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Research Article

Middle School Students' Math Experiences and Creative Skills with Op Art

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Abstract – The present research aimed to explore the perspectives and creations of middle school students regarding Op Art design activities. Four Op Art activities were implemented in this study. The students' opinions were collected through an observation form, an open-ended questionnaire, and individual interviews. Content analysis was employed to analyze the students' responses. The students' Op Art designs were evaluated using a creativity diamond model comprising frequency, flexibility, originality, and elaboration competencies. Three themes emerged from the students' Op Art design process: mathematical expression, visual expression, and creativity skills. Similarly, six themes were identified from the students' viewpoints on Op Art designs: general perspectives on Op Art designs, aspects of Op Art design activities that were liked or disliked, the success of the created designs, exciting aspects of the Op Art activity, perspectives on the use of Op Art activities in mathematics lessons, and instructive aspects of Op Art activities. This study suggests that Op Art activities have the potential to enhance students' creativity, particularly flexibility competencies, and foster an appreciation for the process rather than solely focusing on the end result.

Key words: creativity, experience, geometry, middle school students, Op Art.

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Introduction

Geometry is a branch of mathematics consisting of mathematical shapes and formulas. However, geometry is also heavily associated with art. Geometry and art can always be considered together as inherently intertwined (Heskett, 2007). Since geometry is rich in shapes, lessons emphasizing the relationship between geometry and art can be created (Perignat & Katz-Buonincontrö, 2019; Starko, 2013). Recent studies have shown that the inclusion of art, especially in geometry courses, increases the interest and curiosity of students in learning mathematics (Hesket, 2007; Perignat & Katz-Buonincontrö, 2019). Different kinds of art, such as visual art, origami, fractal, and storytelling, can be used in a wide range of school levels, from kindergarten to high school education, to teach mathematical concepts (Brewer, 1999; Hesket, 2007; Mercat et al., 2017).

Optical Art, Op Art, is a visual art that uses geometric shapes, lines, and colors to create an eye illusion, movement, depth, or vibration (Parola, 1996). Op Art is also abstract art and creates optical illusions in the eyes of the viewer (Parola, 1996; Zanker & Walker, 2004). With the invention and development of movies, television, and the internet in the 20th century, the concept of motion in the visual arts was discussed, and thus kinetic art emerged (Riley, 1999). Kinetic art formed the basis of Op Art, and thus Bridget Riley, one of the first Op Art artists, created illusions that give a sense of movement to still pictures with black and white drawings (Riley, 1999; Solso, 1994). In addition, Op Art attracted attention by integrating concepts such as depth and movement into two-dimensional paintings. Thus, with Op Art, illusions, that is, pictures that evoke a sense of movement, have attracted the attention of psychologists, artists, and many people from different fields (Parola, 1996; Solso, 1994). Today, Op Art activities have been used in mathematics lessons to show the integration of geometry and art, and arouse students' interest (Brewer, 1999; Heskett, 2007; Mercat et al., 2017).

Op Art is often associated with creativity due to its manipulation of visual perception, exploration of form and space, and interactivity (Mercat et al., 2017). Although there are many definitions of the word creativity, the most frequently used concepts in these definitions are genuine, original, and unique (Perkins, 1988; Starko, 2013). For example, Perkins (1988) stated that an innovative product should be original and unique. Creativity is an essential skill for people to produce original ideas. Although creativity was a skill that was considered essential to produce new products or maintaining intense competition in workplaces and companies, today, it is expected that students experience and develop this skill from the first years of education (MEB, 2018). Creativity is also an essential skill that students need to develop in STEAM (Science, Technology, Engineering, Art, and Mathematics) education (Akgündüz et al., 2015; Daugherty, 2013).

Upon reviewing the extant literature pertaining to Op Art, it becomes evident that Op Art has predominantly served as an instructional instrument for imparting various geometric concepts to students within the educational context. To illustrate, the study by Brewer in 1999 explored the use of Op Art visuals as an educational tool for primary school students. The aim was to enhance their understanding of straight lines like vertical, horizontal, perpendicular, parallel, and intersecting lines, as well as the general properties of geometric shapes like rectangles, squares, and ovals. Heskett's work in 2007 showed that Op Art offers students an opportunity to explore geometric concepts in visual art by examining various Op Art works. Some Op Art pieces allowed students to explore symmetry, depth perception, and basic geometry definitions like perspective and similarity. The study also highlighted the potential for students of all grade levels to practice creativity skills in mathematics, emphasizing the relationship between mathematics and creativity in problem-solving and idea development. Thus, Op Art was seen as a valuable tool for promoting creativity in education, as it involves a creative process in addition to the final artistic product.

The studies above show that Op Art can be used as a STEAM activity to improve creativity. However, in the literature on the subject, no research examines the views and experiences of middle school students on the creation process of Op Art. Therefore, examining the views and experiences of middle school students on the Op Art design process is significant. It contributes to the ideas that can be used to develop creativity in mathematics classes. In line with the above reasons, this study examines how middle school students experience their creativity skills while reproducing shapes designed by famous Op Art artists and relating the mathematical concepts in these designs.

The research questions of this study are stated below.

1. How is the process of Op Art design for middle school students?

2. What are the opinions of middle school students toward designing Op Art?

Op Art, Creativity, and STEAM

In his study, Brewer (1999) prepared Op Art visuals with primary school students to better learn the names of straight lines, such as vertical, horizontal, perpendicular, parallel, and intersecting lines. In addition, Brewer showed that with Op Art activities, students better learned the general properties of geometric shapes such as rectangles, squares, and ovals. Heskett (2007), on the other hand, showed that Op Art provides an opportunity for students to see how geometric shapes are used in visual art, and by examining different Op Art works, students find opportunities to explore various geometric concepts. For example, with Op Art named Blue/Red created by Victor Vasarely in Figure 1, students; (a) examine the concept of symmetry, (b) discover that depth can be created by changing some properties of circles given on a two-dimensional surface, and (c) learn some basic definitions such as perspective, symmetry, similarity used in geometry.

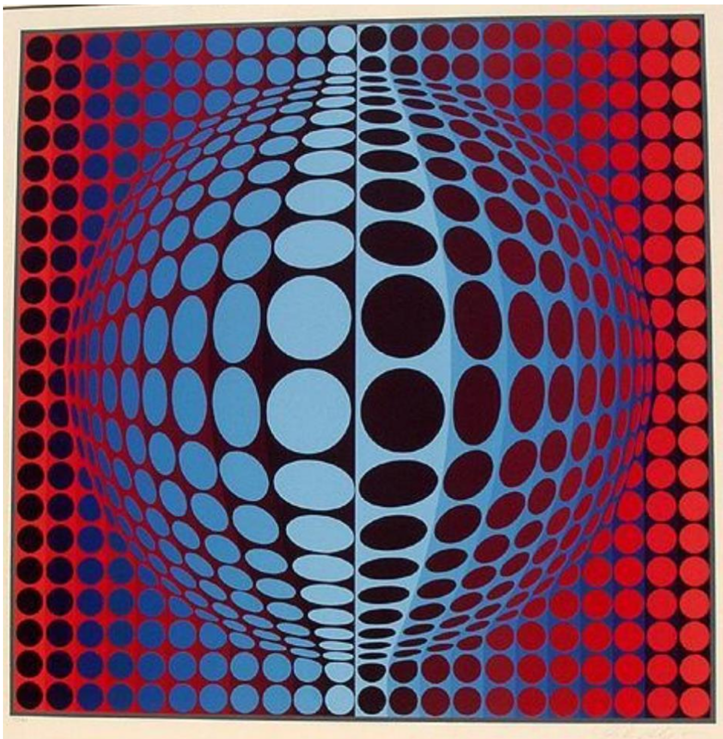


Figure 1 Op Art Blue/Red by Victor Vasarely (Heskett, 2007)

Art activities such as Op Art could have a positive effect on students' success, as they could both attract attention and encourage the use of skills such as creativity (Brewer, 1999; Heskett, 2007; Starko, 2013). Since creating Op Art designs requires a certain process and not only the resultant design (product) but also the process itself is important, it makes an important contribution to creativity (Vygotsky, 2004). Op Art designs can be implemented in a STEAM activity, as it brings together the disciplines of mathematics and art and includes skills that are considered among 21st-century skills, such as creativity (MEB, 2018; Perignat & Katz-Buonincontrö, 2019).

STEM education is an educational model in which the disciplines of Science, Technology, Engineering, and Mathematics interact. STEM education aims to provide students with the ability to think interdisciplinary and thus raise generations whose 21st-century skills such as creativity, problem-solving, critical thinking, and collaboration are developed (Akgündüz et al., 2015; United States Department of Education, 2022). Since STEM education mostly aims to develop student's creativity, innovation (invention), and problem-solving skills by adding art discipline to STEM education (Çepni, 2018; Liao, 2016; Morari; 2023; Perignat & Katz-Buonincontrö, 2019), creativity and invention skills were emphasized more (Daugherty, 2013).

As noted by Henkriksen (2014), incorporating art into the STEM approach has several positive effects on students. It reduces anxiety related to the lesson, boosts motivation and fosters positive attitudes, even though it may be challenging and time-consuming in classrooms. The inclusion of art in the interdisciplinary approach also leads to increased classroom participation (Perignat & Katz-Buonincontrö, 2019). Moreover, it allows students to recognize the connections between Science, Mathematics, Technology, Engineering, and Art. Incorporating the art field into the STEM concept has led to its expansion and widespread adoption as STEAM, as evidenced by studies such as those by Razi and Zhou (2022) and Wu et al. (2021). In STEAM applications, students' motivation for the lesson is enhanced when they create products through small-scale designs. Producing a tangible product at the end of these activities reinforces the practicality of their existing knowledge and encourages them to pursue further learning (Morari, 2023; Ozkan, 2022).

