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Research Article

HOW IS THE DYNAMIC THINKING PROCESS OF PROFICIENT' STUDENTS IN SOLVING TRANSFORMATION GEOMETRY PROBLEMS?

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Abstract
Dynamic thinking is a crucial cognitive skill that enables students to solve complex problems in geometry effectively. This study investigates the characteristics of dynamic thinking among prospective mathematics teachers, focusing on the four key aspects: technique, conceptualization, monitoring, and perception. While previous research has identified these aspects, the specific problem-solving characteristics of dynamic thinking in mathematical contexts remain unexplored. This qualitative study was conducted at Tidar University, involving 54 prospective mathematics teachers identified as dynamic thinkers. Data were collected through a two-stage problem-solving test, structured observations, and in-depth interviews. The research instruments underwent a validation process to ensure reliability. Data analysis followed a systematic approach involving reduction, presentation, and verification to extract patterns of dynamic thinking among proficient problem solvers. The results indicate that students who exhibit proficient dynamic thinking demonstrate completeness and consistency in all four aspects. They effectively integrate multiple strategies, adapt their approaches in response to challenges, and maintain a reflective understanding of their problem-solving processes. Additionally, proficient dynamic thinkers show a higher degree of flexibility and spatial reasoning in geometry problems. This study contributes to the existing body of knowledge by identifying and describing the specific characteristics of dynamic thinking in mathematical problem-solving. The findings provide valuable insights for teacher education programs, emphasizing the need to cultivate dynamic thinking skills among prospective math educators. Future research can explore dynamic thinking across different mathematical domains and cognitive frameworks.

Keywords: Dynamic Thinking, Problem Solving, Transformation Geometry.

INTRODUCTION

The process of learning mathematics is focused on developing students both in learning achievement and problem solving to improve students' abilities (Sarnoko et al., 2024). Problem-solving mathematics has long been seen as an important aspect of mathematics and mathematics learning. Geometry problem solving has grown rapidly as a topic of scientific inquiry since the mid-20th century, but there is a limited understanding of the cognitive and psychological processes underlying mathematical problem-solving (Ulfa et al., 2023; Abdaoui et al., 2024; Sulthon et al., 2024; Trimurtini et al., 2024; Wirnayanti et al., 2024). Problem-solving has been incorporated into maths curriculums around the world with the call to teach problem-solving and to teach mathematics through problem-solving. The skills of mathematical processes are essential skills that include analysis, reasoning and problem solving in a mathematical context (Binti M, & Adeshina, 2024; Kamid et al., 2024; Melinda et al., 2024; Muis et al., 2024). However, at the same time, there is a great dependence on previous knowledge and experience (Schindler & Lilienthal, 2022; Halimah et al., 2024; Rachmanto, & Akande, 2024; Simamora et al., 2024). Problem-solving is a critical component of education, essential for developing 21st-century skills and preparing students to face real-world challenges. It fosters critical thinking, creativity, and the ability to apply knowledge across various contexts (Szabo et al., 2020; Islaihah, 2024; Puspitasari, 2024; Somantri, 2024). The ability to think creatively is very important in learning, because students gain experience using the knowledge and skill they have to apply them to everyday mathematics questions and problems (Habiburrohman et al., 2024; Sunia, 2024; Syutaridho et al., 2024). Therefore, an educator must strengthen thinking and adjust instructional approaches to keep students engaged (Nahar, 2023; Nwune et al., 2024; Hidayat et al., 2024). It is crucial for handling complex situations and obstacles in careers, making it a key educational goal (Kale & Akcaoglu, 2020; Aryadi et al., 2022; Repriani et al., 2022; Nada et al., 2023).

