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Focuses of students' creativity in constructing quadratic functions through pattern generalization

Alexander Hendro Risit, Sudirman *, I Made Sulandra

Department of Mathematics, Universitas Negeri Malang, East Java, Indonesia

*Correspondence: sudirman.fmipa@um.ac.id

Abstract

Creativity is the ability of students to generate new ideas based on their initial situation. The focus of creativity in this study is on mathematical objects that capture students' attention when solving creativity test problems and producing creative solutions. This research aimed to identify student creativity's focus in constructing quadratic functions through pattern generalization. This qualitative case study, grounded in Silver's creativity framework, involved two creative 10th-grade students from a high school in Malang City. Data were gathered through tests and interviews and analyzed using data reduction, data presentation, and conclusion techniques. The findings revealed three focuses of student creativity in constructing quadratic functions through pattern generalization: focusing on intact squares or rectangles in considering the pattern generalization, focusing on separate shapes in considering pattern generalization and focusing on intersecting square shapes in considering pattern generalization. This study has not been conducted before, therefore filling a research gap and laying the foundation for a deeper understanding of how visual patterns foster students' creativity and enhance their comprehension of visual and symbolical quadratic functions.

Keywords: creativity; focus of creativity; pattern generalization; quadratic function

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Introduction

Creativity plays an important role in higher-order mathematical thinking, making it essential to cultivate in students (Vale & Barbosa, 2015; Wahyudi et al., 2020). This aligns with the goals of the Indonesian Independent Curriculum, which highlights creativity as a key indicator in the Pancasila Student Profile that needs to be developed (Kemendikbud, 2020), as well as one of the 21st-century skills for future success (Kemendikbud, 2022; Zayyinah et al., 2022). Mathematics educators and researchers concur that fostering students' mathematical creativity is paramount (Amado et al., 2018; Leikin & Sriraman, 2016; OECD, 2019), as it enhances students' abilities (Leikin & Elgrably, 2022).

The creativity framework employed in this study is based on Silver's (1997) model, which identifies three aspects of creativity in problem-solving: fluency, flexibility, and novelty. These dimensions have been widely used in mathematics education studies (Lisa et al., 2018; Triutami et al., 2021). In this study, fluency was assessed by students' ability to produce at least two different and correct answers, flexibility by students' ability to produce at least two variations of ideas and be correct, and novelty by students' ability to provide completely new mathematical ideas based on their thinking. These three aspects apply to all question items so that each question requires students to demonstrate their ability to produce different and correct answers, variations of ideas, and new ideas from the students.

Several studies have advocated for using multi-solution problem-solving to develop students' creativity (Firdaus. et al., 2016; Silver, 1997; Stupel & Ben-Chaim, 2017). Multi-solution problem-solving is often related to non-routine problems (Schoevers et al., 2022) and is suitable for describing or categorizing students' creative thinking (Kholid et al., 2024). Non-routine problems are problems that students have never encountered before and require them to use facts, procedures, and skills to solve them (Schoevers et al., 2022). Non-routine problems are also challenging, which encourages students to use different heuristic approaches to solve them (Heffernan & Teufel, 2018; Sudia & Lambertus, 2017). On the one hand, Graf (2018) noted that visual pattern is still seldom used to represent quadratic functions, unlike algebraic equations or graphs. As a consequence, visual patterns represent something new and non-routine for students, allowing them to explore their creativity.

One task used to measure students' mathematical creativity is problem-solving involving constructing quadratic functions through the visual pattern generalization. Generalizing visual patterns offers opportunities for students to develop connections between algebraic and geometric representations. A deep understanding of the quadratic function involves the relationship between the concept of "x squared" and the geometric meaning of "square", as well as the ability to visualize that a quadratic expression can be factored when it can be represented as a rectangle by relating a binomial expression to the concept of the area of a rectangle (Kajander, 2018). Visualization-based problem-solving has been shown to enhance students' comprehension (Vale et al., 2018; Zbiek & Heid, 2018).

Quadratic functions, which is commonly represented by the equation $f(x) = ax^2 + bx + c$ for $a, b, c \in \mathbb{R}$ and $a \neq 0$, has various forms of representation that students need to understand to avoid assuming that the quadratic function is just a series of complicated procedures or tricks

(Wasserman, 2018). Quadratic functions provide an important foundation for understanding many algebraic concepts, such as variables and parameters and nonlinear rates of change. However, students still face difficulties in connecting algebraic concepts, particularly in understanding the relationships among variables, parameters, and the nonlinear rate of change in quadratic functions (Wilkie, 2024). For instance, students struggle to grasp how changes in parameter values affect the width and position of a parabolic curve on a graph. criticized traditional approaches to introducing quadratic functions, which often start with abstract algebraic equations. On the other hand, Schwartz dan Yerushalmy (1992) recommended connecting various representations of functions earlier in the learning process. In this case, using visual patterns can be a more effective approach to instilling the concept of quadratic functions in students.

