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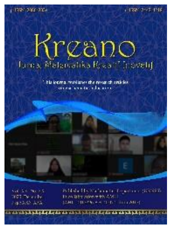

Patterns of Mathematical Creative Thinking Process Based on Learning Styles in Graph Theory Learning

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Abstract

Graph theory demands creative problem-solving skills, but students still experience difficulties in producing solutions. Although learning styles have been widely studied in mathematics education, studies examining their influence on students' mathematical creative thinking processes in graph learning are still limited. This research aims to identify the characteristics of the mathematical creative thinking process based on learning styles in graph learning. The research uses a qualitative approach with test instruments, questionnaires and interviews. Based on the results of the questionnaire, six types of learning styles were obtained, namely visual, auditory, read/write, kinesthetic, combined auditory–kinesthetic, and combined read/write–kinesthetic. Subjects were selected using purposive sampling with one student taken for each type of learning style so that the total number of subjects was 6 students. The data analysis technique uses an interactive analysis model consisting of data collection, data reduction, data presentation, and drawing conclusions. The results of the study indicate that students with various learning styles exhibit almost the same pattern of creative thinking processes in solving graph theory problems. This similarity can be seen in the preparation stage where the problem information has not been written completely, the incubation and enlightenment stages where they still have difficulty understanding and solving the concepts of bipartition graphs and isomorphic graphs, and the verification stage which shows that subjects tend to only re-check the answers they understand so that it depends on the fulfillment of the illumination stage. Thus, this pattern of mathematical creative thinking processes is a consideration for lecturers in providing appropriate learning strategies based on the learning styles of students.

Keywords: Graph Theory; Learning Styles; Creative Thinking; Thinking Process.

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Abstrak

Teori graf menuntut keterampilan pemecahan masalah kreatif, namun mahasiswa masih mengalami kesulitan dalam menghasilkan solusi. Meskipun gaya belajar telah banyak dikaji dalam pendidikan matematika, kajian yang menelaah pengaruhnya terhadap proses berpikir kreatif matematis mahasiswa pada pembelajaran graf masih terbatas. Penelitian ini bertujuan mengidentifikasi karakteristik proses berpikir kreatif matematis berdasarkan gaya belajar dalam pembelajaran graf. Penelitian menggunakan pendekatan kualitatif dengan instrumen tes, angket, dan wawancara. Berdasarkan hasil angket diperoleh enam jenis gaya belajar, yaitu visual, auditory, read/write, kinesthetic, gabungan auditory–kinesthetic, dan gabungan read/write–kinesthetic. Subjek dipilih dengan purposive sampling dengan setiap jenis gaya belajar diambil satu mahasiswa sehingga jumlah subjek sebanyak 6 mahasiswa. Teknik analisis data menggunakan model analisis interaktif yang terdiri dari pengumpulan data, reduksi data, penyajian data, dan penarikan kesimpulan. Hasil penelitian menunjukkan bahwa mahasiswa dengan berbagai gaya belajar menunjukkan pola proses berpikir kreatif yang hampir sama dalam menyelesaikan masalah teori graf. Kesamaan tersebut terlihat pada tahap persiapan yang belum menuliskan informasi secara lengkap, tahap inkubasi dan iluminasi yang masih mengalami kesulitan memahami serta menyelesaikan konsep graf tertentu, dan tahap verifikasi yang menunjukkan seluruh subjek telah memeriksa kembali jawabannya. Hasil ini menunjukkan bahwa pembelajaran teori graf perlu dirancang dengan strategi yang dapat membantu mahasiswa memahami konsep dan mengembangkan proses berpikir kreatif secara lebih optimal.

INTRODUCTION

Mathematical creative thinking skills play an important role in improving the quality of education, especially through developing assessment of student skills at various levels (Suherman & Vidákovich, 2022a). A positive attitude has been shown to make a significant contribution to high-level mathematical creative thinking, and students with a positive outlook are more likely to develop creative thinking (Suherman & Vidákovich, 2024). The creative process itself often arises from subconscious mechanisms that occur after the individual experience compilation. Sudden and unconscious insights play an important role in problem-solving efforts (Haavold & Sriraman, 2021). In addition, students with high academic achievement usually have more developed creative thinking skills than students with low academic achievement (Wang et al., 2025). The creative thinking process has an important impact on achieving academic achievement in mathematics because it makes it easier for students to understand the material being studied (Le, 2023). Creative thinking processes need to be developed to produce new ideas in solving mathematical problems. Students can provide ideas and find more than one answer solution. One of the causes of difficulties in developing creative thinking processes is different learning styles (Hadi et al., 2023; Jagom et al., 2021).

Learning style is a person's style in absorbing information and processing information. There are differences in the creative thinking process at each stage, namely the stages of synthesizing ideas, building ideas, planning the implementation of ideas, and implementing ideas. This difference is due to differences in character and learning style (Ferdiani & Harianto, 2024). Learning styles are divided into 4 dominant styles designed by Fleming & Mills, namely VARK (Visual, Auditory, Reading-writing and Kinesthetic). The VARK model consists of 4 learning styles, namely (1) visual learning, a style where students learn better when they can visualize information to then remember; (2) auditory learning, in this style it can be understood that students learn better by listening to information, processing it until finally understanding and remembering it; (3) reader-writer learning, as the name suggests, students understand better by copying and reading information; (4) kinesthetic learning, which is based on students' preferences in developing exercises to demonstrate what they have to learn (Alanya-Beltran et al., 2023). Learning style is proven to have a significant influence on creative mathematical thinking abilities. Learning style plays an important role in forming creative thinking in solving problems (Muminu et al., 2025; Razali & Zahari, 2025).

