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The inclusion of GeoGebra in learning rotation of figures for the eighth grade and comparison with the classical teaching method

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Abstract. This study explores the teaching and learning of rotation in eighth-grade geometry, with a focus on comparing traditional methods with the use of GeoGebra software. Students in Kosovo often face challenges in understanding and performing geometric transformations due to conventional pedagogical approaches. Using practical exercises and dynamic visualization in GeoGebra, this study demonstrates how students can better comprehend rotation, preserve distances, and correctly interpret positive and negative angles. A quasi-experimental design was implemented with 68 students from four classes, divided into experimental (GeoGebra) and control (traditional) groups. Data collection included tests, questionnaires, and classroom observations. Results indicate that students using GeoGebra tended to achieve higher accuracy, made fewer conceptual errors, and showed increased engagement compared to traditional instruction. The findings suggest that integrating dynamic software with conventional teaching may support conceptual understanding and visualization of rotation concepts.

Keywords: rotation, geometric transformations, GeoGebra, eighth-grade students, visualization, mathematics education

2020 *Mathematics Subject Classification:* 97C70, 97G10, 97U10

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1. Introduction

In today's digital age, technology offers opportunities to enhance mathematics education through interactive tools that visualize abstract concepts. Despite this potential, many classrooms in Kosovo rely on traditional instruction, where teachers explain geometric concepts using chalk, rulers, and compasses. This approach often results in low engagement and conceptual misunderstandings, particularly for geometric transformations such as rotation.

Rotation is a fundamental geometric transformation that preserves distances and shapes while moving figures around a fixed point by a specific angle. Students frequently struggle to understand positive and negative rotations and to maintain geometric properties during rotation exercises. These difficulties highlight the need for innovative pedagogical approaches that support both conceptual understanding and visualization skills.

GeoGebra, a dynamic mathematics software, allows students to manipulate figures interactively, observe transformations in real time, and verify outcomes visually. Previous research shows that GeoGebra can improve students' understanding of geometry, enhance motivation, and reduce common errors [1, 6]. However, studies focusing on eighth-grade students in Kosovo remain limited.

This study addresses the following research questions:

1. How does the use of GeoGebra affect eighth-grade students' understanding of rotation in geometry?

2. What differences exist between students' learning outcomes when rotation is taught using GeoGebra versus traditional methods?

3. How does GeoGebra influence students' ability to visualize and correctly perform rotational transformations?

4. Which common mistakes are reduced when using GeoGebra compared to traditional instruction?

Using a quasi-experimental design, this study examines how GeoGebra supports conceptual understanding, visualization, and problem-solving in rotation, providing insights for teachers and curriculum designers to improve geometry education [7, 9, 10, 16].

2. Methodology

This study employed a quasi-experimental design to explore the role of GeoGebra in supporting eighth-grade students' understanding of rotation in geometry. The research was conducted in a natural classroom setting and compared learning experiences in classes using GeoGebra with those following traditional instruction.

2.1. Participants

The study involved 68 eighth-grade students from “Pjetër Bogdani” School in Pristina, Kosovo. The participants were organized into four intact classes (VIII/1, VIII/2, VIII/3, and VIII/4). Two classes (VIII/1 and VIII/3) formed the experimental group ($n = 34$), where GeoGebra was integrated into instruction, while the remaining two classes (VIII/2 and VIII/4) formed the control group ($n = 34$), receiving traditional teaching. All students had prior knowledge of basic geometric concepts but limited experience with dynamic geometry software.

2.2. Instructional design and procedure

The study was conducted during regular mathematics lessons focused on rotation as a geometric transformation. In the experimental group, instruction incorporated GeoGebra as a dynamic visualization tool. Students interacted with geometric figures, explored rotations by different angles, and worked both individually and in pairs to solve tasks. The use of GeoGebra allowed students to observe transformations in real time and verify properties such as distance preservation and direction of rotation.

In contrast, the control group followed traditional instruction, where the teacher explained concepts using the chalkboard, ruler, and compass. Students completed similar exercises through manual construction and paper-based problem solving.

2.3. Data collection

Data were collected using three sources: classroom tests, a questionnaire, and classroom observations.