Perignat and Katz-Buonincontrö (2019) reviewed 44 articles in a literature review on STEAM education. They stated that in half of the studies, the aim of STEAM education was defined as the development of creativity skills in students. Mathematics is one of the disciplines directly associated with creativity (Leikin, 2009). It is possible for students from all grades to practice creativity skills (Leikin & Siriraman, 2017). Some examples of the relationship between mathematics and creativity are; determining the shapes and the relations between them, approaching them from different perspectives, problem-solving, and developing different ideas (Starko, 2013, p. 228). Liu and colleagues (2023) indicate that mathematics plays a relatively insignificant role within STEAM learning since mathematics serves as a foundational element across various disciplines. Thus, without a solid grasp of mathematics, a comprehensive understanding of other fields becomes challenging to attain.

Op Art can be considered a STEAM activity because it combines elements of science, technology, arts, and mathematics disciplines. Op Art often relies on principles of visual perception and psychology, which are elements of science. Op Art relates with technology in that Op Art designers use technology to manipulate shapes, colors, and patterns to achieve the desired result (Mercat et al., 2017). Mathematics plays a significant role when artists use mathematical principles such as geometry, symmetry, and perspective to create precise and symmetrical patterns and shapes (Brewer, 1999). Furthermore, some calculations are often required to determine the exact measurements and angles needed to create optical illusions. Lastly, considering the art discipline, Op Art is a form of visual art (Parola, 1996). While mathematics is a crucial component in an Op Art design, the primary focus is on creating visually captivating and perceptually challenging artworks that engage viewers intellectually and emotionally. This multidisciplinary approach distinguishes optic art from a purely mathematics activity, primarily focusing on mathematical problem-solving and concepts.

Mercat et al. (2017) stated that Op Art could be used to apply creativity skills in mathematics. While older students could design an Op Art using specified algorithms, younger students could draw or paint a previously produced Op Art in-class activities (Mercat et al., 2017). Likewise, Starko (2013) stated that redrawing a figure is a creative process. While redrawing a previously produced Op Art, students should create a suitable model for the structure of Op Art, identify the basic parts of this model, and comprehend the relations of the determining parts with each other. Thus, the process by which a person creates an Op Art design can be considered a creative process, and the Op Art design is a creative product (Mercat et al., 2017). Therefore, given the creative essence attributed to the process of crafting Op Art designs and the resultant creative products, as posited by Mercat et al. (2017), it is pertinent to introduce the subsequent discussion of the Creativity Diamond model, shown in Figure 2, which was purposefully conceived to scrutinize the intricacies involved in individuals engaging in the creation of Op Art. The development of the Creativity Diamond model was undertaken with the primary objective of investigating the procedural aspects associated with individuals engaging in the creative process of creating Op Art.

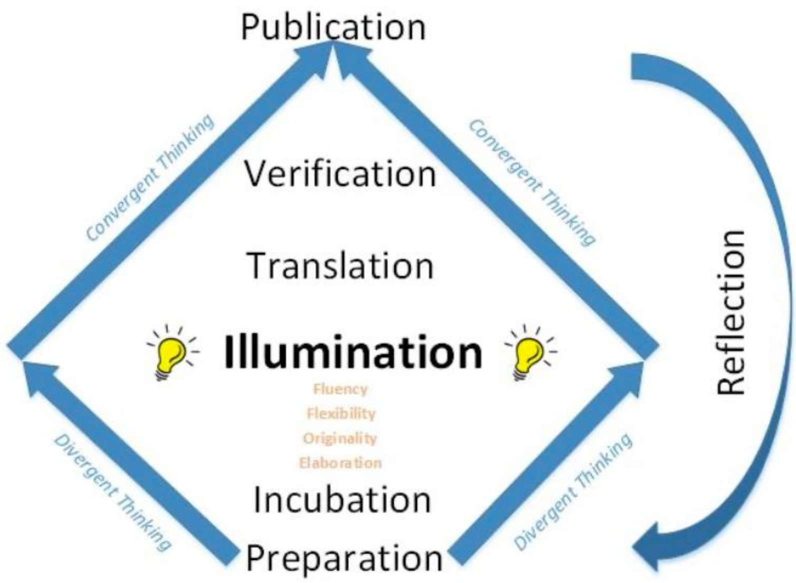


Figure 2 Creativity Diamond Model (Mercat, Filho, & El-Demerdash, 2017)

The Creativity Diamond model was created by integrating and combining various mathematical thinking and creativity theories. This model refers to the creative process that a person uses when solving a mathematical problem. In this model, Divergent Thinking is one of the most important steps and is the part where new ideas are formed. Competencies such as Fluency, Flexibility, Originality, and Elaboration in this step are expressed as follows.

- Fluency: The ability of a person to examine a mathematical problem or situation to develop various ideas about the problem or situation in a short time.

- Flexibility: The ability of the person examining a mathematical problem or situation to develop more than one approach and method toward the problem or situation.

- Originality: The ability of the person examining a mathematical problem or situation to offer original and unique approaches to the problem or situation.

- Elaboration: The person examining a mathematical problem or situation can identify, interpret and generalize the differences in the problem by changing one or more aspects of the problem/situation (Leikin 2009; Leikin & Siriraman, 2017; Mercat et al., 2017; Silver, 1997; Torrance, 1966).

The concepts defined above are included in the Divergent Thinking step and are the competencies that a person applies consciously or unconsciously in the creative process (Guilford, 1950, 1967; Volle, 2017). In the thinking processes, divergent thinking refers to the mental skill where people can produce many possible solutions or ideas when encountering a problem or challenge. Divergent thinking is unique because there is not just one right answer; it is about exploring various possibilities. The cognitive ability described by Volle (2017) highlights how individuals can explore and develop creative solutions when faced with open-ended problems. The illumination step in the model is defined as the turning point of the model. After this turning point, the Convergent Thinking step comes, and the person creates a form, proof, explanation, program, model, conclusion, etc., against the problem or situation that others can see and evaluate. Sternberg and Lubart (1999) explored the idea of convergent-integrative thinking. This kind of thinking is when people break down a problem into its basic parts and devise a plan to see how these parts fit together. Thinkers who are good at this can discover new links, mix different ideas, find hidden patterns, and create new connections between things that seemed unrelated before (Sill,1996).

In 1966, Torrance developed a Test of Creative Thinking called the Torrance Test. This assessment evaluates creative thinking through tasks involving both written and visual elements. It assesses creativity based on several key factors, including:

1. Fluency: This measures the total number of suitable and relevant responses the test-taker provides.
2. Flexibility: It gauges how diverse the categories of responses are, reflecting the test-taker's ability to approach the task from different angles.
3. Originality: This evaluates the uniqueness and rarity of the responses, highlighting the capacity for innovative thinking.
4. Elaboration: It quantifies the level of detail and depth incorporated into the responses, indicating the richness of the generated ideas.

Therefore, Torrance's test comprehensively examines various dimensions of creative thinking across verbal and visual domains (Leikin & Pitta-Pantazi, 2013).

Method

Research Design

In this study, a qualitative approach, the case study method, was used. Middle school students were asked to produce Op Art designs, in which they could employ creativity, individually or in groups of two, for four different Op Art activities organized by the researchers. The researchers observed this design process, and students' views on the activity were taken. In this study, the case study was deemed appropriate since it examined how middle school students used their creativity skills while making Op Art designs. A case study is a qualitative research design that examines a specific phenomenon in-depth (Yin, 2017; Zanial, 2007). In this research, the creativity skills of middle school students in the process of designing Op Art were observed. Student opinions were gathered with interview forms and one-on-one interviews, and then the obtained data were examined in detail (Creswell & Poth, 2016).

Participants

The study group of research consists of 28 voluntarily selected middle school students attending a middle school in a province in the Western Black Sea region. The primary criterion employed for participant selection hinged upon the enrollment status of students in middle school grades. Notably, the activities undertaken in this study did not necessitate a grade-specific proficiency in geometry knowledge. Consequently, the grade level of the participants held no significance in the context of this research. Participants were selected by the convenience sampling method, one of the purposeful sampling types. This method brought speed and practicality to the study (Yıldırım & Şimşek, 2013). This study group consisted of 11 male and 17 female students. Six students from this study group were studying at the 5th-grade level, and 22 students were at the 7th-grade level. The actual names of the participants were not used, but S1, S2, …, and S28 codes were given to name them. Op Art activities were carried out by the authors in this study.

Research Context

Within the scope of the current research, researchers studied the history of Op Art, its types, its relationship with creativity, the relationship between Op Art and STEAM, preparing Op Art-related activities, etc., during 12 weeks. The authors in the study prepared four Op Art activities and applied these activities to middle school students. In this respect, famous Op Art designers were examined, and each activity focused on an Op Art designer. For each activity, characteristics of the works made by the Op Art designers and the geometry they used in their designs were identified. The researchers determined the works of designers that could be repeated by a middle school student. The standards included in the Ministry of National Education (2018) Primary and Secondary School Mathematics Curriculum and associated with the Op Art activities prepared within the scope of this study were as follows:

1. Constructs parallel line segments to a line segment and interprets whether the drawn line segments are parallel or not.
2. In cases where a whole is divided into two parts, it determines the ratio of two parts to each other or each part to the whole. In problem situations, when one of the ratios is given, it finds the other.
3. Recognize the center, radius, and diameter by drawing a circle.
    a) *Studies on using a compass are included.*
    b) *The relationship between the circle and the circle is indicated.*
4. Draws two-dimensional views of three-dimensional objects from different directions.
5. Draws the images of points, line segments, and other shapes resulting from translation.
6. Creates the reflection image of a point, line segment, and other shapes.
7. Creates the image of polygons resulting from translations and reflections.
8. Determines the similarity ratio of similar polygons and creates congruent and similar polygons (Ministry of National Education, 2018).

Detailed information about the famous Op Art designers who took part in the events and the event process is given in Table 1.