In fact, the ability to solve a mathematical problem is still experiencing obstacles. On the other hand, prospective math teachers are expected to be able to develop concepts and solve math problems. Based on the results of observations and interviews, some of the obstacles experienced by prospective math teachers are unfinished in understanding mathematical concepts, the ability of individuals in understanding problems, and differences in thought processes. The results of identifying student difficulties are also based on mistakes made by students when solving transformation geometry problems. The results of the study conducted by Imswatama & Muhassanah stated that the difficulty of students in solving analytical geometry problems of line and circle material is that students only memorize formulas used in problem-solving, difficulty in determining the steps of problem work, and difficulty in understanding the meaning of the problem (Imswatama & Nur'aini, 2016)

The authors have reviewed several studies related to dynamic thinking. Previous research on dynamic thinking in mathematics learning related to cognitive processes includes information processing, abstraction (Reed & Vallacher, 2020), restructuring (Bilalić et al., 2021), creativity (Beaty et al., 2018), self-generated thoughts (Denkova et al., 2019), problem-solving (Bilalić et al., 2021), and mental state (Hou et al., 2020; Papera et al., 2019). Interpretation of dynamic thinking is in line with the conceptualization process in mathematics learning. Dynamic thinking or dynamic mindset is identifying the degree of freedom of the mental state. Dynamic thinking allows students to "put a magnifying glass" to "see" some of the necessary details, to change views when emphasizing certain situations or limiting cases, to change the position of the configuration that wants to be stable, or to decompose the whole into resettable pieces (Pelczer et al., 2014).

Dynamic thinking in geometry allows for the development of intuitive methods for problem-solving (Suwarto et al., 2023). Dynamic thinking in geometry enhances teachers' abilities in problem-solving and geometric reasoning, encouraging flexibility and the use of strategies (Uygun, 2022). Dynamic thinking supports habits of inquiry, reasoning, and considering specific cases, as well as generalizing geometric ideas to solve geometry problems (Bülbül & Güler, 2023). Dynamic thinking positively impacts learning outcomes by improving cognitive flexibility (Stad et al., 2018), problem-solving skills and effect on students achievement.

Dynamic thinking involves identifying the relationship between the problem and what is being asked and known in order to solve the problem using a trial and error strategy (Sari et al., 2020). Furthermore, it is a way of thinking that continuously evolves by adopting and adapting new thinking habits, enabling a person to think and respond to challenges critically and creatively (Schöner, 2014). The dynamic thinking process is recommended by Sari et al (2020) in order to identify the relationship between the question and what is asked and what is known to be able to solve problems with a trial and error strategy.

Dynamic thinking is a way of thinking that emphasizes flexibility and adaptability in facing problems (Schoner & Spencer, 2016). Dynamic thinking can foster creativity and innovation in the learning environment, emphasizing the importance of adaptability in education, and can lead to innovative solutions in various contexts (Kelley & Kelley, 2013). According to (Zhu, 2019), dynamic thinking involves many thinking processes such as creative thinking, critical thinking, and strategic thinking. Pamungkas et al (2021) previously showed that a person's mathematical ability is influenced by the aspect of the dynamic thinking process.

College students, who are 18-20 years old, are in the formal-operational cognitive development stage (Piaget), which allows them to think abstractly, logically, and flexibly (Güner & Erbay, 2021). Students who are prospective mathematics teachers, generally are able to think dynamically, but this level of ability is highly dependent on several factors, such as previous learning experience, the learning they undergo, and support from the academic environment (Juniati et al., 2019). Based on previous, there is no research focus on the development of dynamic thinking characteristics in mathematical problem solving. The purpose of the study was to find patterns or characteristics of dynamic thinking of prospective mathematics teachers with high mathematical ability in solving geometry transformation based on indicators that have been developed. The characteristics of dynamic thinking are seen from the tendency of the pattern of indicator changes indicated by the subject when solving the problems.

RESEARCH METHOD

The approach in this research is a qualitative approach that emphasizes the observation of natural dynamic thinking processes solving geometry problems. Qualitative research is research that intends to examine or understand social phenomena from the point of view or perspective of participants about what students experience such as perception behavior, motivation, action, and others holistically and by way of description in the form of words and language in a special context that is natural and by utilizing various natural methods (Berman, 2017).

The subjects in this study were 54 prospective teachers of mathematics Education Study Program of Universitas Tidar, Indonesia. They have taken transformation geometry courses, have good communication skills and have math skills in high categories (proficient). Determination of tiered categories of math ability of prospective math teachers in proficient, sufficient, and novice based on midterm exam scores. The boundaries are reported in Table 1.