Based on researchers' observations when teaching graph theory material at a private campus, students made mistakes in carrying out mathematical modeling and did not come up with ideas for solving problems. This is supported by the results of previous research which shows that the main obstacle for students lies in the process of communicating mathematical ideas in writing, especially in explaining the relationships between points, trajectories, and the graph models used. Students tend to have difficulty in arranging arguments and writing down solution steps in a coherent manner so that it takes longer to draw conclusions. These conditions show that in solving graph problems, students are not only required to understand graph concepts and representations, but also have clear mathematical thinking skills so that the solutions obtained can be understood well (Rahmawati et al., 2025). All students can understand the essence of the problem and write down the information provided to solve the problem at the preparation stage. At the incubation stage, students at each level of creative thinking have different sequences for getting inspiration. At the illumination stage, students can only write one answer and solution. Then, students can achieve fluency, flexibility, and originality. Finally, at the verification stage, students recheck idea steps, check answers, and correct writing errors (Gunawan et al., 2023). Meanwhile, students who solve graph problems need the ability to think creatively mathematically in processing and conveying information. Problem solving shows the creative thinking processes that students have according to their respective learning styles. Therefore, this research aims to determine the characteristics of students' creative mathematical thinking processes based on their learning styles in the context of graph theory learning.

METHOD

This study uses a qualitative approach that aims to obtain in-depth data while understanding the phenomenon being studied (Creswell et al., 2003). The phenomenon studied is the characteristics of the mathematical creative thinking process based on students' learning styles. The research instruments are in the form of a learning style questionnaire, Mathematical Creative Thinking Ability Test (TKBKM) questions, and interview guidelines. The questionnaire is used to categorize students' learning styles according to (Fleming & Mills, 1992) namely VARK (Visual, Auditory, Reading-writing, and Kinesthetic) and allows for the existence of a combined learning style (a person has more than one type of learning style). Each question in the questionnaire has one answer, namely V/A/R/K, which will then be calculated for the highest score. For example, if the highest score is V, then the student has a visual learning style. However, if there is more than one type of learning style that obtains the highest total score and has the same score, namely V and A, then the student has a combined Visual/Auditory learning style. Learning Style Categories are shown in Table 1.

Tabel 1. Learning Style Categories

Learning Style	Description
Visual	If the highest total score is

	obtained, it is V
Auditory	If the highest total score is A
Read/write	If the highest total score is obtained, it is R
Kinesthetic	If the highest total score is obtained, it is K.
Combined	If there is more than one type of learning style that gets the highest total score and has the same score.

Meanwhile, the TKBKM questions are compiled based on Munandar's indicators of mathematical creative thinking ability (Fluency, Flexibility, Originality, Elaboration). The questions will be tested for validity, reliability, difficulty level, and discriminatory power. Researchers analyze the mathematical creative thinking process based on categorized student learning styles, then conduct interviews to obtain in-depth information data to discover the characteristics and patterns of mathematical creative thinking processes in graph learning.

This research was conducted on 5th semester students of Mathematics Education Study Program at a private university in Semarang who are taking Discrete Mathematics course. The selection of students was based on the consideration that 5th semester students have better creative thinking skills compared to the semesters below and the graph material is contained in the 5th semester Discrete Mathematics course. The research subjects for qualitative data were selected by purposive sampling, namely the selection of research subjects is selective based on specific objectives. Next, the characteristics of the mathematical creative thinking process will be analyzed referring to Wallas' theory. Then, an in-depth analysis of each learning style category will be conducted.

Qualitative data analysis was conducted using an interactive analysis model. Interactive analysis of data analysis activities takes place continuously until completion, and consistent answers have been obtained from the results of data triangulation. After the data is collected, data reduction, data presentation, and conclusion drawing can be carried out (Huberman, 2014; Moleong, 2010). In this study, data validity testing was conducted using a method triangulation technique, namely comparing test results and interview results. The relationship between the creative thinking process and indicators of mathematical creative thinking ability is presented in Table 2.

Tabel 2. Relationship between Creative Thinking Ability and Creative Thinking Process

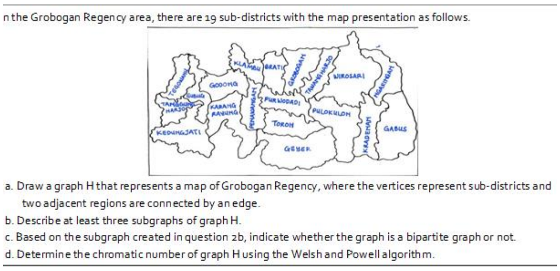
Creative Thinking Process	Mathematical Creative Thinking Indicators	Characteristics	Code
Preparation	Fluency	Students have ideas for writing down what is known and asked regarding the problem presented.	A1
	Flexibility	Students use their own language alternatives in writing down what is known and asked regarding the problems presented.	A2
	Originality	Students create unique concepts from what is known and asked regarding the problem presented.	A3
	Elaboration	Students detail what is known and asked regarding the problem presented.	A4

Creative Thinking Process	Mathematical Creative Thinking Indicators	Characteristics	Code
Incubation	Fluency	Students think of ideas for answers which are expressed in the form of formula scribbles or pictures.	B1
	Flexibility	Students search for appropriate strategies to produce a variety of answers.	B2
	Originality	Students think of unique ways to express their ideas in the form of paper scribbles.	B3
	Elaboration	Students think about more coherent solutions which are written down on paper.	B4
Illumination	Fluency	Students get ideas to solve problems with solution answers.	C1
	Flexibility	Students show a solution with different answers.	C2
	Originality	Students demonstrate greater understanding by generating unique concepts.	C3
	Elaboration	Students develop a solution idea in a coherent manner.	C4
Verification	Fluency	Students re-examine the problem solving with solutions and answers.	D1
	Flexibility	Students re-examine the solution to the problem with various different answers.	D2
	Originality	Students re-examine the solution to the problem in a new or unique way that is different from the answers of other students.	D3
	Elaboration	Students re-examine the problem solving in a sequential manner.	D4