Table 1 Activities and Processes

Activity	Activity Process
Activity 1	The famous Op Art designer who took part in the event is Victor Vasarely and his works are shown. Within the designs, • Different geometric shapes are included. • Concepts such as translation, reflection, and symmetry are included. Students are asked to create a new unique design by considering the Op Art designs examined.
Activity 2	The famous Op Art designer, Richard Anuszkiewicz, took part in the event, and the works of this artist are shown. Within the designs, • There are different geometric shapes. • Rotation, translation, continuing pattern by reducing the shape in certain proportions on geometric shapes, etc., takes place. Students are asked to create a new unique design by considering the Op Art designs examined.
Activity 3	The famous Op Art designer, Bridget Riley, took part in the event, and the works of this artist are shown. Within the designs, • It has different geometric objects. • Geometric shapes have different colors, sizes, and layouts.

	• A three-dimensional effect was created in a two-dimensional plane by mathematical operations such as translation, reflection, and changing areas. Students are asked to create a new unique design by considering the Op Art designs examined.
Activity 4	The famous Op Art designer who took part in the event is Akiyoshi Kitaoka, and his works are shown. Within the designs, • Circle, square, rhombus, and different shapes are used. • There are illusions such as swelling, mobility, and depth in the designs. • There is a perception of swelling due to the use of geometric objects in different sizes in designs. • Concepts such as translation, reflection, symmetry, and pattern are included in the given designs. Students are asked to create a new unique design by considering the Op Art designs examined.

In addition, the implementation process for each of the activities was similar to the lesson plan used by Boaler (2019) for Mathematics and Art lessons (Figure 3).

Activity	Duration	Description	Materials
Information about op art (infographic)	10 min	• Infographics are shown • Information is given about the famous Op Art artist and their designs to be discussed at the event. • Students are asked to work individually or form groups of two.	Infographic posters
Investigation	20 min	• Students' attention is drawn to geometric and mathematical concepts that can be discovered in Op Art designs. • Students are asked to find mathematical relationships within Op Art designs.	• Copies of Op Art designs, • Colorful pencils • Papers
Creativity	20+ min	• Students are asked to create their own designs using the Op Art design they have examined.	Needed materials to complete design
Discussion and presentation	15 min	• Opinions of the students on the Op Art visuals they designed are taken. • Presentations of designs are made.	

Figure 3 Implementation Process of an Event (Boaler, 2019)

Data Collection

The data collection tools used in the study consisted of the observation form used by the researchers during the activity, the open-ended opinion form answered by the participants, and one-on-one interviews with some students. Details are provided below.

Observation Form

Researchers observed the Op Art design processes and creativity skills of the participants using the observation during the Op Art activities. The form used during this observation is given below. This form was created after revising the form developed by Boakes (2019).

Observation-Evaluation Items	1st Group	2nd Group
Participant Names		
Participation in the event	Yes/ Partially/ No	Yes/ Partially/ No
Students' attitudes towards the activity (positive/negative)		
Explaining the materials used during the design with their justifications (ruler, compass, protractor)	Yes/ Partially/ No	Yes/ Partially/ No
Involve teamwork	Yes/ Partially/ No	Yes/ Partially/ No
Include discussions about the event	Yes/ Partially/ No	Yes/ Partially/ No
Creating an original design at the end of the event.	Yes/ Partially/ No	Yes/ Partially/ No
Expressing geometric shapes used in designs.	Yes/ Partially/ No	Yes/ Partially/ No
Expressing the mathematical relationships in the created designs (I combined three line segments, drew the diagonals of the square, drew parallel lines to each other, etc.)	Yes/ Partially/ No	Yes/ Partially/ No

Figure 4 Observation Form

Open-ended Questionnaire

While preparing questions in the questionnaire, researchers paid attention to the principles, such as questions being understood by the participants, not being multidimensional, and not being directive (Bogdan & Biklen, 1992). Then, expert opinions were received on the questions, and the form was arranged in line with expert opinions. The questions in the form are given below:

1. What are your thoughts on designing an Op Art activity? Please explain.

2. Which picture did you draw in the activity, and why did you choose this picture? Please explain.

3. What method did you use while drawing, and what did you pay attention to?

4. Do you think your drawing was successful? Why?

5. Explain what you like and dislike about the activity.

6. What interested you the most in this activity? Explain why.

7. Would you like these kinds of activities to be implemented in your mathematics lessons? Explain why.

8. What are the things that this activity taught you? Please explain.

One-on-one Interviews

At the end of the Op Art activities, a person from the research team conducted one-on-one interviews with the volunteer participants, and open-ended questions were used during the interviews. Some of the questions frequently used in one-on-one interviews are: Which design did you do at the Op Art event, what did you notice? How did you feel about the design you made? What did you learn? What are your suggestions and criticisms about Op Art events? One-on-one interviews were audio-recorded and then transcribed.

Four Op Art activities were implemented with the participating students, each lasting approximately one hour. At the end of the activities, extra time was given to the students to fill in the open-ended questionnaire. A copy of the students' Op Art designs and the filled questionnaire forms were recorded. After the activities were completed, face-to-face interviews were conducted with volunteer students.

Data Analysis

In the data analysis, the data obtained from the open-ended questionnaire and interviews were evaluated in detail by using the content analysis method. The codes were grouped into categories, and then themes were explored (Yıldırım & Şimşek, 2017). The data obtained from each activity in the study were coded independently by two researchers.

Furthermore, in the research conducted by Leikin and Pitta-Pantazi (2013), a creative thinking assessment originally developed by Torrance in 1966 was incorporated. In this study, we used the assessment to evaluate students' creative abilities in the context of Op Art designs. Specifically, the evaluation encompassed four key competencies: Fluency, Flexibility, Originality, and Elaboration, which were employed to assess the level of creativity exhibited in the students' Op Art creations. In the context of this research, it was imperative to introduce an additional component called the Same. The ensuing section provides a detailed breakdown of these assessments.

• Frequency: The number of Op Art designs produced by the student during the activity.

• Flexibility: The Op Art design was inspired by one of the designs presented to the student. However, the design differs from the original model in color and size.

• Originality: The Op Art design was created by combining two designs presented to the student or using shapes not included in the original model.

• Elaboration: The student completed the Op Art design and presented it to the class. The student interpreted the shapes and differences he added to his own design.

• Same: The student took one of the presented Op Art designs and created the same color, size, and shape (Leikin & Pitta-Pantazi, 2013).

Validity and reliability

The inter-coder reliability was checked by using the agreement calculation belonging to Miles and Huberman (1994) ([Number of codes with consensus/(Number of codes with consensus + Number of codes without consensus)] *100.00). As a result of the analysis for each activity, the percentage of agreement between encoders was calculated between 86% and 93%. These values stood sufficient for intercoder reliability as they provide the minimum value of 85% suggested by Miles and Huberman (1994). The researchers discussed and agreed on the codes where disagreements occurred.

Findings

This research examined the processes of middle school students in Op Art activities and their views on these activities. The data obtained in this study were analyzed by content analysis and presented under two headings: Findings regarding middle school students' Op Art designing processes and findings regarding middle school students' views on Op Art designs.

Findings Regarding Middle School Students' Op Art Designing Processes

The findings regarding the Op Art design process of the students were obtained with the observation forms during the activity and the open-ended questionnaire. In this direction, three themes have emerged regarding the processes of middle school students in making Op Art designs: Mathematical expression, visual expression, and creativity skills. The categories within the scope of these themes are presented below.

The students' findings regarding the Op Art design were obtained with the observation forms during the activity and the open-ended questionnaire. With that regard, three themes have emerged from the processes of middle school students' Op Art designs: Mathematical expression, visual expression, and creativity skill. The categories within these themes are presented below.

Table 2 shows the findings for the mathematical expression theme.

Table 2 Findings for the Mathematical Expression Theme.

Categories	Students	f
Drawing equal, symmetrical, and parallel lines	S2, S3, S4, S5, S6, S8, S9, S13, S15, S16, S21, S12	12
Use of materials (ruler, compasses, etc.)	S19, S25	2
Use of geometric shapes (square, rectangle, etc.)	S2, S6, S10, S11, S13, S23	6
Similarity and proportion (growth and shrinkage) in geometric shapes	S8, S12	2
Patterning (with colors and shapes)	S27	1

Under the mathematical expression theme, five categories emerged: Drawing equal, symmetrical, and parallel lines (n=12), use of materials (n=2), use of geometric shapes (n=6), similarity and proportion in geometric shapes (n=2), and patterning (n=1).

The findings under the mathematical expression theme were gathered primarily by the responses to the 3rd question, " What method did you use while drawing, and what did you pay attention to?" in the open-ended questionnaire and notes in the observation form. It has been observed that students could easily express which geometric shape they use in their designs and that they could express their designs using mathematical terms. Below, sample statements by students were given.

In the activity, I drew Figure 10 because it looks like the rectangles are intertwined (S12).

The essence of the picture consists of dark colors; I will stick to it. I will make a pattern using red-black, then purple and blue in the first line. I used patterns in the designs I made today (S27) (Fig. 14)

In addition, during the Op Art activity, it was observed that the students used materials to create mathematically correct shapes (Figure 5).