Table 1. The boundaries of mathematical ability (MA)

Category	Boundaries	Number
Proficient	$MA \geq 75$	13
Sufficient	$60 \leq MA < 75$	21
Novice	$MA < 60$	20

Purposive sampling was used because researchers only focused on dynamic thinker subjects (Putranta & Jumadi, 2019). In this research, the results of one participant (i.e. subjects S-1) because the data already represent the entire data in the proficient category. The instruments used in this study were tests conducted twice, observation sheets, and interview guidelines. From previous studies, dynamic thinking indicators can be formulated. The dynamic thinking indicators based on four aspects. Indicators that have been inferred in each aspect are presented in Table 2.

Table 2. Description of aspects and indicators of dynamic thinking

Aspect	Indicators	Code
Investigation	1. Find a way to understand what is known on the issue	I1
	2. Find a way to understand the question on the issue	I2
	3. Filter information from problems	I3
	4. Know how to get the information you need	I4
Decomposition	1. Develop a plan to solve the problem	D1
	2. Exercise consideration before solving problems	D2
	3. Break down the problem into more detailed issues	D3
	4. Relate previous concepts to solve problems	D4
Insight	1. Conclude the solution correctly	IS1
	2. Willing to fix failures	IS2
	3. Able to change ways when facing difficult situations	IS3

Aspect	Indicators	Code
	4. Know how to avoid difficulties	IS4
Conceptualization	1. Think about the ways that will be used to solve the problem	C1
	2. Know the reason for the solution used to solve the problem	C2
	3. Thinking of other ways to solve the problem	C3
	4. Choosing an effective and efficient way to solve problems	C4

All instruments have gone through a validation process and are declared valid. The number of validators is two people. Experts in mathematics education, and qualitative research education. The advice of the validator is an editorial fix to the problem. They asked for adjustments to mathematical vocabulary so that it was not multi-interpreted. The problem is presented in Figure 1 and Figure 2.

TRANSFORMATION GEOMETRY - TEST ROUND 1

$A(0,0)$, $s=\{(x,y): x=0\}$, and $t=\{(x,y): y=x\}$.

a. Determine the images under M_tM_s of $B(1,0)$, $C(0,3)$, $D(2,-2)$, and $E(4,2)$.

b. If $P(x,y)$ is any point, determine the coordinates of $M_tM_s(P)$.

c. Express the product M_tM_s as a simple transformation.

Figure 1. Transformation geometry problem for test round 1

TRANSFORMATION GEOMETRY – TEST ROUND 2

If $O(0,0)$, $A(1,0)$, dan $B(6,0)$ are given points:

a. Write equations for s and t such that $M_tM_s = R_{0,90}$

b. If $R_{A,\theta}(B)=(4,4)$ write euations for u dan v such that $M_vM_u = R_{A,\theta}$

Figure 2. Transformation geometry problem for test round 2

The data is explored based on the subject's answer sheet, video recording as the subject solves the problem, interviews, and observation sheets. Test instruments are used to determine the characteristics of dynamic thinking in problem solving. Miles et al (2014) state that activities in qualitative data analysis are conducted interactively and continuously until completion, so that the data becomes saturated. Data analysis through the stage of data reduction, data presentation, and concluding. The data reduction stage in this research begins with the analysis of the dynamic thinking test results. Data reduction is also performed on the interview results with the research subjects by simplifying them into a well-structured and neat language. After the data is reduced, the next step is to present the data. According to Sugiyono (2013), the most commonly used method for presenting data in qualitative research is through text and narrative form. The presentation of data in this study is conducted by presenting the results of the dynamic thinking test work that has been selected as the research subject and the recorded interview results. The third step in qualitative data analysis is drawing conclusions and verification. In this study, the conclusions are based on the results of data analysis collected from dynamic thinking tests and interviews.