RESULT AND DISCUSSION

Reslts

Based on the results of the student learning style questionnaire analysis, six learning style categories were obtained, namely Visual (V), Auditory (A), Reading/Writing (R), Kinesthetic (K), combined Auditory-Kinesthetic (A/K), and combined Reading/Writing-Kinesthetic (R/K). From these data, it was identified that there were 2 students with Visual learning styles, 6 Auditory, 3 Reading/Writing, 23 Kinesthetic, 3 Auditory/Kinesthetic, and 3 Reading/Writing-Kinesthetic. For the purpose of the study, one subject from each type of learning style were selected to observe their thinking processes through the stages of preparation, incubation, enlightenment, and verification. Next, students were asked to solve problems on the TKBKM designed to explore the characteristics of the mathematical creative thinking process. The questions given require students to have a fluency indicator in drawing graphs based on the given map, students need to fulfill the flexibility indicator to write various strategies in drawing subgraphs, students need to fulfill the originality indicator to be able to prove bipartition graphs based on graphs that have been made previously, and students can determine the chromatic number with the Welsh and Powell algorithms in detail through the elaboration indicator. The Mathematical Creative Thinking Ability Test is shown in Figure 1.


n the Grobogan Regency area, there are 19 sub-districts with the map presentation as follows.

a. Draw a graph H that represents a map of Grobogan Regency, where the vertices represent sub-districts and two adjacent regions are connected by an edge.
b. Describe at least three subgraphs of graph H.
c. Based on the subgraph created in question 2b, indicate whether the graph is a bipartite graph or not.
d. Determine the chromatic number of graph H using the Welsh and Powell algorithm.

Figure 1. The Mathematical Creative Thinking Ability Test

Description of Mathematical Creative Thinking Process Characteristics of Students with Visual Learning Style (Subject M35)

Subjects with a visual learning style exhibit certain characteristic at each stage of the mathematical creative thinking process. In the preparation stage, the subject does not explain in detail what is known or asked in the problem, and does not present a unique concept, but immediately draws a graph complete with its vertices and edges.

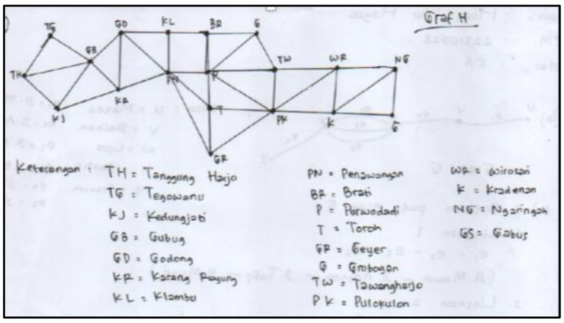


Figure 2. Subject M35's Test Result on Question 2a

Based on Figure 2, Subject M35 was able to understand the information in the question and transform it into a graph with explanations, thus meeting the fluency and flexibility indicators. Subject M35 did not elaborate on the information in the question regarding the known and asked questions and did not demonstrate uniqueness in his presentation, thus failing to meet the elaboration and originality indicators. This is supported by the results of the interview between the researcher (P) and the student (M35) below.

P : *What information can you write based on question number 2?*
M35 : *I didn't write the known and asked questions but instead drew the graph directly. For example, on the map here, Kedung Jati (KJ) is adjacent to Sambungharjo, Gubuk, and Karangrayung, so I connected them.*
P : *What if two areas are not adjacent but only separated by a point?*
M35 : *In my opinion, that doesn't constitute a direct connection. So the two regions are not connected by an edge.*
P : *Are there any difficulties in drawing the graph?*
35 : *No. I'll draw it like the example problem I already understand.*

In the incubation stage, the subject experiences difficulty in designing various strategies, especially in determining paths and in finding the right way to construct isomorphic graphs and bipartition graphs.

P : *Based on the subgraph created in number 2b, indicate whether the graph is bipartite or not.*
M35 : *In my opinion, no vertex sets in parts A and B should be duplicated.*
P : *Does that mean no vertex can be in two vertex sets? But here, there are vertices in two sets. Why is it concluded that the graph is bipartite?*
M35 : *Maybe I wasn't careful enough.*

Next, in the illumination stage, the subject begins to be able to write alternative paths, but the answer is still inaccurate because it does not include the correct writing of vertices and edges. The subject can draw an isomorphic graph, but without explaining the vertex correspondence, and writes a proof of a bipartition graph through partitioning two sets, although there are still errors in the relationship between vertices. This condition indicates that weaknesses in the incubation stage have an impact on imperfect answers in the illumination stage.

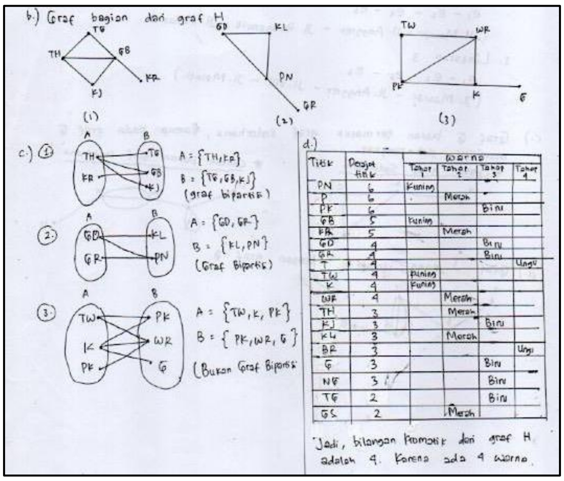


Figure 3. Subject M35's Test Result on Question 2b, 2c,2d

In the verification stage, the subject stated that he had rechecked his answer, but the findings showed errors in writing vertices and edges and no final conclusion after solving the problem. Overall, the pattern of the mathematical creative thinking process of subjects with a visual learning style can be seen in Figure 4.

