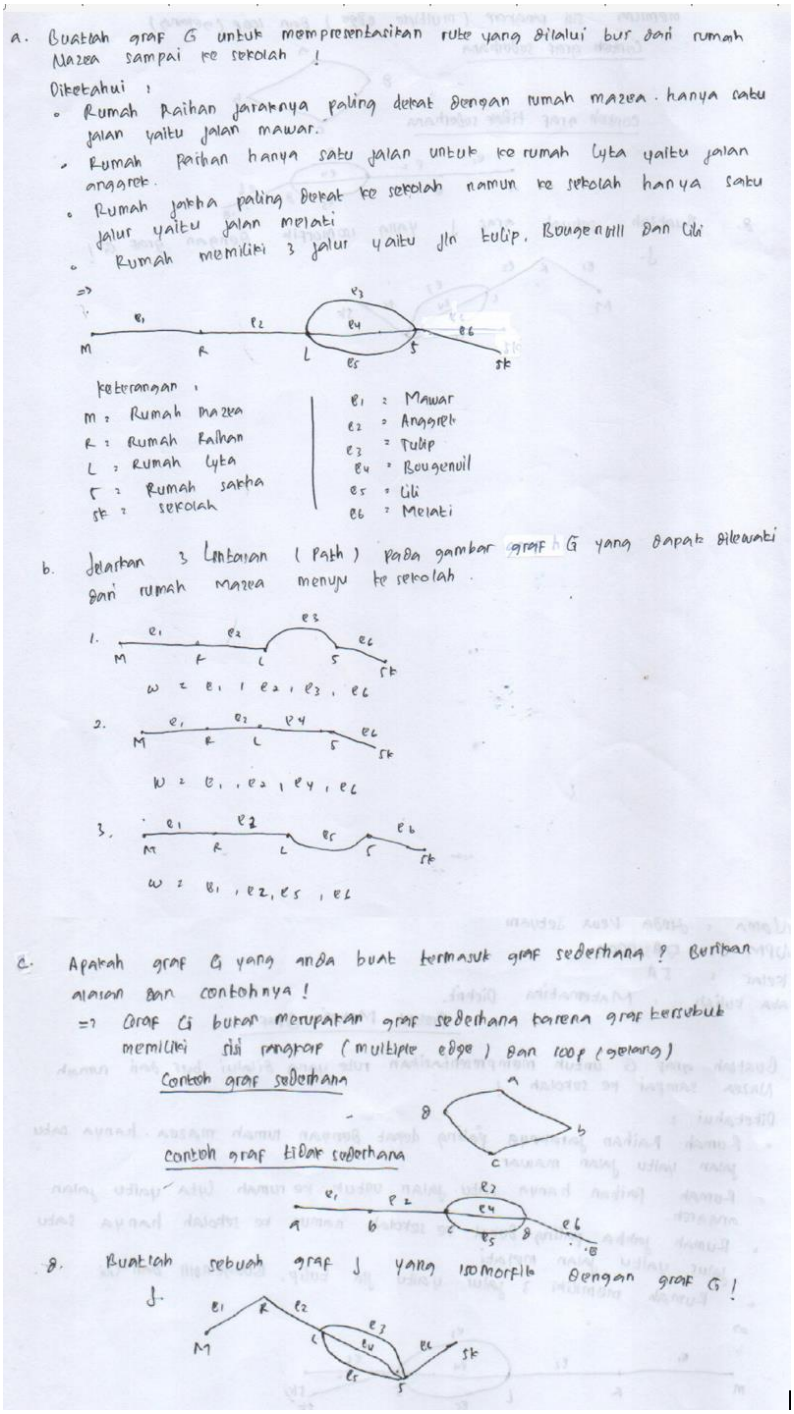


Figure 3. Subject M23's Answer Results

Subject M23 is able to understand the information in the question so that he can write down what is known before drawing the graph. The writing of symbols for sides, points, and graph shapes is different from other students so that the indicators of fluency and originality are met. This is reinforced by the results of the researcher's interview with student M23 below.

P : Have you written down what is known and asked?

M23 : Yes, I have explained what is known based on the question.

P : Did you explain it in your own language? How did you describe it in the graph?

M23 : Yes, I explained it in my own language and drew the graph according to my own thoughts and did not copy those of other friends.

In the incubation stage, subject M23 was able to think about how to draw graphs, alternative answers to routes from Mazea's house to school, and new concepts related to simple graphs. Thus, subject M23 met the indicators of fluency, flexibility, and elaboration. The results of the interview related to the incubation stage are as follows.