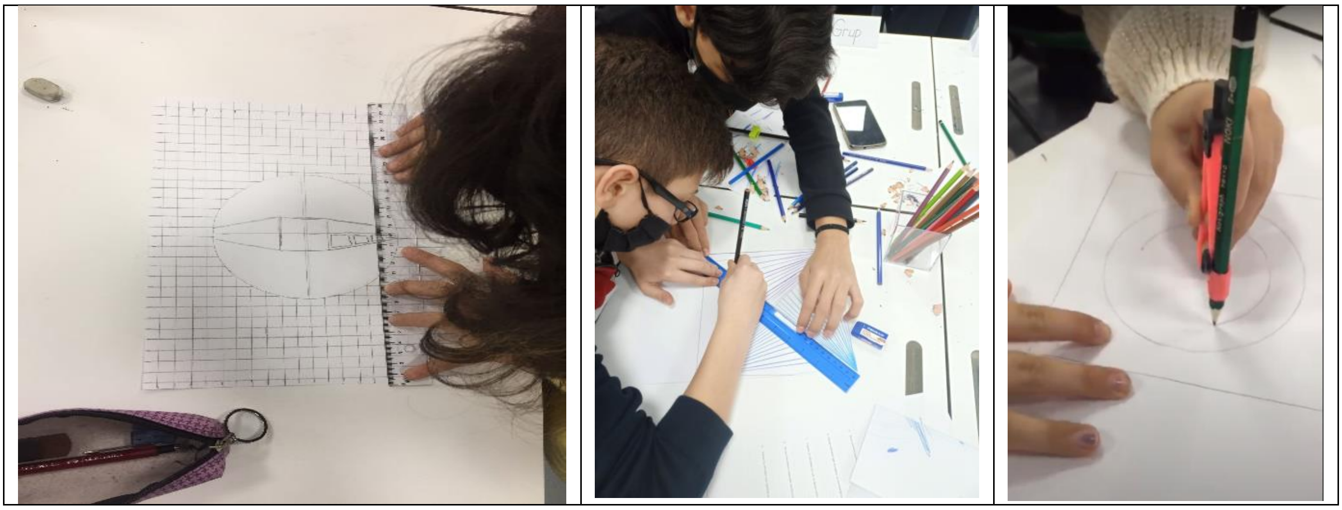


Figure 5 Pictures for Students' Use of Materials.

Findings regarding students' ability to identify and use appropriate materials for design were coded as "yes, partially, no" based on the observation form. In Table 3, it is seen that most of the students could "partially" explain the materials they used in their design.

Table 3 Findings on Material Use

Categories	Codes	Students	f
Can students explain the materials and their justifications while they were used during the design?	Yes	S7, S8, S27, S1, S16, S4, S21, S22, S12, S28	10
	Partially	S15, S2, S5, S6, S13, S14, S18, S19, S20, S23, S24, S25, S26	13
	No	S3, S9, S10, S11, S17	5

The number of students who did not provide any findings regarding material use was 5. These students did not use any materials (rulers, compasses, etc.) during the activities.

The number of students who did not express any opinion on the mathematical expression theme was 10. Students with the codes S1, S12, S14, S19, S20, S21, S22, S24, S5, S16, S22, and S26 expressed their views on the mathematical expression theme only in one activity (Activity 3).

The findings of the visual expression theme are given in Table 4.

Table 4 Findings Regarding the Visual Expression Theme.

Categories	Students	f
Drawing proper lines and shapes	S1, S14, S19, S20, S21, S22, S24	7
Using colors and painting	S5, S12, S16, S22, S26	5
Three-dimensional drawing	S12	1

As seen in Table 4, three categories under the visual expression theme emerged. These categories are: Drawing proper lines and shapes (n=7), Using color and painting (n=5), and Three-dimensional drawing (n=1). S2, S3, S4, S6, S7, S8, S9, S10, S11, S13, S15, S17, S18, S23, S25, S27, and S28 did not present any findings for the visual expression theme. Table 4 shows that most of the students presented findings on Drawing proper lines and shapes. However, one student presented findings in the category of three-dimensional drawing. Below are some students' expressions on drawing proper lines and shapes.

We paid attention to drawing the lines straight (S14).

While drawing, I paid attention to how it grows and shrinks (S5).

While drawing, we tried to be careful while taking the measurements and drawing correctly (S20).

While drawing, we mostly used a ruler so that each line was smooth and the picture looked beautiful (S19).

We paid attention to color harmony and drawing the lines straight (S22).

While drawing, I used the method of having a three-dimensional picture and drawing black and white (S12).

Another theme obtained from students' Op Art design process is the creativity skill theme. The findings regarding the creativity skill theme are detailed in Table 5.

Table 5 Findings on the Creativity Theme.

Categories	Activity 1	Activity 2	Activity 3	Activity 4	Total Frequency
Frequency	f = 2 S25, S26	f = 1 S11	f = 0	f = 0	f = 3
Flexibility	f = 14 S2, S3, S4, S5, S6, S7, S8, S9, S10, S13, S14, S15, S16, S17, S18, S19, S20, S23, S24, S25, S26, S27, S28	f = 13 S1, S3, S4, S5, S6, S7, S8, S10, S11, S12, S13, S14, S15, S16, S17, S18, S19, S20, S27, S28	f = 6 S3, S9, S10, S23, S24, S27	f = 7 S1, S2, S12, S13, S14, S15, S16, S27	f = 40
Originality	f = 3 S1, S11, S12, S25, S26	f = 4 S11, S21, S22, S23, S24, S25, S26	f = 2 S12, S2, S25, S26	f = 4 S11, S21, S22, S23, S24, S25, S26	f = 13
Same	f = 1 S21, S22	f = 0	f = 10	f = 5	f = 16

		S1, S4, S5, S6, S7, S8, S11, S13, S14, S15, S16, S19, S20, S21, S22	S4, S5, S6, S7, S8, S9, S10, S19, S20	
Elaboration f=4 S6, S7, S27, S28	f=3 S8, S16, S22	f=3 S18, S21, S5,	f=3 S25, S26, S15	f=13

As seen in Table 5, students produced 20 designs in the first activity. S25 and S26 worked together, showed their frequency skill, and developed two designs. When Table 5 is examined, it is seen that most of the students (n=23) made flexible designs (f=14) in Activity 1, while a small number of students (n=5) made original designs (f=3). Figures 6 and 7 show the flexible and original designs made by the students in Activity 1.

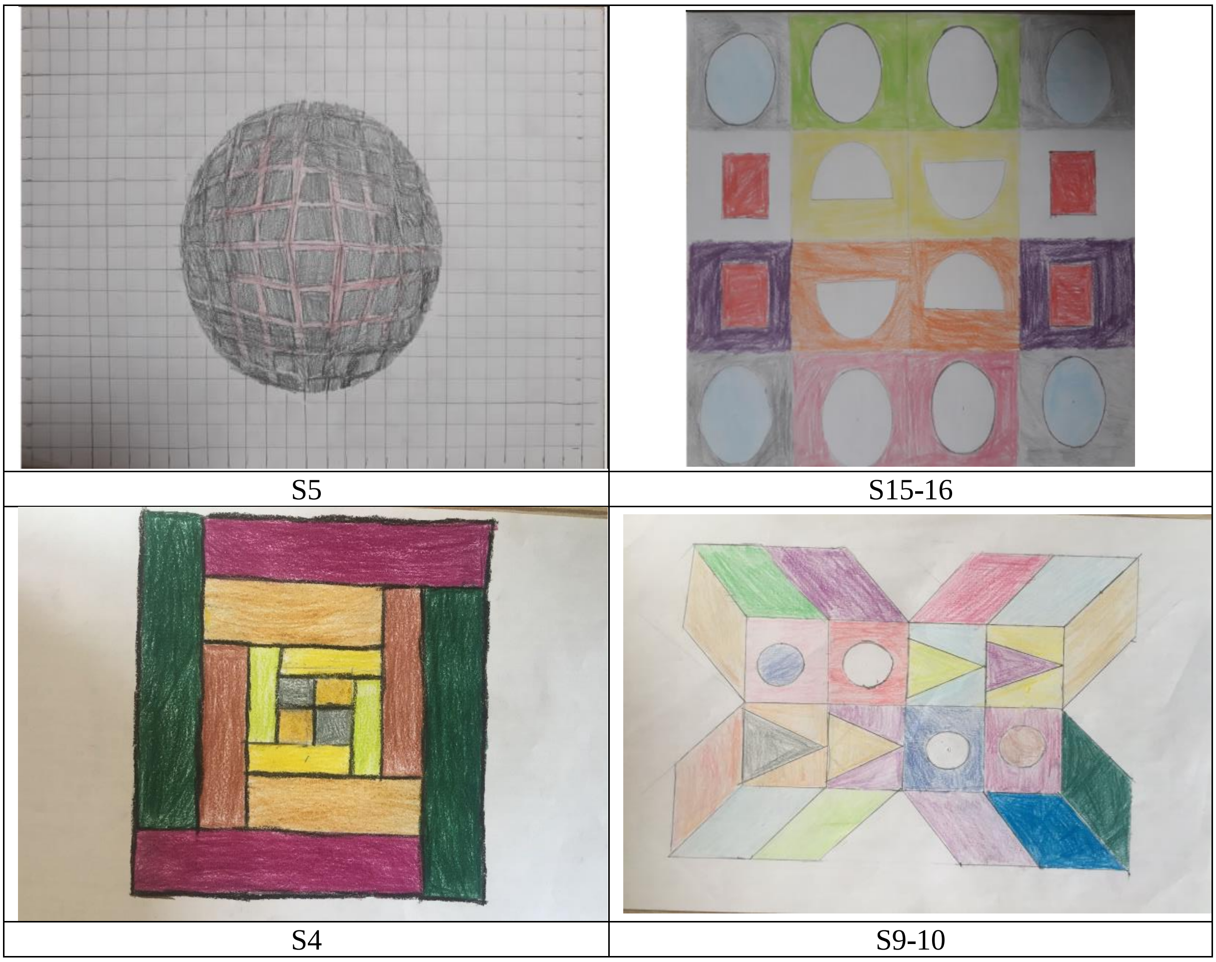
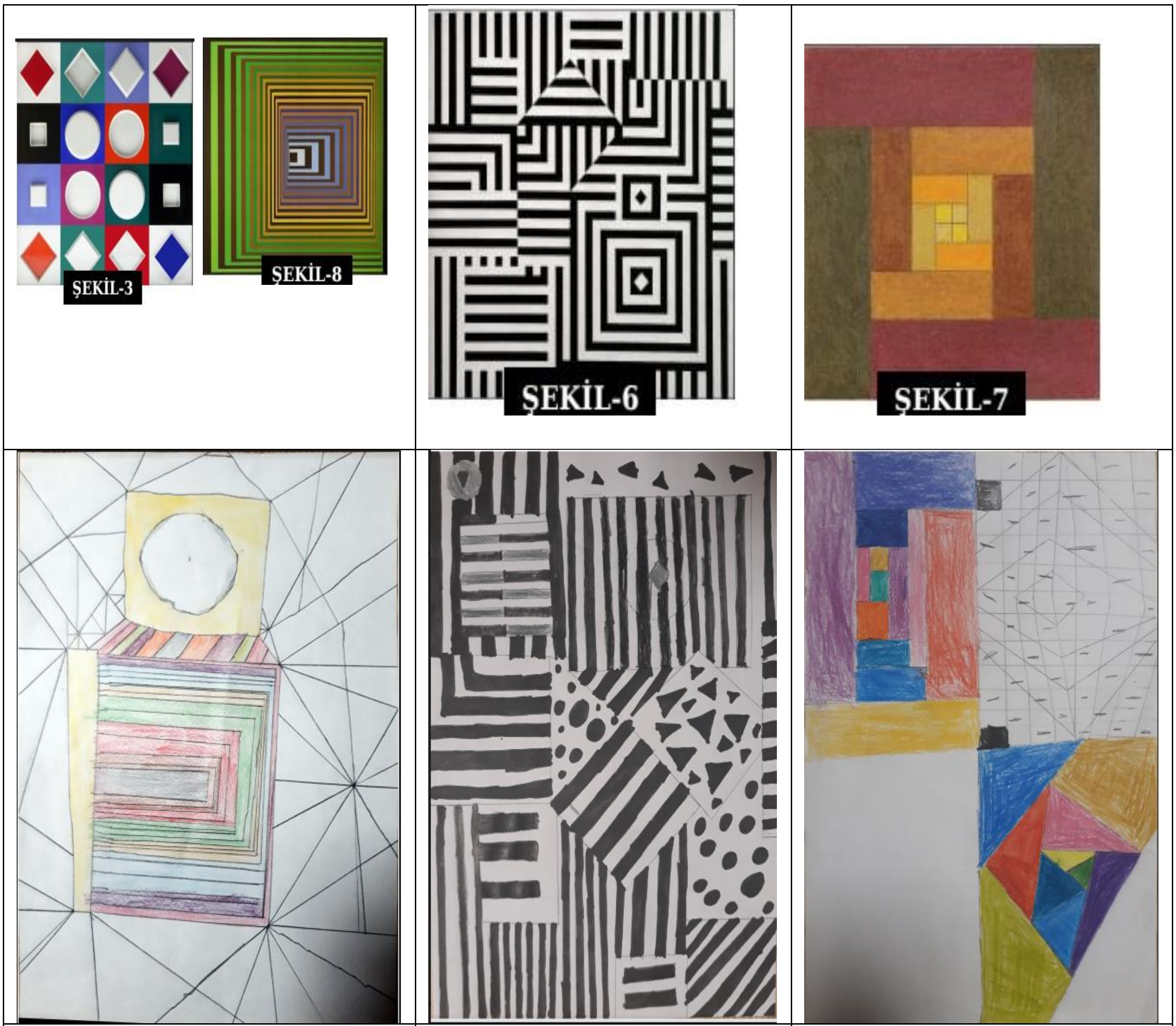