Several studies relate to visual patterns, such as the study by Erdogan & Gul (2022), which used visual patterns to see the generalization strategies used by gifted students in completing the visual patterns and the study by Wilkie (2019, 2024), which used visual patterns to help students connect visual and algebraic reasoning and understand the concept of quadratic functions. Unlike prior research, this study discussed the focus of students' creativity in constructing quadratic functions by generalizing visual patterns. This study is also different from other creativity studies because research related to creativity has never been linked to symbolic generalization and discusses more geometry (de Vink et al., 2023; Gridos et al., 2022; Palwa et al., 2024; Schoevers et al., 2022), story problems (Sari & Hidayati, 2024; Shalahuddin et al., 2019), or statistical problems (Fadilla et al., 2024; Ferdiani & Harianto, 2024).

The characteristics, traits, patterns, or conceptual objects students pay attention to are called focus centers (Wilkie, 2024). Wilkie (2024) also stated that these focus centers can be observed through written answers or sentences spoken by students. In this study, the focus of creativity involved mathematical objects that students pay special attention to when solving creativity test problems and generating creative solutions. These objects are like geometric shapes or patterns that are the starting point for students to innovate. Students' attention to these mathematical objects affects not only their thinking but also their ability to generate creative solutions to the problems they face. This will encourage students to be more active and creative in solving problems with many solutions and improve their ability to solve mathematical problems innovatively.

Specifically, this study aimed to identify the focus of students' creativity in constructing quadratic functions through the generalization of visual patterns. Using this approach, the researcher wanted to understand the focus of students' creativity when constructing quadratic functions. This is in line with Kholid et al. (2024) that students can better understand mathematical concepts through creative thinking. Therefore, identifying students' creativity in constructing quadratic functions through visual pattern generalization enriches their understanding of related concepts and prepares them for complex challenges.

Methods

This qualitative case study was conducted in a natural setting, with the researcher directly interacted with the data source. The observed cases in this research were the creative focuses demonstrated by students as they constructed quadratic functions through the generalization of visual patterns.

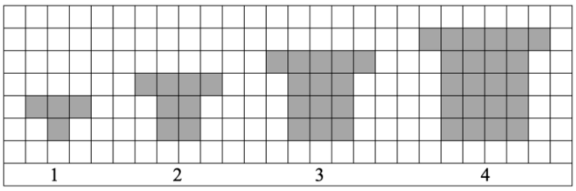
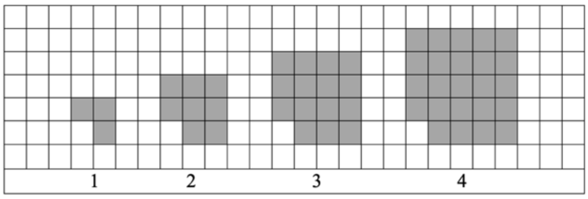
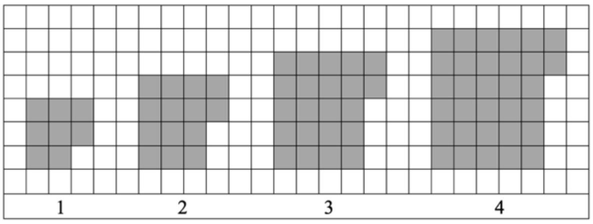
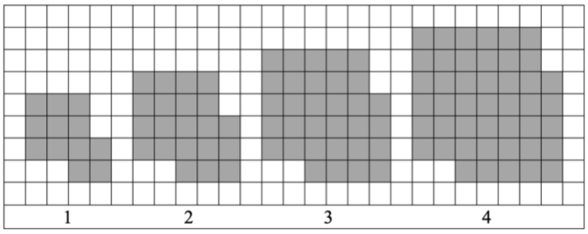
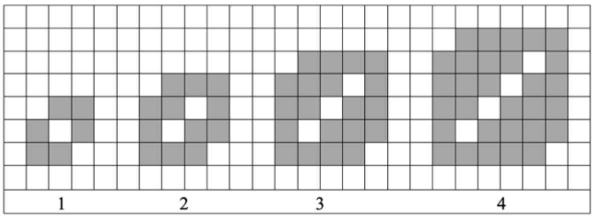
The subjects of this study were two creative students selected from twenty 10^{th} -grade high school students in Malang City. They were coded as S1 and S2. The selection was made using a purposive sampling technique. These two students were chosen as research subjects because they demonstrated fluency, flexibility, and novelty in solving the five creativity test questions (Table 1).