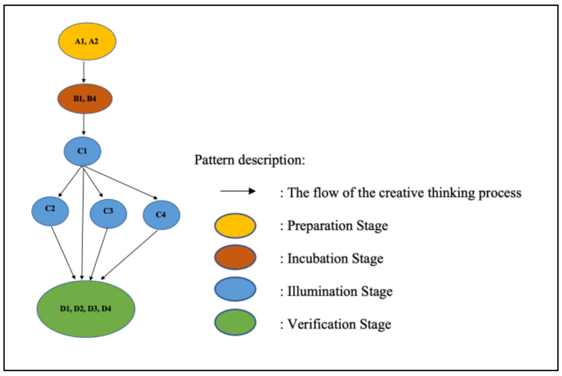


Figure 4. Mathematical Creative Thinking Patterns in Visual Subjects

In visual subjects, the illumination and verification stages were able to meet the indicators of fluency, flexibility, originality, and elaboration. Fluency was evident in the ability to generate several alternative paths, flexibility in varying solution approaches, originality in efforts to construct isomorphic and bipartite graphs, and elaboration in the process of proving and checking answers. This is in line with the finding that subjects with a visual learning style successfully met the indicators of flexibility, originality, and elaboration (Imron et al., 2025). The verification stage in visual subjects demonstrated metacognitive awareness to check answers. However, the reflection process was not fully comprehensive because it did not end with a conclusion or systematic correction of errors. From a metacognitive perspective, verification requires structured monitoring and evaluation to ensure solutions are valid and coherent. Thus, although subjects demonstrated creative tendencies, the process of conceptual understanding needs to be strengthened.

However, weaknesses in the preparation stage indicate suboptimal initial information identification activities. From a mathematical problem-solving perspective, the problem understanding stage is the primary foundation before designing a solution strategy. When subjects do not specify what is known and what is being asked or do not present information uniquely, the elaboration and originality indicators are not optimally met. This is evident in subjects who do not write detailed graph descriptions or do not present representations that differ from examples in class. In the incubation stage, subjects' difficulties in visualizing graph paths, constructing isomorphic graphs, and identifying bipartition graphs indicate limitations in cognitive flexibility.

Theoretically, flexibility is a crucial component of creativity because it involves the ability to switch between representations and strategies (Silver, 1997). When subjects only consider alternatives verbally without drawing or are unable to develop different representations, flexibility and originality are suboptimal.

Description of Mathematical Creative Thinking Process Characteristics of Students with Auditory Learning Style (Subject M30)

The characteristics of subjects with an auditory learning style show that in the preparation stage, the subject does not elaborate in detail and does not generate unique concepts related to what is known and asked in the problem. However, the subject immediately draws a graph along with information about its vertices and edges.

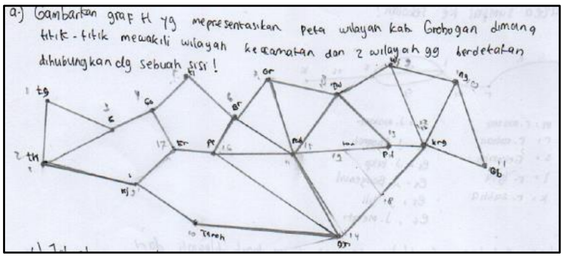


Figure 5. Subject M30's Test Result on Question 2a

In the incubation stage, the subject still has difficulty thinking about the concepts of isomorphic graphs, bipartition graphs, simple graphs, and chromatic numbers. This is supported by the results of the interview between the researcher (P) and the student (M30) below.

P : *How can you explain answer 2a?*

M30 : *That's it. My shortcoming in answer 2a was that I didn't provide any information about what was known and what was asked, which made it difficult to answer the next question.*

P : *I only wrote the point symbol without any explanation, right?*

M30 : *Yes.*

P : *Then for number 2b, about the subgraph. What were your thoughts before working on it?*

30 : *For a subgraph, we clearly take some of the vertices and edges of the graph created in 2a.*

P : *Okay, so you understand subgraphs. What about number 2c, which asks us to prove whether the graph we created previously is a bipartite graph or not?*

M30 : *I understand that a graph is said to be bipartite if the set of vertices can be divided into two. But I'm confused about dividing it.*

P : *In question 2d, what are the difficulties you encountered regarding coloring?*

M30 : *I don't understand the steps.*

In the illumination stage, the subject has difficulty creating isomorphic graphs, identifying bipartition graphs, providing examples that are not simple graphs, and determining chromatic numbers.

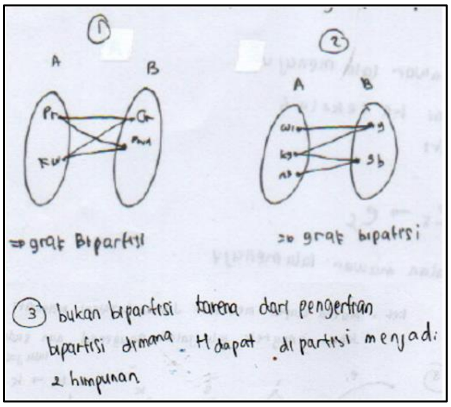


Figure 6. Subject M30's Test Results on Question 2c

In the verification stage, the subject does not re-check the answers about isomorphic graphs, bipartition graphs, simple graphs, and determining chromatic numbers. The pattern of mathematical creative thinking processes of subjects with an auditory learning style based on indicator achievement is shown in Figure 7.