Figure 6 Flexible Designs by Students S5, S15-16, S4, S9-10 in Activity 1.

It has been determined that the designs created by students in Figure 6 differed from the original designs by color and size.



S12-13	S1	S25-26

Figure 7 Original Designs by Students S12-13, S1, S25-26 in Activity 1.

As shown in Figure 7, the students presented different Op Art designs from the Victor Vasarely designs (the images in the first row) presented to them. The students created original designs by combining two different designs presented to them or integrating different geometric shapes into the existing design (Figure 7).

When Figure 7 is examined, S12-13's Op Art design differs from the work presented to them in terms of size and geometric shape. The students also included different geometric shapes (various triangle and quadrilateral shapes in the background of the Op Art design), which were different from the work presented to them. S1 integrated two different works into his design in a unique way. S25-26 students, on the other hand, showed frequency skill in their designs. While showing flexibility in one of their designs, they redesigned the same design by using different geometric shapes (triangles) and produced original work. While in the original design, the depth perception was given with rectangles, in their design, students tried to give the depth perception by using triangles.

As shown in Table 5, most of the students (n=20) made flexible designs (f=13); however, few students (n=7) made original designs (f=4) in Activity 2. S11 demonstrated frequency skills and produced two designs. Figure 8 and Figure 9 show sample flexible and original designs made in Activity 2.

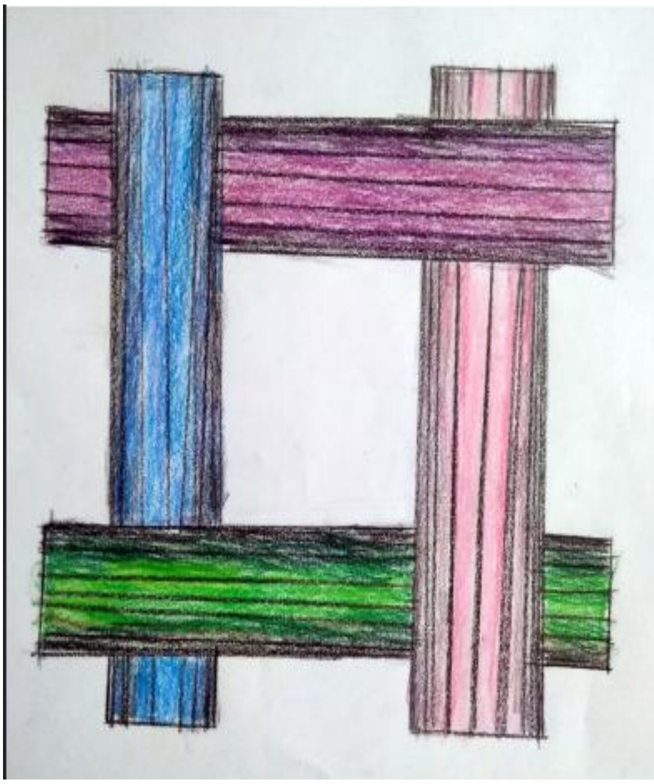
	
S19-20	S7-8

Figure 8 Flexible Designs by Students S19-20 and S7-8 in Activity 2.

It has been determined that the students' designs in Figure 8 differed from the original designs by color and size.

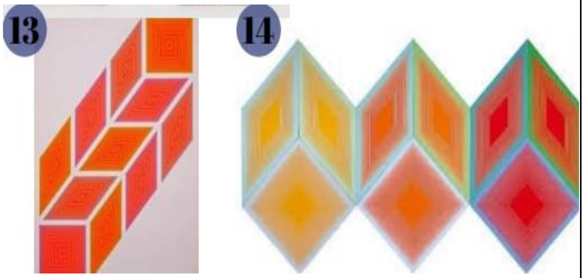
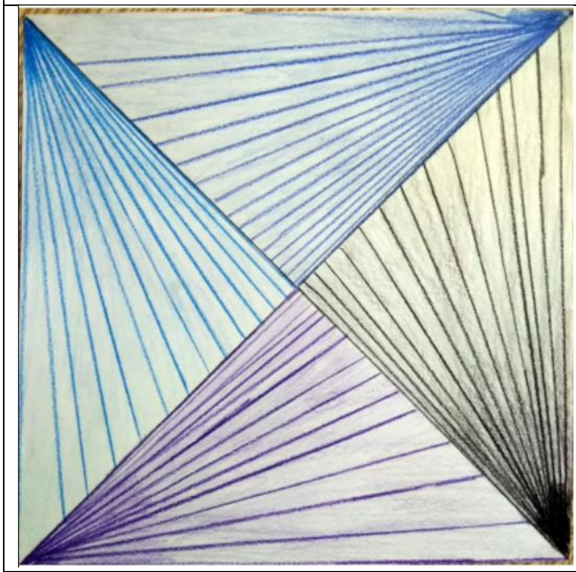
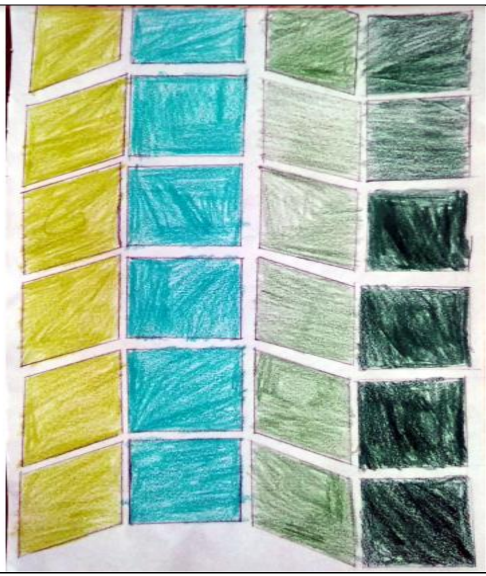
	
	
S21-22	S23-24

Figure 9 Original Designs by Students S21-22 and S23-24 in Activity 2.

In Figure 9, it is seen that the students produced an original design or brought together two different designs presented to them. S21-22 made an original study by changing the form presented to them. S23-24, on the other hand, interpreted the direction of depth perception in their designs differently compared to the original works. In the original work, the cube is observed on the surface. However, the students' works show the rectangles' directions and the depth of the angles.

We used lines going from close to wide (S21).

I tried to draw on the same plane as the lines in the original picture (S22).

As shown in Table 5, most of the students (n=15) made the same designs (f=10) in Activity 3. However, a small number of students (n=6) made flexible designs (f=6), and few students (n=4) made original designs (f=2). S11 demonstrated frequency skills and produced two designs. Examples of the same, flexible, and original designs made in Activity 3 are presented in Figure 10, Figure 11, and Figure 12, respectively.