Table 1. Criteria for selecting research subjects based on creativity aspects

Student	Creativity Aspects in each question															Category
	Fluency					Flexibility					Novelty					
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
1	3	3	2	3	2	3	3	2	3	2	3	3	2	3	2	Creative
2	3	3	3	3	2	3	3	3	3	2	3	3	3	3	2	Creative
3	2	2	1	1	1	2	2	1	1	1	2	2	1	1	1	Non-creative
4	1	1	2	0	0	1	1	2	0	0	1	1	2	0	0	Non-creative
5	2	1	1	1	0	2	1	1	1	0	2	1	1	1	0	Non-creative
6	2	2	1	1	1	2	2	1	1	1	2	2	1	1	1	Non-creative
7	2	1	1	0	0	2	1	1	0	0	2	1	1	0	0	Non-creative
8	1	1	2	0	0	1	1	2	0	0	1	1	2	0	0	Non-creative
9	3	2	1	1	1	3	2	1	1	1	3	2	1	1	1	Non-creative
10	1	2	1	1	0	1	2	1	1	0	1	2	1	1	0	Non-creative
11	2	2	1	1	1	2	2	1	1	1	2	2	1	1	1	Non-creative
12	1	1	2	0	0	1	1	2	0	0	1	1	2	0	0	Non-creative
13	2	2	1	1	1	2	2	1	1	1	2	2	1	1	1	Non-creative
14	2	2	1	1	0	2	2	1	1	0	2	2	1	1	0	Non-creative
15	1	2	1	1	1	1	2	1	1	1	1	2	1	1	1	Non-creative
16	2	1	1	1	0	2	1	1	1	0	2	1	1	1	0	Non-creative
17	1	2	2	1	0	1	2	2	1	0	1	2	2	1	0	Non-creative
18	3	2	1	0	1	3	2	1	0	1	3	2	1	0	1	Non-creative
19	1	2	2	1	0	1	2	2	1	0	1	2	2	1	0	Non-creative
20	2	1	1	0	0	2	1	1	0	0	2	1	1	0	0	Non-creative

The researchers served as the primary instrument, while the creativity test functioned as a supporting instrument. The creativity test questions comprised five distinct visual pattern questions on each number (Table 2) in the form of open-ended questions.

Table 2. Creativity test questions

No.	Questions	Visual pattern forms
1	Based on the visual pattern on the side, provide as many ways as possible to determine the quadratic function formula $f(n)$, where n is the nth visual pattern and $f(n)$ the number of small grey squares in the nth visual pattern.	
2		
3		
4		
5		

This study employed a creativity test and interviews to collect data. Prior to data collection, the test was validated (Tutticci et al., 2017). A mathematics professor at Universitas Negeri Malang validated the creativity test questions. The five creativity test questions presented different visual pattern forms, allowing for the assessment of students' creativity. Simultaneously, individual interviews were conducted using a semi-structured format to explore students' thought processes, clarify their responses in the creativity test, and ensure data validity by cross-referencing their written answers. Furthermore, data analysis refers to Miles & Huberman (2014) which involves data reduction, data presentation, and conclusion. Source triangulation was employed to ensure data validity, with student answers cross-referenced with interview responses to confirm consistency.

Results

This study identified three key findings regarding the focuses students' creativity in constructing quadratic functions: (1) focusing on intact square or rectangular shapes in considering pattern generalization, (2) focusing on separate shapes in considering pattern generalization, and (3) focusing on intersecting square shapes in considering pattern generalization. The following explain the three findings, below is a description showing three findings related to student focus when constructing quadratic functions.

Student creativity focusing on intact square or rectangular shapes in considering pattern generalization

What is meant by focusing on an intact square or rectangle when considering the generalization of patterns is that when solving problem 1, students focus on the intact rectangle as an example taken from answer number 1 from S1's answer sheet, as shown in Figure 1 below.