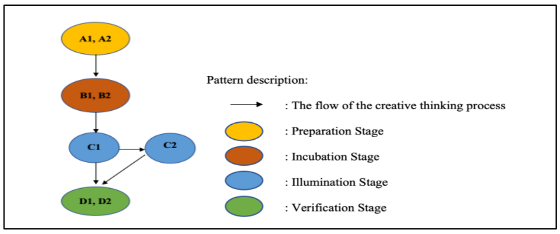


Figure 7. Mathematical Creative Thinking Patterns in Auditory Subjects

During the preparation, incubation, illumination, and verification stages, auditory subjects tended to be unable to demonstrate adequate creative thinking skills. During the preparation stage, subjects did not elaborate on known and questioned information in detail and tended to imitate example problems without in-depth reflection on their understanding, thus failing to meet the originality and elaboration indicators. These findings indicate that students' mathematical creative thinking abilities are often influenced by the problem understanding process and the assessment of creative skills themselves, particularly in the indicators of novelty and elaboration of solution ideas (Suherman & Vidákovich, 2022b).

Furthermore, during the incubation and illumination stages, the obstacles experienced by subjects in considering the concepts of isomorphic graphs, bipartition graphs, and chromatic numbers reflect limited flexibility and originality. This is in line with findings showing that the development of creative thinking skills in mathematical problem solving requires stimulation of various open-minded strategies (divergent thinking) and in-depth conceptual understanding, which are often lacking in students with auditory learning style tendencies in tasks that require visual and symbolic representations. Auditory subjects often experience difficulties in tasks that require complex visual and symbolic representations (Pitta-Pantazi et al., 2018). Finally, during the verification stage, the subjects' failure to reevaluate their answers indicated low metacognitive regulation. This emphasizes that the monitoring and evaluation stages are key pillars of higher-level problem solving. These findings confirm that auditory learning styles influence students' active role in achieving originality and elaboration indicators.

Description of Mathematical Creative Thinking Process Characteristics of Students with Read/write Learning Style (Subject M24)

Subject M24 when completing question number 2, his thinking process was still lacking in the preparation stage, subject M24 presented an unclear graph because it was not accompanied by a point description, there was no uniqueness in the graph presentation and did not write in detail what was known and asked so that it did not meet the flexibility, originality and elaboration indicators.

In the incubation stage, subject M24 had difficulty thinking of a strategy in identifying bipartition graphs and did not write the stages in determining chromatic numbers in detail so that it did not meet the originality and elaboration indicators.

In the illumination stage, subject M24 could not prove the bipartition graph clearly and did not write the stages of the Welsh and Powel algorithm to determine chromatic numbers so that it did not meet the originality and elaboration indicators.

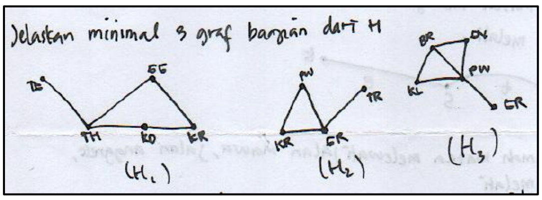


Figure 8. Subject M24's Test Results on Question 2b

In the verification stage, subject M24 did not re-check the answers related to proving bipartition graphs and determining chromatic numbers so that it did not meet the elaboration and originality indicators. This is supported by the results of the interview between the researcher (P) and the student (M24) below.

P : *Have you checked the answer to number 2?*
M24 : *Yes, ma'am.*
P : *What did you find?*
M24 : *I noticed that number 2a didn't have a dot description, but I didn't have time to add it.*
P : *Did you check the answer to number 2c regarding the bipartition proof and number 2d regarding the chromatic number?*
M24 : *I didn't check because I was still confused about the proof, and for the answer to 2d, I didn't write down the Welsh and Powell algorithm because time was up.*

The pattern of mathematical creative thinking processes of subject with a read/write learning style, based on indicator achievement, is shown in Figure 9.

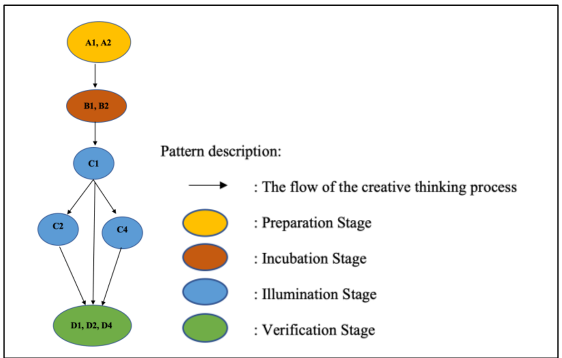


Figure 9. Mathematical Creative Thinking Patterns in Read/write Subjects

The read/write subjects demonstrated an inability to meet the indicators of originality, elaboration, and flexibility at each stage of the creative thinking process (preparation, incubation, illumination, and verification). The preparation stage is the foundation for the emergence of creative ideas. The subjects' inability to write down in detail what was known and asked, as well as their tendency to reproduce the same graph shapes, indicated a lack of in-depth problem exploration.

In the incubation and illumination stages, confusion in constructing isomorphic graphs, identifying bipartition graphs, and determining chromatic number using the Welsh-Powell algorithm indicated limited flexibility in strategies and the development of alternative ideas. When students simply replicated graph shapes without meaningful modification, the indicators of originality and flexibility were not met. Furthermore, difficulties in proving and generalizing graph concepts were often related to weak conceptual understanding and connections between symbolic and visual representations (Bicer, 2021). In the verification stage, the lack of double-checking of answers indicates low metacognitive regulation. This demonstrates that self-monitoring and evaluation are key components in successfully solving complex problems. Without adequate verification, generated ideas fail to undergo a refinement process, hindering achievement of the elaboration indicator.

Description of Mathematical Creative Thinking Process Characteristics of Students with Kinesthetic Learning Style (Subject M19)

The characteristics of subjects with a kinesthetic learning style, show that during the preparation stage, kinesthetic subjects did not write down in detail what was known and what was asked and did not demonstrate any uniqueness. During the incubation stage, kinesthetic subjects were still confused about how to draw isomorphic and bipartite graphs. This is supported by the results of the interview between the researcher (P) and the student (M19) below.