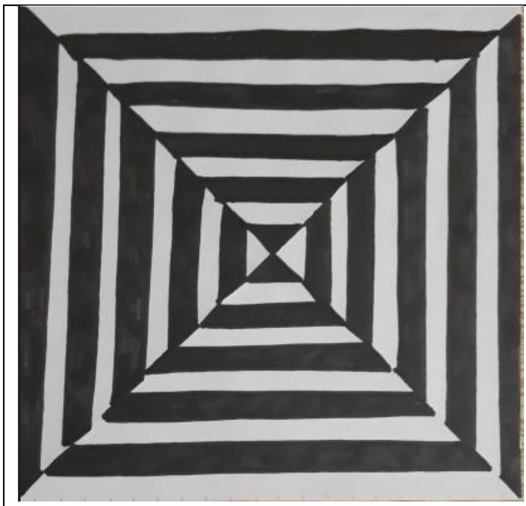
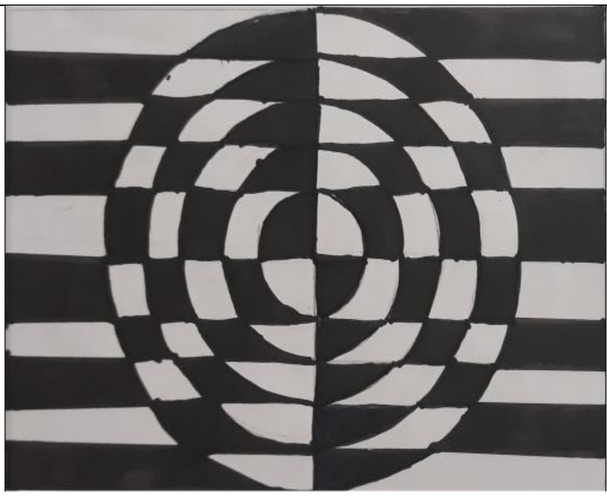
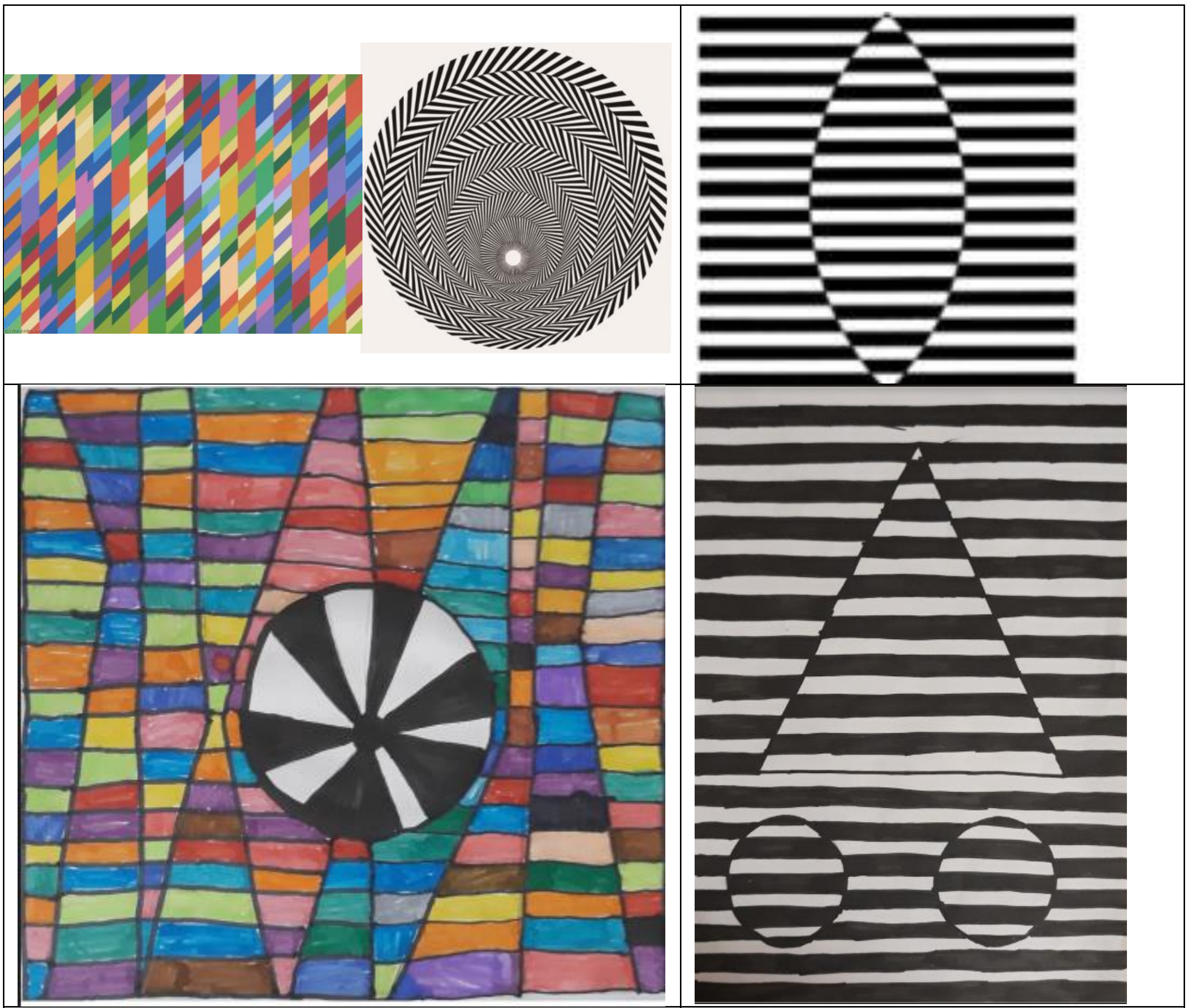
	
S19-20	S8

Figure 10 Same Designs by Students S19-20, S8 in Activity 3.

	
S23-24	S27

Figure 11 Flexible Designs by Students S23-24, S27 in Activity 3.

It has been determined that the students' designs in Figure 11 differed from the original designs by color and size.



S25-26	S12

Figure 12 Original Designs by Students S25-26, S12 in Activity 3.

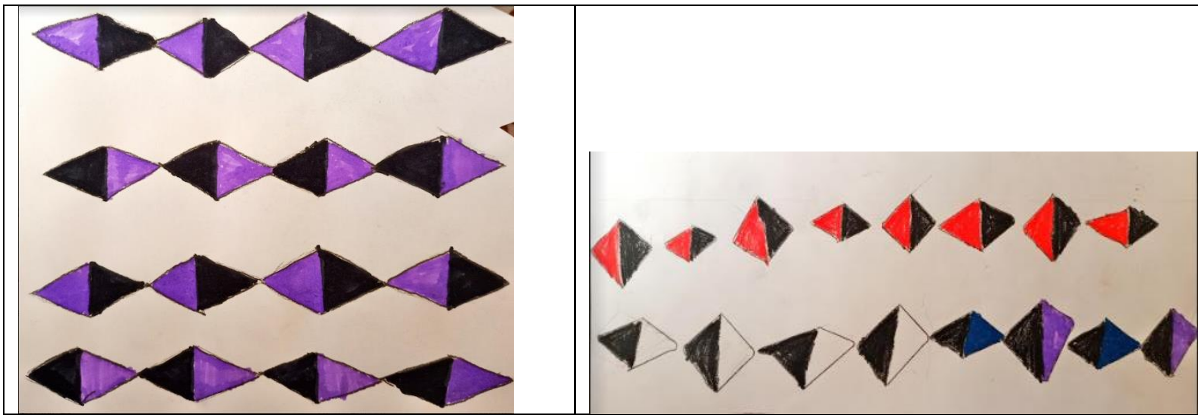
As shown in Figure 12, students combined two designs presented to them or used a geometric shape different from the original one. S25 and S26 were inspired by two different works and created the original design. S12 included geometric shapes (circles and triangles) in his work, which differs from the original work. The created work differs in size and geometric shape from the original design.

Table 5 shows that the majority of the students (n=9) made the same designs (f=5) and flexible designs (n=8, f=7) in Activity 4. However, few students (n=7) made original designs (f=4). Examples of the same, flexible, and original designs made in Activity 4 were presented in Figure 13, Figure 14, and Figure 15, respectively.

S7-8 S5-6

Figure 13 Same Designs by Students S7-8 and S5-6 in Activity 4.

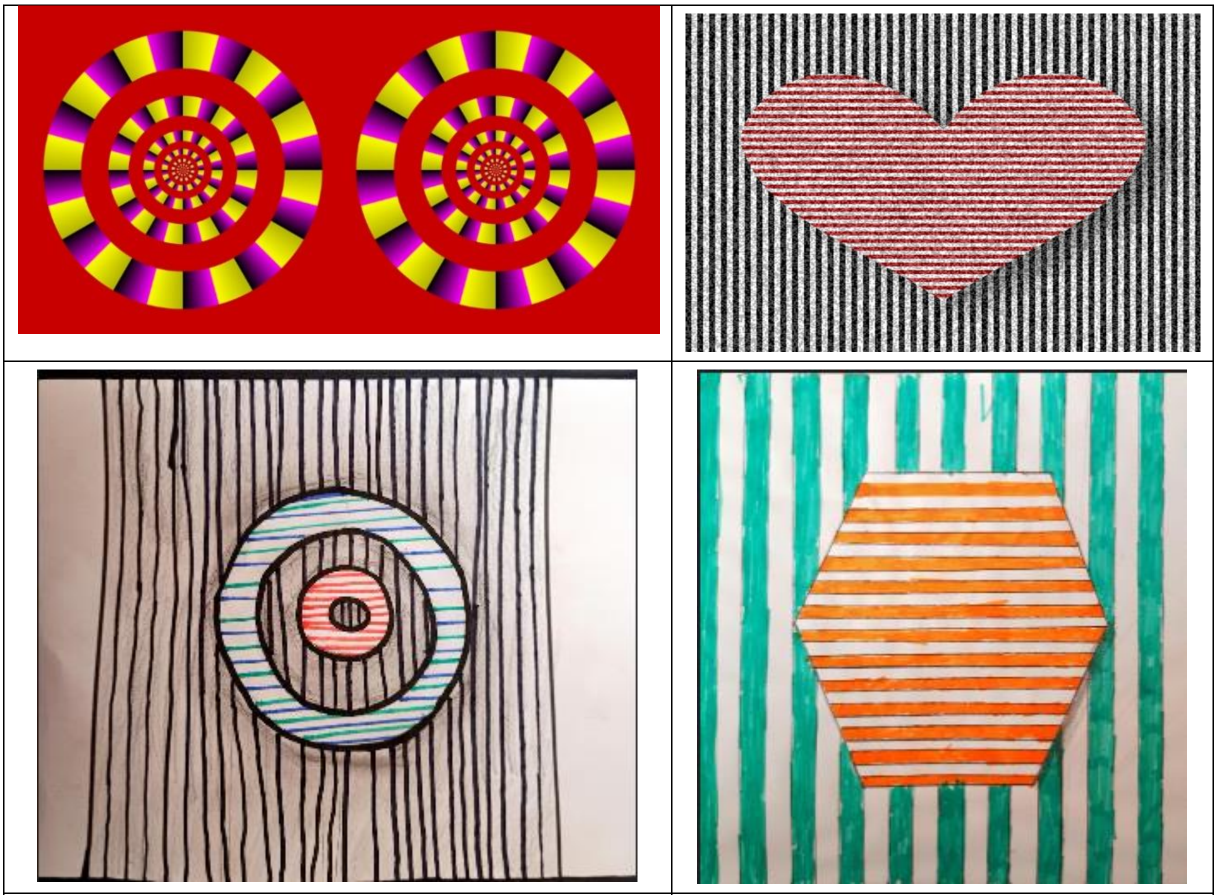
Figure 13 shows that the students made the same designs presented to them.