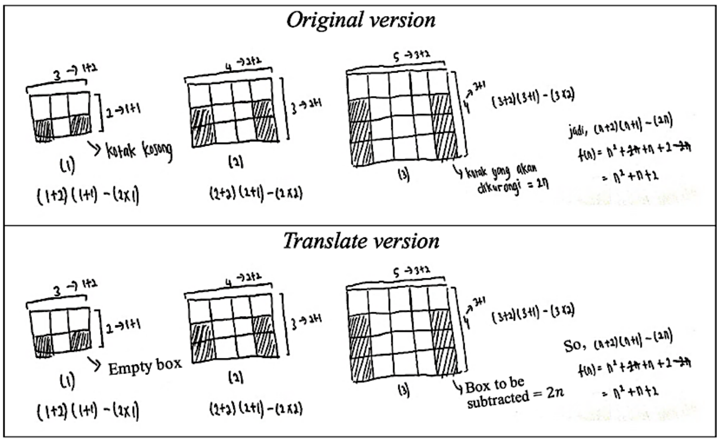


Figure 1. An example of S1 focusing on a complete rectangle

Based on Figure 1, S1 considered that the small white squares were inside a rectangle. This means that when focusing on the whole rectangle, the small white squares were part of it. Next, S1 only needed to subtract the small shaded squares because they were not included in the initial pattern to obtain a symbolic generalization of the quadratic function form matching the actual pattern.

In the picture, it can be seen that S1 made three rectangular pictures with different sizes: the first picture with 3×2 because the S1 saw the first picture as the visual pattern number 1 so 3×2 was stated in the form of $(1 + 2)(1 + 1)$, the second picture with 4×3 because the S1 saw the second picture as the visual pattern number 2, and therefore 4×3 was stated in the form of $(2 + 2)(2 + 1)$, and the third picture with 5×4 because the S1 saw the third picture was the visual pattern number 3 so 5×4 was stated in the form of $(3 + 2)(3 + 1)$. This is following the statements expressed by S1 in the interview excerpt below.

Researcher : *Why did you replace number* 3 *with* $(1 + 2)$*?*

S1 : *Because of the visual pattern number* 1*, number* 3 *can be replaced with (*$1 + 2$*).*

Next, because the small shaded squares were not included in the initial pattern, it was necessary to reduce each pattern of the image so that from the visual pattern number 1 with the 2 small shaded squares as expressed in the form of (1×2), it was obtained $(1+2)(1+1)-(1 \times 2)$, from the visual pattern number 2 with the 4 small shaded squares as expressed in the form of (2×2), it was obtained$(2+2)(2+1)-(2 \times 2)$, and from the visual pattern number 3 with the 6 small shaded squares as expressed in the form of (3×2) it was obtained $(3+2)(3+1)-(3 \times 2)$. This is following the statements expressed by S1 in the interview excerpt below.

Researcher : *Why did you reduce* (1×2) *of visual pattern number* 1*?*

S1 : *There are two squares (pointing to the small shaded squares), so in the visual pattern number* 1*, I replace* 2 *with* (1×2).

After looking at the three initial patterns as a whole, the S1 stated that the visual pattern number n must be $(n+2)(n+1)-2n$ or the form of the quadratic function is $f(n)=n^2+n+2$.

When completing problems 2, 3, 4, and 5, students focused on the intact square. For instance, consider S2's response, particularly question number 2, as shown in Figure 2 below.

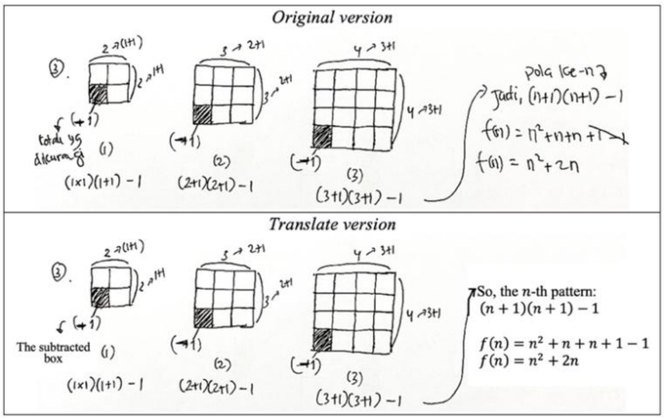


Figure 2. An example of S2 focusing on the intact square

Based on Figure 2, S2 considered that the small white squares were inside a whole square. This means that when focusing on the whole square, the small white squares were part of the whole square. Next, S2 just needed to subtract the small shaded square because it was not included in the initial pattern to obtain a symbolic generalization of the quadratic function form that matches the actual pattern.

In the picture, three square-shaped images have different sizes: the first image is 2×2 because the S2 saw the first image as the visual pattern number 1 so 2×2 is expressed in the form $(1+1)(1+1)$, the second image is 3×3 because the S2 saw the second image as the visual pattern number 2 so 3×3 is written in the form of $(2+1)(2+1)$. The third image is 4×4 because the S2 saw the third image as the visual pattern number 3 so 4×4 is written in the form of $(3+1)(3+1)$. This is following the statements expressed by S2 in the interview excerpt below.