P : *What's on your mind regarding the bipartition graph in question 2c?*

M19 : *I think a bipartition graph is a set of vertices in the graph that can be divided into two sets, but I'm still confused about how to divide them.*

The illumination stage, kinesthetic subjects struggled to create isomorphic graphs and prove bipartite graphs.

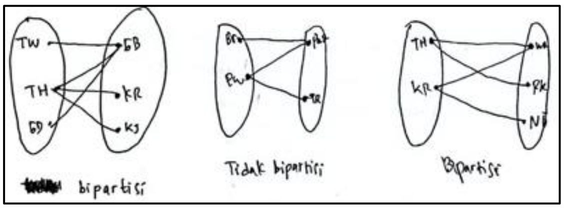


Figure 10. Subject M19's Test Results on Question 2c

During the verification stage, kinesthetic subjects did not recheck their answers about isomorphic and bipartite graphs. The pattern of mathematical creative thinking processes of subject with a kinesthetic learning style, based on indicator achievement, is shown in Figure 11.

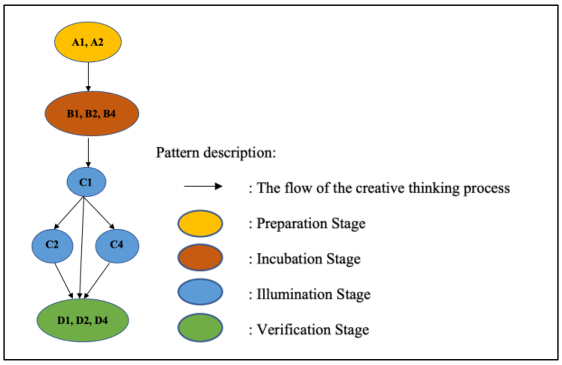


Figure 11. Mathematical Creative Thinking Patterns in Kinesthetic Subjects

The analysis of kinesthetic subjects showed that they were unable to meet the originality and elaboration indicators at all stages of the creative process: preparation, incubation, illumination, and verification. The preparation stage is a crucial phase in understanding and formulating problems in depth. The subjects' inability to write down what is known and asked in detail, as well as their tendency to replicate example problems, indicates that the problem internalization process is suboptimal. This condition aligns with research findings confirming that clear problem representation and in-depth initial exploration contribute significantly to the emergence of original ideas in mathematical problem solving (Bicer, 2021).

During the incubation and illumination stages, the subjects' difficulties in distinguishing simple graph concepts, drawing structurally equivalent isomorphic graphs, and proving bipartition graphs indicate limited strategic flexibility and conceptual understanding. This suggests that mathematical creativity is characterized by the ability to generate a variety of different answers and solution strategies. When students only change the vertex symbols without meaningfully modifying the relational structure, the originality indicator is not met. In addition, difficulties in proving and classifying graph concepts are often related to weak mathematical creative thinking skills in connecting visual, symbolic, and reasoning (Elgrably & Leikin, 2021). During the verification stage, subjects did not double-check their answers for isomorphic or bipartition graphs. This indicates low metacognitive regulation. These findings emphasize that self-monitoring and self-evaluation are crucial components for successful complex problem-solving.

Description of the Characteristics of the Mathematical Creative Thinking Process of Students with a Combined Auditory and Kinesthetic Learning Style (Subject M12)

The characteristics of subjects with an Auditory/Kinesthetic style show that in the preparation stage, Auditory/Kinesthetic subjects do not write down in detail what is known and asked and do not show anything unique. In the incubation stage, Auditory/Kinesthetic subjects are still confused about how to draw isomorphic graphs and bipartition graphs. This is supported by the results of the interview between the researcher (P) and the student (M12) below.

P : *In question number 2b, how do you explain the three subgraphs of graph H?*

M12 : *I wrote down 3 types of travel routes because I'm still confused about the concept of section graphs, ma'am.*

In the illumination stage, Auditory/Kinesthetic subjects have difficulty creating isomorphic graphs and proving bipartition graphs. Subject makes an isomorphic graph the same as graph G only giving a different vertex symbol.

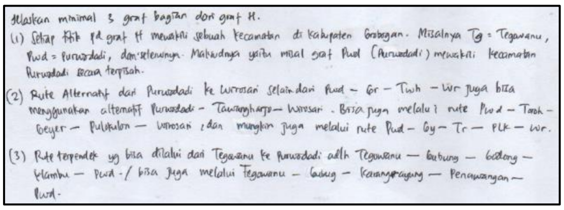

Jelaskan minimal 3 graf bagian dari graf H.
(1) Setiap titik pd graf H mewakili sebuah kecamatan di Kabupaten Grobogan. Misalnya Tg = Tegowanu, Pwd = Purwodadi, dan seterusnya. Maksudnya yaitu misal graf Pwd (Purwodadi) mewakili kecamatan Purwodadi secara terpisah.
(2) Rute Alternatif dari Purwodadi ke Wirosari selain dari Pwd – Gr – Twh – Wr juga bisa menggunakan alternatif Purwodadi – Tawangharjo – Wirosari. Bisa juga melalui rute Pwd – Toroh – Geyer – Pulokulon – Wirosari, dan mungkin juga melalui rute Pwd – Gy – Tr – PLK – Wr.
(3) Rute terpendek yg bisa dilalui dari Tegowanu ke Purwodadi adlh Tegowanu – Gubug – Godong – Klambu – Pwd. / bisa juga melalui Tegowanu – Gubug – Karangrayung – Penawangan – Pwd.

Figure 12. Subject M12's Test Results on Question 2b

In the verification stage, Auditory/Kinesthetic subjects do not re-check their answers about isomorphic and bipartition graphs. The pattern of mathematical creative thinking processes of subjects with an Auditory/Kinesthetic learning style based on indicator achievement is shown in Figure 13.