P : In question number 1b, you are asked to explain 3 paths in graph G, what is it like in your mind?

M23 : Have to find a path.

P : What is meant by a path?

M23 : The path has several paths that lead to the final route or the destination.

P : Are there any points that are the same that are passed?

M23 : They are all different.

At the illumination stage, subject M23 was able to create a bus route graph from Mazea's house to school, describe three alternative routes based on graph G, identify simple graphs, and create isomorphic graphs with different graph shapes from graph G. Thus, subject M23 met the indicators of fluency, flexibility, elaboration, and originality. The next stage of the creative thinking process is the verification stage.

At the verification stage, subject M23 has rechecked his answers so that they meet the indicators of fluency, flexibility, elaboration, and originality. The interview results that support the data of subject M23 at the verification stage are as follows.

P : Did you recheck your answer?

M23 : Yes, I rechecked my answer. I found that the example of a non-simple graph was still drawn like a known graph, I wanted to change it but I was still confused so I only changed the name of the vertex.

Description of the Characteristics of the Mathematical Creative Thinking Process of Students with Read/Write Learning Style (Subject M6)

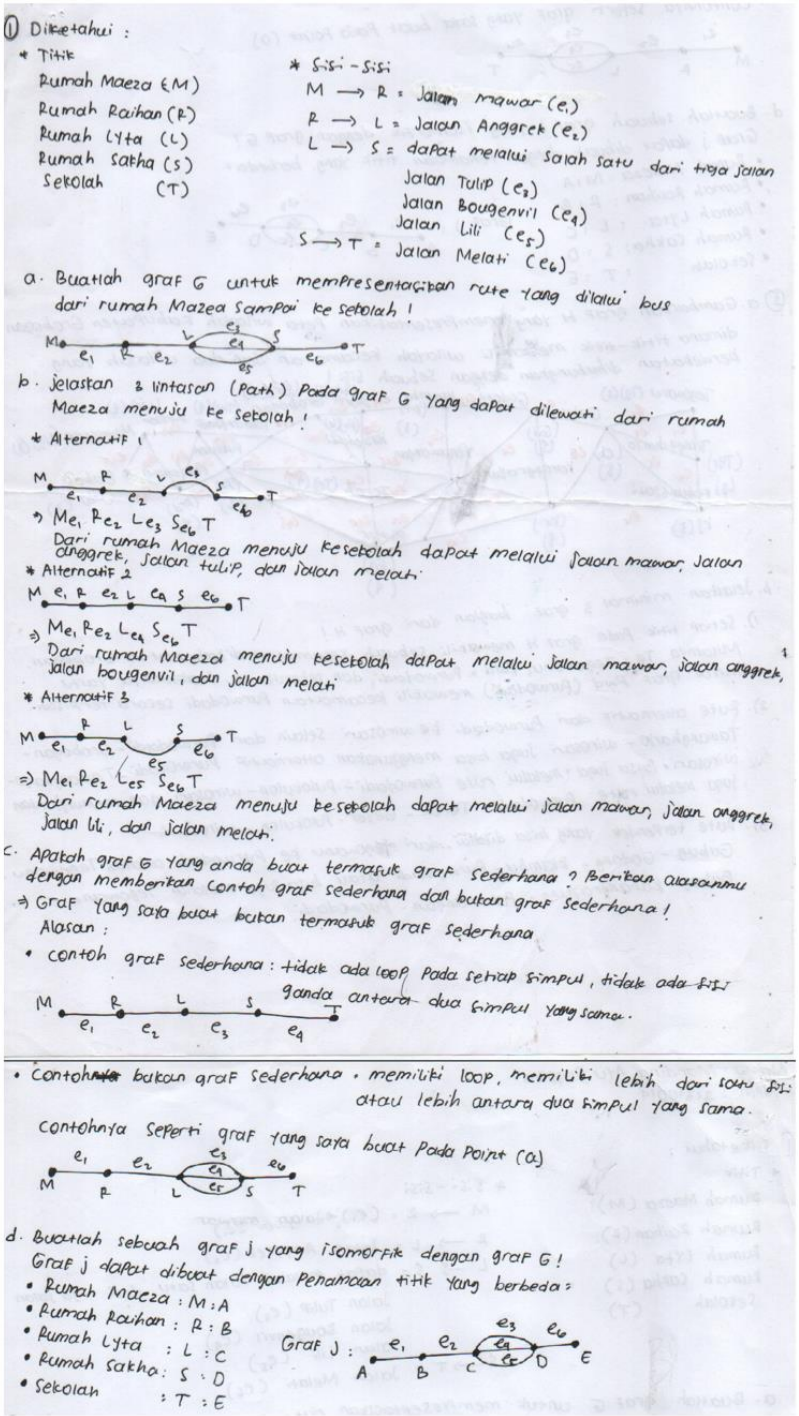


Figure 4. Subject M6's Answer Results

In the preparation stage, subject M6 was able to understand the information in the questions so that he could write down what was known. The writing of symbols for sides, points, and graph shapes was different from other students so that it met the indicators of fluency and originality. The results of the preparation stage interview are as follows.

Results of the interview between the Researcher (P) and Student (M6):

P : Did you write what was known and asked?
M6 : Yes, I wrote down the examples of points and sides based on the information in the question. Then I drew the graph according to what was in my mind because I already understood what was being asked.
P : When you wrote what was known based on the story questions that had been given, were there any obstacles?