S13-14 S27

Figure 14 Flexible Designs by Students S13-14 and S27 in Activity 4.

The designs presented in Figure 14 differ only in color from the original designs presented to the students.



S25-26	S21-22

Figure 15 Original Designs by Students S25-26 and S21-22 in Activity 4.

The designs in Figure 15 show that the students combined two designs presented to them or used a geometric shape different from the original design. Ö25-26 created utterly original work in their designs. The students' design differs from the original work regarding color, size, and geometric shape. Similarly, Ö21-22 employed distinct coloring, sizes, and geometric shapes in their designs and produced original work.

Findings Regarding Middle School Students' Views on Op Art Designs

As a result of the students' responses in interviews and open-ended questionnaires, their opinions on Op Art design were gathered. After investigating the students' opinions, six themes occurred: General views on Op Art designs, Liked/disliked aspects of Op Art design activity, the success of the designs made, the exciting aspects of the Op Art activity, the views on the use of Op Art activities in mathematics lessons, instructive aspects of Op Art activities. Table 6 presents the general views of the students about Op Art designs.

Table 6 General Views on Op Art Design.

Categories	Codes	Students	f
Positive views	Nice	S1, S2, S3, S4, S5, S7, S8, S10, S11, S12, S13, S14, S15, S16, S19, S20, S21, S22, S27, S28	20
	Enjoyable	S1, S4, S5, S6, S8, S10, S19, S23, S24	9
	Instructive	S2, S9, S11, S12, S27	5
	Product design	S8, S26	2
	Effective	S25	1
	3D view	S13, S25	2
Negative views	Compelling	S8	1
	Difficult	S8	1
Neutral views	Different, odd	S25	1

As shown in Table 6, three categories emerged regarding the general views of middle school students about Op Art activities: Positive, negative, and neutral opinions. Most of the students reported positive opinions about Op Art activities. Below are sample positive views of some students about Op Art activities.

I think it brought a different dimension to mathematics. I am happy that I discovered this aspect of mathematics and think it was a good activity (S22).

It was beautiful because it encouraged people to think and draw geometry (S27).

On the other hand, few students expressed negative or neutral opinions about Op Art activities.

Table 7 represents the categories and codes related to the Liked/disliked aspects of the Op Art design activity theme.

Tablo 7 Liked/Disliked Aspects of the Op Art Activity.

Categories	Codes	Students	f
Liked aspects	Nice	S1, S2, S5, S6, S7, S9, S15, S19, S20, S21, S22, S23, S24, S28	14
	Exciting	S13	1
	Instructive	S4, S11	2
	Illusion	S8, S14	2
	Researchers' interests in us	S10, S12	2
	Drawing and painting	S3, S12, S16	3
	Materials used	S26	1
Disliked aspects	Difficulty	S18	1
	Time limit	S27	1
Uncertain	Uncertain	S25	1

According to Table 7, 25 students stated their favorite aspects of Op Art activities, two stated disliked aspects, and one used an ambiguous expression. Below are some students' views on the liked aspects of the Op Art design activity.

What I liked about the activity was that it was like an illusion. It makes you feel like you are in it. There are no aspects that I did not like (S8).

What I liked was that we were working in groups. There is no aspect that I did not like (S21).

Table 8 shows the findings regarding the students' successes in Op Art designs.

Table 8 Students' Successes in Op Art Designs.

Categories	Codes	Students	f
Successful	I tried, I worked hard	S1, S16, S18	3
	I cared, drew in detail	S2, S7	2
	I liked	S12, S19, S20, S28	4
	I showed in 3D	S8, S13	2
	I could draw the same shape	S3, S5	2
	I paid attention to mathematical proportions	S4, S8, S15, S27	4
	We worked as a team	S6	1
	I used colors carefully	S9, S26, S27	3
	I completed my design	S21	1
Partially successful	I could not simulate the given design.	S11	1
	I could not paint properly	S25	1
Unsuccessful	I did not like	S10	1

As shown in Table 8, most of the students found their Op Art designs successful, two students found them partially successful, and one student found them unsuccessful. Below are some sample student views.

Yes, successful. Because I could create color animation and parallel edges in the best way (S27).

It was successful because there was depth in it(S13).

Yes. Because I tried to do the exact figure (S5).

I think it was successful. Because I tried (S1).

The subjects that most interested students in Op Art activities are given in Table 9.

Table 9 Attractive Aspects from the Op Art Activity.

Categories	Codes	Students	f
Visuals	Drawing methods	S6	1
	Colors	S8, S10, S11, S12, S15, S16, S23	7
Geometry	Geometric shapes	S3, S4, S25	3
	Having the geometry in the picture	S5, S14, S20	3
Optic illusion	Illusion	S8, S13, S26	3

	Three-dimensional appearance	S11, S28	2
Artist	Methods used by the artist	S1, S2, S15, S22, S27	5
	Artist	S24	1
Materials	Materials used	S19	1
Not attractive	Nothing attractive	S7	1

In Table 9, it is seen that the subjects that attract the attention of most students in Op Art activities are visuals, geometry, optical illusion, Op Art artist, and the materials used. However, it was also found that one student did not find Op Art activities interesting.

The shapes intrigued me. All of them were beautiful and different from each other (S4).

I was most interested in the relationship between painting and mathematics (S5).

Picture. Because I was not very interested in painting before (S6).

I understood that mathematics works in every field (S14).

Connecting figures and pictures to mathematics in a way (S20).

Students' views on using Op Art activities in mathematics lessons are given in Table 10.

Table 10 Opinions on Using Op Art Activities in Mathematics Lessons.

Categories	Codes	Students	f
Yes	Lessons will have more fun	S1, S2, S4, S5, S8, S9, S11, S12, S14, S15, S16, S18, S19, S20, S22, S26, S28	17
	Lessons become instructive	S2, S27	2
	The activity requires math	S3, S6, S13, S15, S23	5
	Our interest in the lesson increases	S8	1
No	I like regular class more	S24	1
	Makes math class harder	S25	1

As seen in Table 10, 25 students want the Op Art activities to be implemented in mathematics lessons, while two students do not. Below are examples of students' views on whether they want Op Art activities to be used in mathematics lessons.

Yes. It can make our lessons more fun (S19).

Yes. I usually struggle with geometric objects, but I can understand better if such happens (S27).

No. Because I am more interested in numbers (S6).

Table 11 indicates the instructive aspects of Op Art activities for students.

Table 11 Instructive Aspects of Op Art Activities.

Categories	Codes	Students	f
Instructive	The relations between painting and geometry	S1, S2, S5, S6	4
	Different use and appearance of shapes	S3, S8, S11	3
	Learned a new Op Art artist	S4, S8	2
	Illusions by shapes and colors (Op Art)	S8, S24	2
	Mathematics is everywhere	S10, S13, S14, S15, S16, S18, S19, S20, S27	9
	Drawing geometric shapes more precisely and accurately	S12	1
	Use of materials (ruler, compass, …)	S12, S21	2
	Drawing, painting, use of colors	S23, S26, S28	3
Not instructive	Did not learn anything	S9	1
	Not meaningful	S25	1

As shown in Table 11, the students generally find the Op Art design activities instructive, and they state that Mathematics can be in many fields. Some students' views on the instructive aspects of Op Art activities are given below.

> *Pictures are misleading. Drawing geometric objects and appearing as if they are not part of the picture (S1).*

> *I learned to use geometric shapes more neatly and accurately and use the protractor for a different purpose (S12).*

> *I learned that most things are not limited to a single dimension and that there are different dimensions (S22).*

Discussion

In this study, a deliberate selection of Op Art designs crafted by renowned artists, which intricately incorporated mathematical concepts aligned with the middle school curriculum, were selected. Subsequently, students were instructed to replicate these selected designs in the activities. The research undertook a comprehensive examination of both the procedural aspects involved in creating Op Art designs and the perspectives articulated by the students in the process. The data collection involved using observation forms to meticulously record the students' actions and procedures during the creative activities. Additionally, photographic documentation was employed to capture the Op Art designs generated by the students as an outcome of the activities. Furthermore, the research encompassed the solicitation of the students' views through the administration of an open-ended questionnaire.