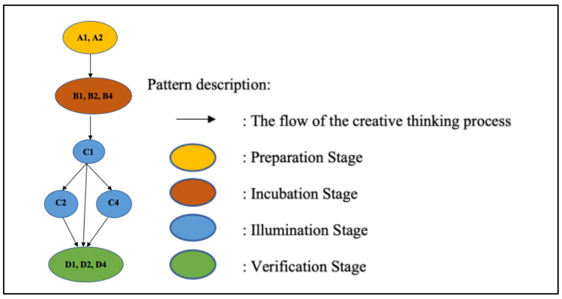


Figure 13. Mathematical Creative Thinking Patterns in Auditory/Kinesthetic Subjects

The analysis of the Auditory/Kinesthetic subject showed that the subjects were unable to meet the originality, elaboration, and flexibility indicators at several stages of the creative thinking process, particularly in the isomorphic and bipartite graphs. Based on Graham Wallas' theory of creative process stages, the preparation and incubation stages play a crucial role in building problem understanding and generating alternative ideas. When subjects fail to write down in detail what is known and what is being asked and only replicate previously provided examples, this indicates low idea exploration and underdevelopment of the originality and elaboration indicators.

In the incubation and illumination stages, the subjects' difficulties in constructing structurally equivalent isomorphic graphs and identifying and proving bipartite graphs indicate limited strategic flexibility. When students simply replace vertex symbols without modifying the relation structure or are unable to present more than two alternative subgraphs, the flexibility and originality indicators are not optimally met. Difficulties in graph proof and structural classification are often caused by weak connections between visual, symbolic, and formal reasoning representations. The subject's failure to verify indicates a lack of metacognitive regulation. Self-monitoring and self-evaluation are crucial components for successfully solving complex problems. Without rechecking, the resulting solution fails to undergo reflection and refinement, thus limiting the quality of idea elaboration.

Description of the Characteristics of the Mathematical Creative Thinking Process of Students with Combined Read/Write and Kinesthetic Learning Styles (Subject M10)

The characteristics of subjects with the Read-write/Kinesthetic style show that in the preparation stage, Read-write/Kinesthetic subjects do not write in detail what is known and asked and do not show anything unique.

In the incubation stage, Read-write/Kinesthetic subjects are still confused about how to draw isomorphic graphs and bipartition graphs. This is supported by the results of the interview between the researcher (P) and the student (M10) below.

P	:	*What are your thoughts on bipartition graphs?*
M10	:	*As far as I know, bipartition will form two sets of vertices. So, I proved the subgraph I wrote earlier, then I proved whether it is a bipartition graph or not. However, I'm still confused about the proof.*

In the illumination stage, Read-write/Kinesthetic subjects have difficulty creating isomorphic graphs and proving bipartition graphs. In the verification stage, Read-write/Kinesthetic subjects do not re-check their answers about isomorphic graphs and bipartition graphs.

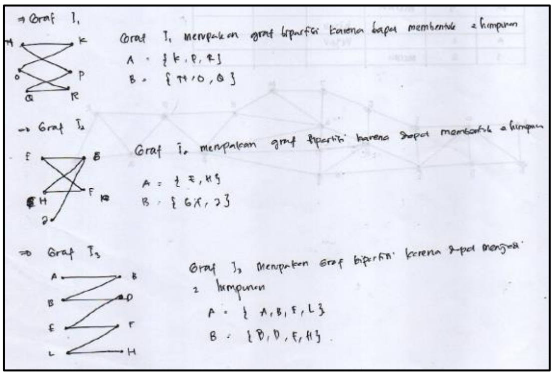


Figure 14. Subject M10's Test Results on Question 2c

The pattern of mathematical creative thinking processes of subjects with the Read-write/Kinesthetic learning style based on indicator achievement is shown in Figure 15.

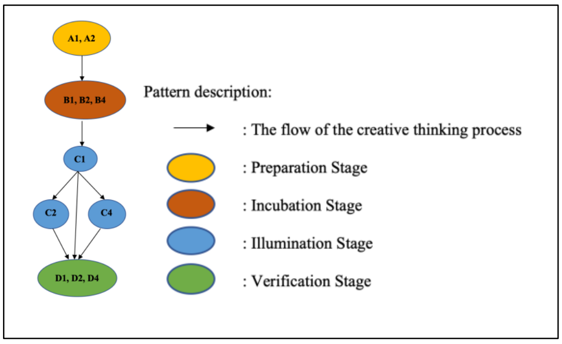


Figure 15. Mathematical Creative Thinking Patterns in Read-write/Kinesthetic Subjects

The analysis of the Read-Write/Kinesthetic subject indicates that the subject has not been able to consistently meet the originality and elaboration indicators at each stage of the creative thinking process, particularly in solving isomorphic and bipartite graph problems. Based on Graham Wallas' theory of creative process stages, the preparation stage serves as the foundation for building problem understanding. When the subject does not write down in detail what is known and what is asked and does not demonstrate uniqueness in presenting ideas, the problem internalization process becomes less in-depth. The quality of the initial problem representation is crucial for the emergence of original ideas in mathematical problem solving.

In the incubation and illumination stages, the subject's difficulty in constructing isomorphic graphs that meet the rules of structural correspondence and in identifying and proving bipartite graphs indicates limited strategic flexibility and depth of conceptual understanding. Mathematical creativity is characterized by the ability to generate a variety of solution strategies and meaningful representations. When the subject only modifies symbols without considering structural appropriateness or is unable to present a clear proof, the originality indicator is not optimally met. Difficulties in proving and classifying graphs are often related to weak connections between visual, symbolic, and formal reasoning representations. The subject's omission of the verification stage indicates low metacognitive regulation. Self-monitoring and self-evaluation skills are key factors in successfully solving complex problems. Without double-checking answers, the resulting solutions fail to undergo reflection and refinement, resulting in limited elaboration quality.