Researcher : *Why did you replace number* 2 *with* $(1+1)$*?*

S2 : *Because of the visual pattern number* 1, *so* 2 *can be replaced with* $1+1$.

Furthermore, because only one small shaded square is not included in the initial pattern, it is necessary to subtract each visual pattern so that from the visual pattern number 1 it was obtained $(1+1)(1+1)-1$, from the visual pattern number 2 it was obtained $(2+1)(2+1)-1$, and from the visual pattern number 3 it was obtained $(3+1)(3+1)-1$. This follows the statement expressed by the S2 in the interview excerpt below.

Researcher : *Why did you subtract number* 1 *in each visual pattern?*

S2 : *I subtracted it because this one square (pointing to the small shaded square) is not included in the initial pattern.*

After looking at the three initial patterns as a whole, the S2 stated that the visual pattern number n must be $(n+1)(n+1)-1$ or the quadratic function is $f(n)=n^2+2n$.

Student creativity focusing on separate shapes in considering pattern generalization

What is meant by focusing on separate shapes in considering pattern generalization is that when solving problems 1, 2, 3, 4, and 5, students focus their attention on several separate shapes, as an example taken from answer number 3 of S1's answer sheet is shown in Figure 3 below.

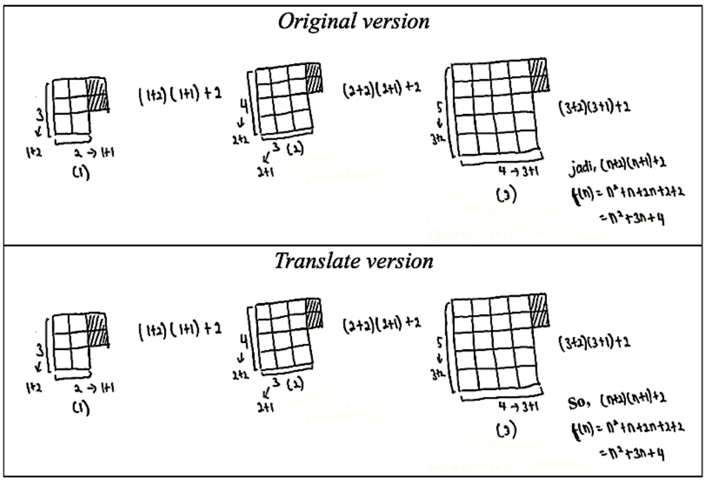


Figure 3. An example of S1 focusing on separate shapes

Based on Figure 3, S1 considered that the shape can be divided into separate parts. This means that the visual pattern can be divided into several planes, such as a white rectangle and a shaded rectangle. Next, S1 only needed to understand how each divided plane could remain the same or increase from the visual pattern number 1 to the visual pattern number 3. The results of the symbolic generalization of each plane were then added up to obtain a symbolic generalization of the quadratic function form that corresponded to the actual pattern.

In the picture, there are three images with different sizes: the first image consists of a white rectangle of 2×3 because the S1 saw image number 1 as the visual pattern number 1 so 2×3 was written in the form of $(1+1)(1+2)$ and there were two shaded rectangles so from the visual pattern number 1 , it was obtained $(1+1)(1+2)+2$, the second image consists of white rectangle of 3×4 because the S1 saw the second image as the visual pattern number 2 so 3×4 was written as $(2+1)(2+2)$ and there were 2 shaded rectangles so from the visual pattern number 1 it was obtained $(2 + 1)(2 + 2) + 2$, and the third image consists of white rectangle of 4×5 because the S1 saw the third image the visual pattern number 3 and therefore 4×5 was written in the form of $(3 + 1)(3 + 2)$ and there were 2 shaded rectangles so from the visual pattern number 1 it can be obtained $(1 + 1)(1 + 2) + 2$. This follows the statements expressed by S1 in the interview excerpt below.

Researcher : *Why did you replace* 2 *with* $(1 + 1)$ *in the white rectangles?*

S1 : *Because the visual pattern is number* 1*, so* 2 *can be replaced with* $1 + 1$.

After looking at the three initial patterns as a whole, the S1 stated that the visual pattern number n must be in the form of $(n + 1)(n + 2) + 2$ or the quadratic function was $f(n) = n^2 + 3n + 4$.

Student creativity focusing on intersecting square shapes in considering pattern generalizations

Focusing on the intersecting squares in considering the generalization of patterns means that when solving question number 4, S2 focused on 2 intersecting squares, as an example can be seen in the Figure 4 below.