RESULTS AND DISCUSSION

Looking at the S-1 answer sheet, observation sheet, interview transcript, and analysis, the S-1 dynamic thinking change pattern in the round 1 test can be described as follows. In solving the round 1 test, S-1 brings up the I1, I2, I3, and I4 indicators. This is demonstrated by S-1 reading questions repeatedly, writing known information, writing questions, and drawing sketches of information. Indicator C1 marked S-1 determines the correct sketch first before writing an answer. Indicators C2, D4, and IS3 appear when the S-1 is thought of other solutions in determining the mirroring asym direction of each point. S-1 was having a bit of confusion so he monitored whether the answer was correct or not. In addition, the S-1 step is carried out to answer the answer. S-1 runs the D3 indicator. This can be seen when the S-1 monitors the completion of the steps of the written Question (a).

In resolving question (b), S-1 begins with confusion to investigate whether the sketches made correspond to the information provided. However, the S-1 seemed motivated by the confusion experienced. This indicates that the S-1 displays the IS1 and IS2 indicators. S-1 realizes that it takes a few steps before determining the mirroring result if it is known that the coordinates are *P(x,y)*. Therefore, S-1 makes plans and considerations to answer the question (b). The plan is to determine the matrix to be used and operate it with that point. An alternative plan is investigating whether the matrix used can be simplified. In determining the results of such mirroring, he knows how to avoid difficulties. By simplifying the matrix used. The answer in investigating whether the results of *Mt.Ms* reflection is very clear and systematic. This indicates that the S-1 works the IS1, D4, and IS2 indicators.

In solving question (c), S-1 displays the C1, C3, and C4 indicators. It is marked that S-1 has determined how to be used before answering a question, linking the results of question (a) and Questions (b) with subsequent questions, and linking some mathematical concepts. He experienced confusion several times, but he was able to show mastery of the material so that he knew every reason for the answers that had been written.

Looking at the S-1 answer sheet, observation sheet, interview transcript, and analysis, the S-1 dynamic thinking change pattern in test 2 can be explained as follows. In solving the round 2 test, S-1 brings up the I1, I2, I3, and I4 indicators. This is demonstrated by S-1 reading questions repeatedly, writing known information, writing questions, and drawing sketches of information. The C1 indicator marked S-1 determines the correct sketch first before writing down the answer and determines the angle between *s* and *t*. C2, D4, and IS3 indicators appear when S-1 uses two methods in determining the s and t equations. He experienced a bit of confusion so he used more than one way to monitor whether the answer was correct or not. Also, this step was taken to give confidence in the answer. S-1 performs the D3 indicator. This is seen when the S-1 monitors the resolution steps of the written Question (a).

In resolving Question (b), S-1 begins with a confusing error. However, he seemed motivated and corrected the mistake. This indicates that he did the IS1 and IS2 indicators. S-1 realizes that it takes a few steps before determining the µ and v equations. To that result, S-1 makes plans and considers answering the question (b). The plan to solve the question (b) is to draw a graph and determine the matrix to be used. In determining which matrix to use, he knows how to avoid difficulties. The method used is to substitute the matrix using trigonometry, not memorization. The solution in determining the equations u and v is written very clearly and systematically. This indicates that the S-1 runs the D1, IS4, and D2 indicators. In solving the question (b), S-1 displays the C1, C3, and C4 indicators. It is marked that S-1 has determined how to be used before answering a question, linking the results of the question (a) with the next question, and linking some mathematical concepts. He was confused several times, but he was able to demonstrate mastery of the material so that he knew every reason for the answers that had been written.

In solving the transformation geometry test both rounds 1 and 2, S-1 performs 16 dynamic thinking indicators namely 4 indicators of investigation aspects, 4 indicators of decomposition aspects, 4 indicators of insight aspects, and 4 indicators of conceptualization aspects. In Question (a), subject performs indicators I1, I2, I3, I4, C2, D4, IS3, D3, in Question (b) he performs indicators IS1, IS2, D1, IS4, and D2 on Questions (c), he performs indicators C1, C3, and C4. Pattern change indicators in the completion of the transformation geometry test both rounds 1 and 2 are presented in Figure 3. The box's colors describe investigation aspects, decomposition, insight, and conceptualization respectively. The circles in each box describe dynamic thinking indicators in every aspect. The direction of the arrows indicates the order in which each indicator changes.