M6 : To understand the story questions which were a bit lacking. However, I tried to on paper first, finally I was able to draw the graph.

At the incubation stage, subject M6 was able to think about how to draw graphs, was able to think of alternative answers to the route from Mazea's house to school so as to meet the indicators of fluency and flexibility. The following are the results of interviews between researchers and M6 students at the incubation stage.

P : In question number 1b, what is on your mind after reading the question?
M6 : I think the path must have different points and sides.
P : How do you explain the 3 paths in graph G?
M6 : First, I made a graph from Mazea's house first then to school, I can go through Jalan Mawar, Jalan Angkor, Jalan Tulip, and Jalan Melati. Then for the second alternative path, Jalan Mawar, Jalan Orchid, Jalan Bougenfil, and Jalan Melati, then for the third alternative it can go through Jalan Mawar, Jalan Orchid, Jalan Lili, and Jalan Melati.

At the Illumination stage, Subject M6 was able to describe the route taken by the bus from Mazea's house to the school, three alternative routes based on the G graph, and identify simple graphs. Thus, subject M6 met the indicators of fluency, flexibility, and elaboration. The next stage of the creative thinking process is the verification stage.

At the verification stage, Subject M6 had rechecked the results of his answers so that at the verification stage he had met the indicators of fluency, flexibility, elaboration and originality. The results of the researcher's interview with student M6 at the verification stage are as follows.

P : Did you recheck the answers before they were submitted?
M6 : Yes, initially I found the answer 1d exactly the same as the previous graph image, so in the end I made it different for the vertex names on the graph that is isomorphic to graph G.

Description of the Characteristics of the Mathematical Creative Thinking Process of Students with Kinesthetic Learning Style (Subject M36)

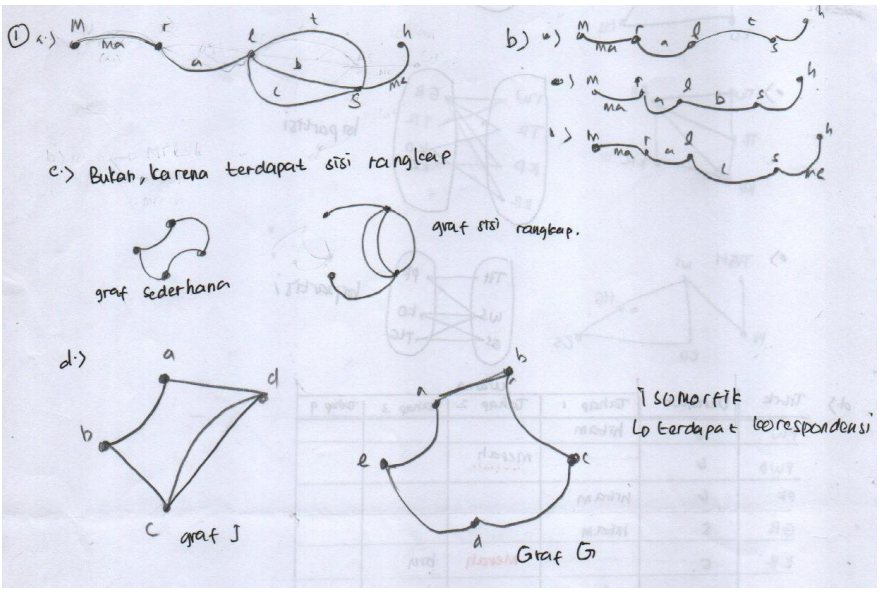


Figure 5. Subject M36's Answer Results

In the preparation stage, subject M36 was able to draw a graph but had not written a description representing the known points and sides. This is also shown from the following interview results.