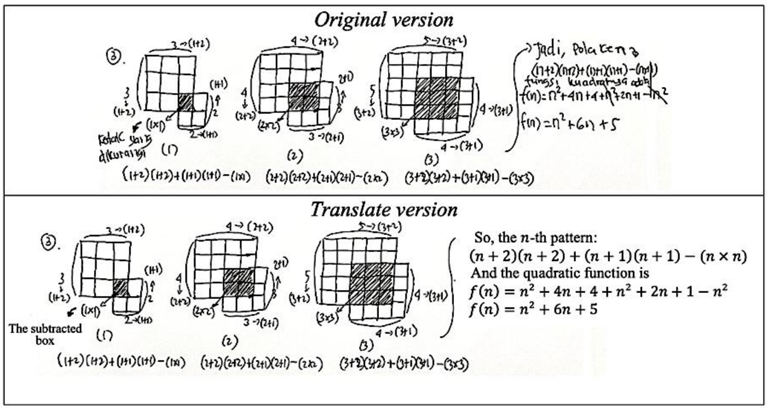


Figure 4. An example of S2 focusing on intersecting squares

Based on Figure 4, S2 considered the first and second shapes as each seen as intersecting squares. Next, S2 only needed to subtract the shaded squares because they had been calculated twice to obtain a symbolic generalization of the quadratic function form matching the actual pattern.

In the picture, there are three images with different sizes: the first image consists of a large white square of 3×3 and a small white square of 2×2 because the S2 saw the first image as the visual pattern number 1 so 3×3 was written as $(1 + 2)(1 + 2)$ and 2×2 was written as $(1 + 1)(1 + 1)$, the second image consists of a large white square of 4×4 and a small white square of 3×3 because the S2 saw the second image as the visual pattern number 2 so 4×4 was written as $(2 + 2)(2 + 2)$ and 3×3 was written as $(2 + 1)(2 + 1)$, and the third image consists of a large white square of 5×5 and a small white square of 4×4 because the S2 saw the third image as the visual pattern number 3 so 5×5 was written as $(3 + 2)(3 + 2)$ and 4×4 was written as $(3 + 1)(3 + 1)$. This follows the statement expressed by the S2 in the interview excerpt below.

Researcher : *Why did you replace* 3 *with* $(1+2)$ *in the large white square?*

S2 : *Because it is the visual pattern number* 1, *so* 3 *can be replaced with* $(1+2)$.

Next, because the shaded square has been counted twice, it is necessary to subtract it from each pattern so that from the visual pattern number 1 with the shaded square of 1×1 it was obtained $(1+2)(1+2)+(1+1)(1+1)-(1\times 1)$, from the visual pattern number 2 with the shaded square of 2×2 it was obtained $(2+2)(2+2)+(2+1)(2+1)-(2\times 2)$. From the visual pattern number 3 with the shaded square of 3×3 it was obtained $(3+2)(3+2)+(3+1)(3+1)-(3\times 3)$. This follows the statement expressed by the S2 in the interview excerpt below.

Researcher : *Why did you subtract* (1×1) *in the visual pattern number* 1*?*

S2 : *Because the shaded square in the center was* 1, *so I replaced* 1 *in the visual pattern number* 1 *with* (1×1), *likewise the next visual pattern only looked at the size of the shaded square.*

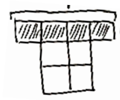
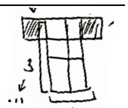
After looking at the three initial patterns as a whole, the S2 stated that the visual pattern number n must be in the form of $(n+2)(n+2)+(n+1)(n+1)-(n\times n)$ or the form of quadratic function was $f(n)=n^2+6n+5$.

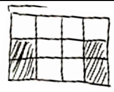
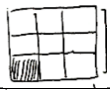
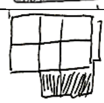
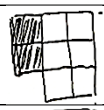
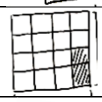
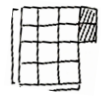
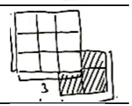
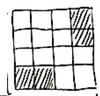
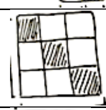
The following presents details of the focuses of creativity in both subjects, helping readers understand more deeply the role of S1 and S2 creativity in constructing quadratic functions in each creativity test questions.

The focus of S1's creativity in constructing quadratic functions in each creativity test question item

In solving creativity test questions, S1 did not always focus on complete squares or rectangles. However, it used a combination of two focuses: (1) focusing on the whole square or rectangle, and (2) focusing on the separate shapes in considering the pattern generalization. When completing question number 1, S1 focused on the whole rectangle and focused on the separate shapes in considering the pattern generalization. Similar things also happened when solving problems 2, 3, 4, and 5. S1 focused on the intact square and the separate shapes when considering pattern generalization. Overall, the combination of S1's creativity focuses that describe fluency, flexibility, and novelty can be seen in Table 3 below.