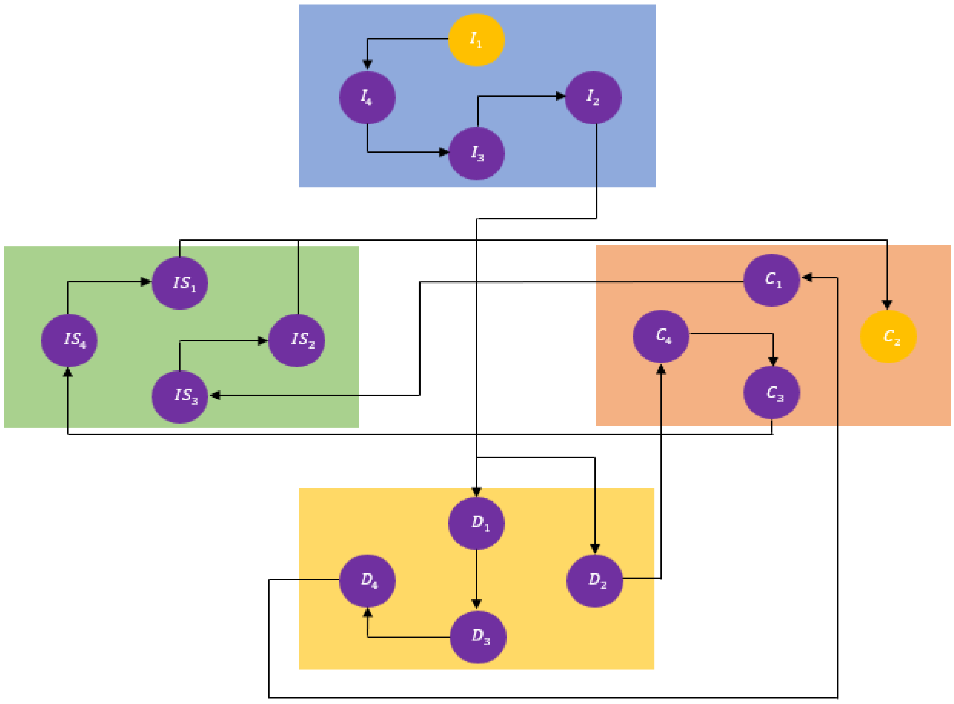

Figure 3. The Dynamic Thinking Pattern

Figure 3 explains the sequence of dynamic thinking pattern changes S-1 in completing both tests. The sequence starts from the orange circle in the blue box and ends in orange circle in the orange box. The order of indicators performed by S-1 is I1, I4, I3, I2, D1, D3, D4, C1, IS3, IS2, D2, C4, C3, IS4, IS1, and C2 (symbol description for Figure 3 can be seen in Table 3).

Table 3. Symbol Description

Symbol	Description
	Investigation Aspect
	Decomposition Aspect
	Insight Aspect
	Conceptualization Aspect
	The beginning and end of dynamic thinking indicator
	Indicator performed
	The direction of change pattern

The results of data analysis show that S-1 perform all dynamic thinking indicators. In both tests, S-1 showed change patterns of I1, I4, I3, I2, D1, D3, D4, C1, IS3, IS2, D2, C4, C3, IS4, IS1, and C2. There are interesting findings that can be revealed. They showed complete and consistent changes in both round 1 and 2 tests. Prospective math teachers who are proficient carry out all dynamic thinking indicators on both tests. This conconsistencies show that prospective math teachers who are proficient show the same pattern of change between the round 1 and 2 tests. With dynamic thinking, students can organize and prepare routine strategies to achieve new knowledge configurations to emerge, develop, and even dissing again (Putranta & Jumadi, 2019).