P : Did you write down what was known and asked?

M36 : Not yet.

P : Why haven't you written it down?

M36 : Because from me myself, for example what is known in the form of numbers then I will tend to write it down, but if it is known in the form of sentences I rarely write it down.

At the incubation stage, subject M36 was able to think about how to draw a graph but did not write down the description of the points and sides clearly based on the information in the question, think about alternative answers, think about simple graphs in providing examples. Thus, subject M36 met the indicators of fluency, flexibility, and elaboration. This is reinforced by the results of the interview at the following incubation stage.

P : Next, question number 1b, what's on your mind?

M36 : I think it's the same as a route but asked for a specific part of the graph. In my opinion, it can pass through 3 paths from home to school.

P : Did you draw a graph without a description too?

M36 : Yes, I did.

P : What do you think about question number 1c?

M36 : Because what was asked was only to show, it means the answer is between a simple graph or not a simple graph. I remember that if a graph has a double edge, it is not a simple graph. So, I immediately gave an example that one of the graphs that is not a simple graph has a double edge.

At the illumination stage, subject M36 was able to create a graph G but had not written down information on its vertices and edges, could describe three alternative paths, could identify simple graphs and was able to provide reasons. However, subject M36 only answered briefly and only drew a graph without any information. In addition, subject M36 did not write down the solution sequentially in providing examples of simple graphs, had not been able to draw an isomorphic graph with graph G according to his own thoughts. Thus, subject M36 had not met the indicators of fluency, flexibility, elaboration and originality. The next stage of the creative thinking process is the verification stage.

At the verification stage, subject M36 had rechecked the results of his answers so that at the verification stage he had met the indicators of fluency, flexibility, elaboration and originality. The results of the researcher's interview with student M36 are as follows.

P : From question number 1, have you tried to check it again?

M36 : Yes, I have.

P : What did you find?

M36 : I read the question instructions. Because the command is only "make a graph", so I only draw the graph without providing information about the vertices and edges on the graph.

P : That means, the next question needs to be completed with detailed commands, right?

M36 : Yes, I feel obliged to write clear information in making a graph.

Students with visual learning styles, fulfill all indicators of creative thinking ability at the illumination and verification stages. While the preparation stage has not yet shown the elaboration and flexibility indicators. The incubation stage has not yet shown the flexibility and originality indicators because students are still confused about determining alternative paths and proving isomorphic graphs according to their own thoughts. Students with auditory learning styles, fulfill all indicators of creative thinking ability at the verification stage. While the preparation stage has not yet shown the elaboration and flexibility indicators. The incubation and illumination stages have similarities, namely not meet the originality indicator because students are still confused when thinking about ideas and drawing graphs that are isomorphic to graph G. Students with read/write learning styles, fulfill all indicators of creative thinking ability at the verification stage. While the preparation stage has not yet shown the flexibility indicator. The incubation stage has not meet the elaboration and originality indicators because they are still confused when thinking about simple graphs and giving examples based on their own thoughts. The illumination stage has not meet the originality indicator. Students with kinesthetic learning styles, fulfill all indicators of creative thinking ability at the verification stage. Meanwhile, in the preparation stage and the illumination stage, the indicators of fluency, flexibility and elaboration have not yet appeared. This is because

students only draw graphs without writing down the vertex and edge information for the answers given so that they have not provided any solution ideas. The incubation stage has not met the originality indicator because students have difficulty in understanding how to draw graphs that are isomorphic to graph G according to their own thoughts.

Students with different learning styles apparently have different indicators of mathematical creative thinking achievement (Kartono et al., 2022). This is a concern for a lecturer to provide appropriate teaching to improve students' creative thinking abilities (Arumningsih et al., 2023; Dermawan & Andartiani, 2022). A learning environment that suits learning styles encourages students to think and helps students acquire the skills needed in an educational environment (Mohsenipouya et al., 2024).

CONCLUSION

The results of the study showed that the mathematical creative thinking process of the average of the four students' learning styles at the preparation stage did not meet the indicators of flexibility and originality. The incubation and illumination stages still need assistance to bring up the originality indicators. While the verification stage has met the four indicators of mathematical creative thinking ability completely. Thus, the findings of this study can be used as a consideration for lecturers in understanding the differences in students' learning styles. Lecturers can provide appropriate *scaffolding* to make it easier for students to solve graph problems.

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