Discussion

One of the research findings through the learning style questionnaire according to Fleming & Mills is the discovery of 6 types of learning styles, namely Auditory, Read-write, Kinesthetic, Auditory-kinesthetic, Read/write-kinesthetic, combined auditory-kinesthetic learning styles and combined read/write-kinesthetic learning styles. Students with their respective learning styles have different characteristics and patterns of mathematical creative thinking in learning graph theory. Graph theory is a material in discrete mathematics courses that stimulates students to convey creative ideas.

The preparation stage, the mathematical creative thinking process of subjects with a visual learning style only met the fluency and flexibility indicators. This means they understood the information in the problem by writing down the points and edges that form the graph and then converting what was known in the problem into a graph image. Therefore, they did not write down in detail what was known and what was being asked. This also occurred in other students with auditory, read-write, kinesthetic, auditory-kinesthetic, and read/write-kinesthetic learning styles. Furthermore, the indicator of originality in creative thinking ability also did not appear for the six learning styles because the representation of information related to what was known and what was being asked in the problem could not be found to be unique.

The incubation stage, subjects with a visual learning style were able to brainstorm answer ideas and develop detailed solutions. Subjects with auditory and read-write learning styles were similar in that they were able to brainstorm answer ideas and develop various solution strategies. Meanwhile, subjects with kinesthetic, auditory-kinesthetic, and read/write-kinesthetic learning styles were similar in that they were able to brainstorm answer ideas, develop various solution strategies, and develop more coherent solutions. Therefore, the indicator of mathematical creative thinking ability that did not emerge was originality, as students rarely developed unique approaches to problem-solving.

The illumination stage, subjects with a visual learning style can solve problems by generating ideas, producing diverse answers, obtaining unique concepts and writing them down in detail.

Meanwhile, subjects with an auditory learning style are only able to generate solution ideas and produce diverse answers. Subjects with read/write, kinesthetic, auditory-kinesthetic and read/write-kinesthetic learning styles have similarities in that they are able to generate solution ideas, produce diverse answers and develop ideas coherently. Thus, there is one indicator of mathematical creative thinking ability that does not appear, namely originality where subjects should be able to demonstrate a deeper understanding of unique concepts. The unique concept presented in the graph theory material of this study is related to the proof of a bipartition graph and presents a graph that is isomorphic to a certain graph.

In the verification stage, subjects double-check their answers based on the concepts they understood through solving the problems in the illumination stage. Therefore, the verification stage relies on the illumination stage. Conversely, students do not double-check answers they do not understand. During the verification stage, it is important for students to double-check their ideas, check their answers, and correct any spelling errors (Kartono et al., 2022). Therefore, lecturers need to pay attention to students' abilities during the verification stage.

Based on the above description, it is clear that improving creative thinking skills by training students in problem-based learning is crucial for creating independent learning situations and generating ideas for solving mathematical problems with multiple solutions (Maskur et al., 2020; Mubarika et al., 2022). Lectures should be designed to enhance critical and creative thinking skills through student engagement in problem-solving until learning objectives are achieved (Hasanah et al., 2023; Kardoyo et al., 2020). Each student, with their own learning style, has a unique problem-solving pattern. Indicators of mathematical creative thinking skills that do not emerge during the creative thinking process require appropriate and effective support that students can use to solve problems. Scaffolding that can be used to overcome difficulties effectively is oriented towards learning objectives, and is in the form of manipulative media that students can apply actively. Providing assignments with more than one solution and problems with varying levels of complexity is an effective tool for testing students' mathematical creativity (Leikin & Lev, 2007; Susilo & Prihatnani, 2022; Vlasenko et al., 2020).

Visual, auditory, and kinesthetic learning styles have been shown to significantly influence mathematical creative thinking skills. Learning styles play an important role in shaping creative thinking and problem-solving skills (Muminu et al., 2025; Razali & Zahari, 2025). The process of mathematical creative thinking in students can be seen from the achievement of indicators in mathematical creative thinking skills. On average, students from the four learning styles (Visual, Auditory, Read/Write, and Kinesthetic) in the preparation stage did not meet the flexibility and originality indicators. The incubation and illumination stages still require assistance to improve the originality indicator. Meanwhile, the verification stage has fully met the four indicators of mathematical creative thinking skills, namely fluency, flexibility, originality, and elaboration. A lecturer needs to understand the differences in student learning styles so that they can provide appropriate scaffolding for students in solving problems and improving their mathematical creative thinking skills (Rahmawati et al., 2025).

Implication

This research has important implications for mathematics education, particularly in graph theory learning at the higher education level. Identifying different patterns of mathematical creative thinking processes based on students' learning styles has provided input for lecturers about creative thinking is not a uniform process but varies according to student learning characteristics. Lecturers need to design learning activities that accommodate various learning styles. Scaffolding is very necessary to overcome difficulties faced by students in the preparation, incubation, illumination, and verification stages. Therefore, researchers need to develop scaffolding in graph theory learning that can improve mathematical creative thinking skills in generating unique ideas, finding solution strategies, solving problems sequentially, evaluating and reflecting on the results of problem solving.

Limitation

Research is limited in its in-depth analysis of the creative thinking process during the verification stage. This is because researchers have difficulty observing how students double-check their answers. Furthermore, students rarely write conclusions for each solution, so researchers can only obtain data from direct interviews with the subjects.

CONCLUSION

The results of the study indicate that students with various learning styles exhibit almost the same pattern of creative thinking processes in solving graph theory problems. This similarity can be seen in the preparation stage where the problem information has not been written completely, the incubation and enlightenment stages where they still have difficulty understanding and solving the concepts of bipartition graphs and isomorphic graphs, and the verification stage which shows that subjects tend to only re-check the answers they understand so that it depends on the fulfillment of the illumination stage. Thus, this pattern of mathematical creative thinking processes is a consideration for lecturers in providing appropriate learning strategies based on the learning styles of students.

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