Table 3. Aspects of creativity, focus, and examples of S1 answers in 5 creativity test questions

Question Number	**Aspects of creativity**			**Focus**	**Examples**
	Fluency	**Flexibility**	**Novelty**		
1	3	3	3	(1) S1 focusing on separate shapes in considering pattern generalization	
				(2) S1 focusing on separate shapes in considering pattern generalization	

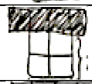
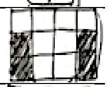
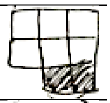
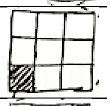
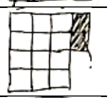
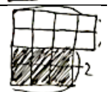
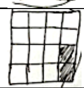
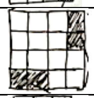
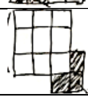
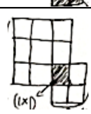
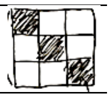
Question Number	Aspects of creativity			Focus	Examples
	Fluency	Flexibility	Novelty		
				(3) S1 focusing on intact rectangles in considering the pattern generalization	
2	3	3	3	(1) S1 focusing on intact squares in considering the pattern generalization	
				(2) S1 focusing on separate shapes in considering pattern generalization	
				(3) S1 focusing on separate shapes in considering pattern generalization	
3	2	2	2	(1) S1 focusing on intact squares in considering the pattern generalization	
				(2) S1 focusing on separate shapes in considering pattern generalization	
4	3	3	3	(1) S1 focusing on separate shapes in considering pattern generalization	
				(2) S1 focusing on intact squares in considering the pattern generalization	
				(3) S1 focusing on separate shapes in considering pattern generalization	
5	2	2	2	(1) S1 focusing on intact squares in considering the pattern generalization	
				(2) S1 focusing on separate shapes in considering pattern generalization	

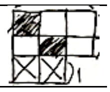
The researcher conducted an interview to confirm whether S1 faced challenges while solving the given problems. S1 responded, "*This problem was new to me, so I had to think harder to find possible answers*." S1 further stated that the problem was challenging. The researcher then asked whether there were other variations of ideas that could be made from the problem, and S1 answered, "*I think there are still other possible ideas for this problem.*" All mathematical ideas presented by S1 were entirely his own, without any help from other students. S1 also stated that the problem was new to him. When the researcher asked whether S1 had ever encountered a similar problem, S1 replied, "*This is the first time I have worked on a problem like this. The visual pattern is unique, and it turns out to be related to the quadratic function.*"

The focus of S2's creativity in constructing quadratic functions in each creativity test question item

In addressing each creativity test questions item, S2 did not always focus on the complete square or rectangle. Instead, S2 used a combination of three focuses: (1) focusing on the whole square or rectangle, (2) focusing on the separate shapes, and (3) focusing on the intersecting square shapes when considering the pattern generalization. For problem 1, S2 focused on the intact rectangle and separate shapes to derive the pattern generalization. The same approach was observed in problems 2, 3, and 5, where S2 focused on the intact square and the separate shapes to consider the pattern generalization. However, when solving problem number 4, S2 employed all three focuses: focusing on the intact square, focusing on the separate shapes, and focusing on the intersecting square shapes in considering the pattern generalization. Overall, Table 4 below illustrated the combination of S2 creativity focuses depicting fluency, flexibility, and novelty.

Table 4. Aspects of creativity, focus, and examples of S2 answers in 5 creativity test questions

Question Number	Aspects of creativity			Focus	Examples
	Fluency	Flexibility	Novelty		
1	3	3	3	(1) S2 focusing on separate shapes in considering pattern generalization	
				(2) S2 focusing on separate shapes in considering pattern generalization	
				(3) S2 focusing on intact rectangles in considering the pattern generalization	
2	3	3	3	(1) S2 focusing on separate shapes in considering pattern generalization	
				(2) S2 focusing on separate shapes in considering pattern generalization	
				(3) S2 focusing on intact squares in considering the pattern generalization	
3	3	3	3	(1) S2 focusing on separate shapes in considering pattern generalization;	
				(2) S2 focusing on separate shapes in considering pattern generalization;	
				(3) S2 focusing on intact squares in considering the pattern generalization;	
4	3	3	3	(1) S2 focusing on intact squares in considering the pattern generalization;	
				(2) S2 focusing on separate shapes in considering pattern generalization;	
				(3) S2 focusing on intersecting square shapes in considering pattern generalization;	
5	2	2	2	(1) S2 focusing on intact squares in considering the pattern generalization;	