S-1 begins solving complex problems by taking steps to find and understand how to comprehend what is known in the question based on the available information. S-1 filters that information and then shifts to what is being asked. S-1 does not seem to have difficulty thinking of the method to be used in solving the problem while stating the plan, making considerations, and elaborating on the information found in more detail. Here, S-1 is quite critical in carrying out the dynamic thinking process by engaging in several thinking activities simultaneously, utilizing the relevant information found. Based on the above, the M process is a good initial step, meaning that S-1 has chosen an efficient method and linked it to a concept to obtain a possible solution to the problem. According to

Christiyanto et al (2018) a good planning process and the selection of ideas by applying critical thinking can produce accurate solutions. On the other hand, during the process of considering problem-solving, there was an error in data analysis regarding information related to requirements that had not yet been added. Nevertheless, he is willing to rectify the potential failure, which is also related to his ability to change his approach when facing difficult situations. From that line of thinking, S-1 successfully drew a solution conclusion accompanied by the right reasoning as an answer to the problem-solving. S-1 also processed the problem-solving well by knowing other ways to solve the problem to avoid difficulties. This is in line with Solso's theory that a lack of control and monitoring activity in an individual's thinking process results in difficulties in problem-solving (Chairani, 2015). Thus, it can be said that the characteristics of subject S-1 indicate that he is trying to direct the thinking process to work on possibilities that have not yet occurred in the future, with a focus first on processing the problems currently happening.

Subject S-1 is able to produce dynamic thinking patterns and processes very well, marked by his ability to integrate and organize problem-solving strategies, starting from understanding information and questions, planning and outlining solutions, thinking of effective ways to avoid potential failures in information analysis, to drawing very precise reasoned conclusions. Not much encouragement is needed to guide subject S-1 in processing the flow of complex problem-solving. Just by providing prompting questions during the interview, he was able to demonstrate and explain the problem-solving steps used. Dynamic thinking means the ability of an individual to prepare routine strategies and reconfigure competencies through a combination of intuitive, analytical, and synthetic thinking to address environmental changes (Zhu, 2019). The characteristics that emerge in S-1 show that he is very much in line with how dynamic thinking should be implemented.

Dynamic thinking can be focus on creating (Taylor et al., 2020). Prospective math teachers with dynamic thinking categories can connectively overcome confusion by connecting all math concepts, principles, and processes related to math problems or solutions. Prospective math teachers with dynamic thinking categories overcome confusion by using the logical structure of related concepts. In addition, the ability to draw from the information provided is also an important aspect in solving geometry problems. Studies show that using strategic knowledge about drawing may be one means of improving drawing and modeling skills especially among underachieving students in geometry (Rellensmann et al., 2020). Dynamic thinking reflects a proposition that captures and represents a functional interdependence between two concepts. Dynamic thinking is also a studied and stable pattern of collective activity in which students can systematically generate and modify their problem solving routines to achieve better effectiveness and when a person understands how a complex system changes over time through its interacting parts (Peretz et al., 2023). According to Setiyani et al (2024), considering computational representation in problem-solving means determining the acquisition of the most effective and efficient solutions in dynamic thinking.

CONCLUSION

We have concluded that qualified math teachers have complete and consistent dynamic thinking characteristics. The complete characteristic meaning is that prospective math teachers perform all dynamic thinking indicators on both tests. Consistent traits mean prospective math teachers show the same pattern of change between the round 1 test and the round 2 test. Characteristic patterns are observed based on aspects of investigation, decomposition, insight, and conceptualization. Dynamic thinking significantly enhances learning outcomes by fostering cognitive flexibility, improving problem-solving skills, and enabling better adaptation to changing environments. This is evident across various educational contexts, from classroom teaching to dynamic decision-making tasks and game-based learning environments. Embracing dynamic models and testing methods can lead to more effective educational practices and improved student performance. The implication of this study is that the dynamic thinking process in solving complex problems in advanced students has been maximized so that the adoption of the application of a series of dynamic thinking activities in learning in other courses, especially in the study of geometry for all categories of students.

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AUTHOR CONTRIBUTIONS

Conceptualization, MDP; Methodology, MDP; Validation, SBW, SM, and I; Formal Analysis, SBW, SM, and I; Investigation, MDP; Data Curation, MDP; Writing – Original Draft Preparation, MDP; Writing – Review & Editing, MDP; Visualization, MDP; Supervision, SBW, SM, and I; Project Administration, MDP.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

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