The outcomes derived from the process of creating Op Art designs revealed that a majority of students demonstrated proficiency in incorporating geometric forms within their Op Art designs. To achieve this, they frequently employed tools such as rulers and compasses to ensure precise construction of these geometric elements. Moreover, congruent with the findings regarding the Op Art design process, the results indicated that engagement in Op Art activities facilitated the cognitive processes associated with conceiving and rendering various geometric configurations such as encompassing parallel lines, intersecting lines, distinct quadrilateral classifications, and circular forms. These activities additionally prompted the application of mathematical principles for the purpose of quantifying alterations made to these geometric configurations. This aligns with existing literature, which posits that Op Art activities offer a conducive platform for acquiring a comprehensive understanding of the fundamental attributes of geometric shapes, exploration of diverse geometric concepts, investigation of symmetry as a concept, manipulation of geometric shape characteristics to achieve visual depth, and acquisition of geometric definitions such as symmetry and similarity (Brewer, 1999; Heskett, 2007).

The present study augments the extant body of literature by investigating the utilization of mathematical principles by middle school students in the context of their Op Art endeavors, thereby enriching the relatively scanty research in this domain. Furthermore, it underscores the significance of Op Art activities in enhancing students' attention towards aesthetic and visual aspects, encompassing precision in geometric rendering, adept handling of color, and the creation of three-dimensional forms. This underscores the proposition that Op Art designs possess the potential to function as a STEAM (Science, Technology, Engineering, Arts, and Mathematics) activity, bridging the realms of mathematics and art, as previously articulated in the works of Çepni (2018), Morari (2023), Ozkan (2022), Perignat, and Katz-Buonincontrö (2019), and Starko (2013).

Upon in-depth analysis of the Op Art designs produced by the middle school students, the investigation identified five distinct categories that pertain to creativity, denoted as Frequency (f=3), Same (f=16), Flexibility (f=40), Originality (f=13), and Deepening (f=13). This outcome resonates with the fundamental objectives of STEAM (Science, Technology, Engineering, Arts, and Mathematics) education, which places a paramount emphasis on nurturing and cultivating creativity skills, as asserted by Perignat and Katz-Buonincontrö (2019).

The process involved in creating Op Art designs, as evidenced in this study, inherently embodies a creative endeavor, and the resulting Op Art products serve as tangible manifestations of creativity, a perspective that aligns with the assertions made by Mercat et al. (2017). Notably, the study revealed that many of the Op Art designs crafted by students exhibited adaptability and originality. Throughout the instructional activities, students were exposed to Op Art designs created by renowned artists in the field, allowing them to emulate these exemplars or formulate their own unique designs. The results indicated that most students opted for the latter, demonstrating their capacity to produce distinct designs.

In essence, these findings underscore the efficacy of Op Art activities as a potent pedagogical tool within the STEAM framework, serving to cultivate and augment creativity skills, a perspective that aligns with the viewpoints articulated by Çepni (2018), Daugherty (2013), Liao (2016), and Perkins (1988).

The present investigation revealed that most of the participating students, totaling 25, expressed favorable opinions regarding the Op Art design activity. Students conveyed that they found the activities to be both engaging and informative, emphasizing their aesthetic appeal. This resonance with student perceptions is consistent with prior studies, which underscores the engaging and instructional nature of Op Art activities, as discussed in the works of Brewer (1999), Heskett (2007), Mercat et al. (2017), and Starko (2013).

Furthermore, a subset of 20 students conveyed a sense of accomplishment in relation to their Op Art designs. They suggested that this sense of achievement was attributed to factors such as diligence, attention to detail, utilization of geometric elements, consideration of mathematical proportions, collaborative teamwork, and the fulfillment of the design process. This observation underscores the discernment that students who perceive their Op Art designs as successful do not solely focus on the ultimate output (i.e., the end product) but also attach significance to the intricacies of the design process itself (Ozkan; 2022; Morari, 2023). This congruence with the multifaceted nature of creative endeavors aligns with the tenets of Vygotsky (2004), who emphasized the integral role of both the process and the outcome in the creative act.

"It must not be forgotten that the basic law of children's creativity is that its value lies not in its results, not in the product of creation, but in the process itself. It is not important what children create, but that they do create, that they exercise and implement their creative imagination." (p. 72)

Additional themes extracted from the responses to open-ended questionnaires encompassed the captivating facets of the Op Art activity, its educational value, and the students' perspectives regarding its incorporation into mathematics instruction. The outcomes from these thematic areas illuminated that a substantial proportion of the students expressed a keen interest in integrating Op Art activities within their mathematics curriculum, recognizing its multifaceted appeal and instructional efficacy. Notably, students found the convergence of geometry and optical illusion within Op Art particularly captivating. This facilitated their comprehension of the concept that geometric shapes and their inherent properties could be harnessed to generate three-dimensional or dynamically shifting visual constructs within the confines of a two-dimensional plane, which is consistent with the observations made by Riley (1999).

In the present study, Op Art design activities were administered to middle school students, encompassing a spectrum of geometric shapes and conveying a perceptual impression of depth, motion, and illusion. Subsequently, the study investigated the students' perspectives regarding their Op Art designs and activities. In future research, it is conceivable to integrate Op Art activities within specific mathematical subjects or concepts. After such tailored Op Art activities are developed, the views and experiences of students and educators involved in the instructional process may be assessed.

Conclusions and Suggestions

The primary focus of this study centered on investigating the perspectives and artistic creations of middle school students engaged in Op Art design activities. Specifically, this research incorporated select designs crafted by renowned Op Art artists, integrating mathematical principles aligned with the middle school curriculum. The outcomes revealed that students predominantly formed geometric shapes and employed instruments such as rulers and compasses to ensure precision in their geometric representations. Engagement in Op Art activities significantly contributed to students' proficiency in conceptualizing and crafting diverse geometric configurations. Additionally, it fostered their competence in applying mathematical measurements and effecting alterations within these geometric constructs. Notably, this study extends the existing body of scholarship by delving into how middle school students harness mathematical concepts within the realm of Op Art activities and underscores the potential of Op Art designs as STEAM activities, integrating mathematical principles with artistic creativity.

Regarding creativity, most Op Art designs created by the students exhibited notable degrees of flexibility and originality. The research underscored the capacity of Op Art activities to foster and enhance creativity skills, aligning with the overarching objectives of STEAM education. Furthermore, the students conveyed positive appraisals of the Op Art design activity, characterizing it as engaging and instructive, and appreciating its aesthetic appeal. Moreover, students attributed their accomplishments in Op Art design to various factors, including diligent effort, careful attention to mathematical proportions, effective teamwork, and an appreciation of the design process itself.

Creativity plays a pivotal role in middle school education, and Op Art provides a remarkable avenue for its cultivation within the framework of STEAM education. With its complex interplay of geometric shapes, optical illusions, and aesthetic appeal, Op Art offers students a dynamic platform to explore and express their creative potential. Studying Op Art in middle school can expose students to the captivating world of visual arts and integrate mathematical concepts seamlessly into the creative process. Through Op Art activities, students can engage in designing captivating and mathematically informed visual compositions, which, in turn, fosters the development of creativity skills. This interdisciplinary approach aligns with the goals of STEAM education, which seeks to develop in students the ability to approach complex problems from multiple perspectives and to harness creative thinking to innovate across various domains.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

We have no conflicts of interest to declare.

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Credit author statement

Authors contribution rates: 1st author %40, 2nd author %20, 3rd author %15, 4th author %15, 5th author %10

Research involving Human Participants and/or Animals

This study has the Bartin University Ethics Committee Approval Document; date: 30.12.2020, protocol number: 2020-SBB-0283.

Ortaokul Öğrencilerinin Op Art ile Matematik Deneyimleri ve Yaratıcılık Becerileri

Özet:

Bu araştırma ortaokul öğrencilerinin Op Art tasarımlarını ve tasarım etkinlikleri hakkındaki görüşlerini araştırmayı amaçlamıştır. Araştırma kapsamında, öğrencilere dört farklı Op Art etkinliği uygulanmıştır. Veri toplama aracı olarak gözlem formu ve açık üçlü anket formu kullanılmıştır. Ayrıca öğrencilerin görüşlerini detaylı bir şekilde elde etmek için birebir görüşmeler yapılmıştır. Toplanan veriler içerik analizi yöntemi kullanılarak analiz edilmiştir. Öğrencilerin Op Art tasarımları frekans, esneklik, özgünlük ve ayrıntılandırma becerilerini içeren yaratıcılık elması modeli kullanılarak analiz edilmiştir. Analizlerin sonucunda matematiksel ifade, görsel ifade ve yaratıcılık becerileri gibi üç temel tema ortaya çıkmıştır. Bu temalar, Op Art etkinliklerinin öğrencilerin matematiksel ve görsel ifade becerilerini geliştirdiğini ve yaratıcılık gelişimlerine katkı sağladığını göstermektedir. Ayrıca, öğrencilerin Op Art tasarımlarına verdikleri yanıtların analizi sonucunda Op Art tasarım etkinliğine dair genel görüşler, beğenilen ve beğenilmeyen yönler, oluşturulan tasarımlara dair başarı algıları, Op Art etkinliğinin heyecan verici yönleri, matematik derslerinde Op Art etkinliklerinin kullanımına ilişkin görüşler ve Op Art etkinliklerinin öğretici yönlerini içeren altı tema ortaya çıkmıştır. Bu çalışma, Op Art etkinliklerinin öğrencilerin yaratıcılık becerilerine, özellikle de esneklik yeterliklerine katkıda bulunabileceğini ve öğrencilerin sonuç ile beraber sürecin de önemli olduğunu keşfetmelerine yardımcı olacağını vurgulamaktadır. Bu bulgular, Op Art etkinliklerinin matematik derslerinde öğrencilerin matematiksel ve görsel ifade becerilerini ve yaratıcılık becerilerini geliştirebileceğini göstermektedir.

Anahtar kelimeler: matematik, geometri, op art, ortaokul öğrencileri, yaratıcılık

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