Question Number	Aspects of creativity			Focus	Examples
	Fluency	Flexibility	Novelty		
				(2) S2 focusing on separate shapes in considering pattern generalization;	

The researcher conducted an interview to confirm whether S2 faced challenges while solving the given problems. S2 responded, "*Initially, I took a few minutes to understand the problem, and after fully comprehending it, I explored possible answers. This problem was challenging* " When asked if other variations of solutions could be generated from the problem, S2 replied, “*There are still other variations.*” All mathematical ideas presented by S2 were completely self-generated, without assistance from other students. S2 also confirmed that the problem was unfamiliar, stating “*I have never solved a problem like this before, Sir. This is the first time I've seen a problem like this*.” when asked if S2 had previously encountered a similar problem.

Discussion

Overall, the students' responses exhibited fluency in answering the five creativity test questions from the creativity focuses. It aligns with the fluency aspect, which suggests that students are fluent if they can provide at least two different and correct answers. Fluency is the ability to generate multiple ideas quickly in response to open-ended questions (Ayua et al., 2023; Trisnayanti et al., 2020). Triutami et al. (2021) similarly noted that fluency in solving open-ended problems is demonstrated when students offer several possible interpretations or answers.

In addition, both students exhibited flexibility in their responses to five creativity test questions. Students are considered flexible when they produce at least two correct variations of ideas. Flexibility is a cognitive process reflecting a student's ability to easily shift approaches or perspectives (Weiss & Wilhelm, 2022). According to Chiu et al. (2019), flexibility entails solving problems from various perspectives. Anggorowati et al. (2024) also emphasized that flexibility involves providing diverse solutions based on information drawn from the problem.

Both students fulfilled the novelty aspect by answering five creativity test questions. Both students provided novel responses without collaborating. The creative ideas stemmed entirely from the students' thoughts without guidance from established theories. Students provide truly new mathematical ideas based on their thoughts. The ability of students to solve problems using new or unconventional solutions that align with their developmental stage or knowledge level is referred to as novelty in problem-solving (Triutami et al., 2021). Anggorowati et al. (2024) further defined novelty as the skill of delivering unique and innovative solutions.

Despite its contributions, this study has several limitations that warrant consideration. It specifically focuses on identifying the focus of students' creativity in constructing quadratic functions through visual pattern generalization without exploring other aspects, such as potential correlations between creativity and algebraic thinking or creativity with visual thinking. More intricate factors, including student personality traits or learning styles, should be examined by integrating creativity with algebraic thinking.

Nevertheless, this study underscores mathematical creativity's significant role in enhancing students' abilities and comprehension. The creativity test questions revealed in this study proved to be effective tools for probing students' creative potential. Unfortunately, teachers usually only prioritize assignments with a low difficulty level to ensure that students achieve the minimum completion criteria (Siswono, 2018). This practice limits students' comprehensive understanding of mathematical concepts and hampers their ability to develop ideas fully. Students require assistance in enhancing their creative abilities through creative problem-solving tests. Yee et al. (2015) suggested that creativity tests can enhance students' thinking skills, enabling them to overcome challenges in generating innovative ideas.

Conclusion

The primary question of this article is to examine student creativity's focus in constructing quadratic functions through visual pattern generalization. The study identified three main focuses of student creativity in constructing quadratic functions through pattern generalization: focusing on intact squares or rectangles in considering pattern generalization, focusing on separate shapes in pattern generalization, and focusing on intersecting square shapes in pattern generalization. Both S1 and S2 employed a combination of these focuses in solving creativity test questions. S1 combined a focus on intact squares or rectangles in considering the pattern generalization and on separate shapes in considering pattern generalization, whereas S2 integrated all three focuses, as previously explained.

This study is limited by the small number of participants, affecting its findings' generalizability. Nevertheless, it is significant because it highlights how students' creativity in constructing quadratic functions through visual pattern generalization enables them to understand them better, formulate strategies, and solve complex problems. Beyond specific findings, this study provides insights into the role of creativity in mathematical problem-solving. As an essential component of mathematical reasoning and a key 21st-century skill, understanding how students generalize visual patterns to construct quadratic functions offers a new perspective in mathematics education. Additionally, this study addresses a research gap in symbolic generalization related to quadratic functions and is expected to enrich academic literature while supporting the development of students' mathematical creativity.

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Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this manuscript.

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Author Contributions

Alexander Hendro Risit: Conceptualization, writing - original draft, formal analysis, methodology, editing, and visualization; **Sudirman:** Conceptualization, review, formal analysis, and methodology; **I Made Sulandra:** Validation and supervision.

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