At the end of the instructional period, all students completed a test consisting of rotation tasks designed to assess their ability to correctly perform rotations, interpret angles, and preserve geometric properties.

A short questionnaire was administered only to students in the experimental group to capture their perceptions of understanding, clarity, and engagement when learning with GeoGebra.

In addition, classroom observations were conducted throughout the lessons to document student participation, interaction, collaboration, and common difficulties encountered during the learning process.

2.4. Variables

The study focused on several key aspects of learning rotation:

1. understanding of rotation, defined as the correct execution of rotations with appropriate angle and direction;

2. accuracy, reflected in the preservation of distances and geometric properties;

3. interpretation of angles, particularly distinguishing between positive and negative rotations;

4. engagement, observed through student participation and interaction during lessons.

2.5. Data analysis

Data analysis included descriptive statistics such as mean, standard deviation, and range to summarize students' test scores across the four classes and compare performance between experimental and control groups.

Questionnaire data were analyzed using frequencies and percentages to describe students' perceptions of understanding and engagement when using GeoGebra. A chi-square test and Cramer's V were applied to explore possible relationships between variables, but results were interpreted cautiously due to the small sample size and low expected frequencies.

All questionnaire findings were treated as self-reported perceptions rather than objective learning outcomes.

Classroom observations were analyzed qualitatively to identify patterns in student engagement, collaboration, and learning difficulties during instruction.

2.6. Ethical considerations

Participation in the study was voluntary, and parental consent was obtained for all students. Data were anonymized to ensure confidentiality, and all responses were handled in accordance with ethical standards for educational research.

3. Literature review

While the explanation of rotation is a major challenge for teachers, the interpretation and understanding of rotation by eighth-grade students, who face difficulties and challenges in comprehending the topic, has encouraged substantial research aimed at solving these problems.

There are many scientific works on this topic, each approaching it in different ways, particularly regarding the integration of software applications in the explanation of rotation and geometric transformations. Most of these studies focus on the use of GeoGebra for explaining rotation concepts and geometric transformations.

This scientific work is also based on these studies, where each has reached different conclusions. Mathematics is a powerful tool that requires understanding, respect, and application. In a world where life's challenges often require complex solutions, mathematics provides logical and analytical reasoning that can guide us in daily life. However, despite its importance, mathematics is often considered one of the most challenging subjects for students [13].

We realized that using GeoGebra enhanced one or more modern pedagogical approaches and motivated students to learn mathematics. Based on experiences with students, the study demonstrates that the use of GeoGebra in teaching and learning geometric transformations can positively influence students' understanding.

Based on students' classroom activity, it was also found that GeoGebra helps students visualize abstract mathematical concepts and encourages critical thinking. Using GeoGebra offers a dynamic and insightful journey into the world of mathematics [15].

Research has supported policymakers and curriculum designers in integrating ICT-based pedagogy for 21st-century learners [3].

Studies with students have shown that GeoGebra helps learners retain knowledge related to geometric transformations. Research also demonstrates that GeoGebra can make mathematics more attractive and enjoyable for both students and teachers through improved understanding and interaction.

Increasing the use of ICT applications in mathematics classrooms can help both students and teachers contextualize mathematical concepts [4].

Integrated mathematics lessons depend on the teacher's knowledge of software usage. Therefore, seminars and training programs are necessary for mathematics teachers to become more familiar with how software can be effectively integrated into teaching [12].

4. Transform-rotation

When discussing geometric transformations, we immediately think about figures moving in a coordinate plane, often appearing attractive and engaging to students. Geometric transformations represent changes made to objects in a coordinate plane, either in position or shape [12]. In this context, a transformation does not necessarily imply a change in the figure's shape but rather a displacement.

Practical examples include graphics in video games, mass production of CDs, opening and closing artificial heart valves, and playing musical instruments, all of which involve geometric transformations. In a Dynamic Geometry Environment (DGE), transformations can be determined by dynamic data, such as rotation by a movable angle, helping students understand geometric transformations in a visual and interactive way [6].

Geometric transformations are generally divided into three main categories: rotation, reflection, and translation [5]. In this study, we focus specifically on rotation. Rotation represents the turning of a figure around a fixed point by a specified angle. Every point of the figure moves around this fixed point according to the given angle.

So, figuratively, we have:

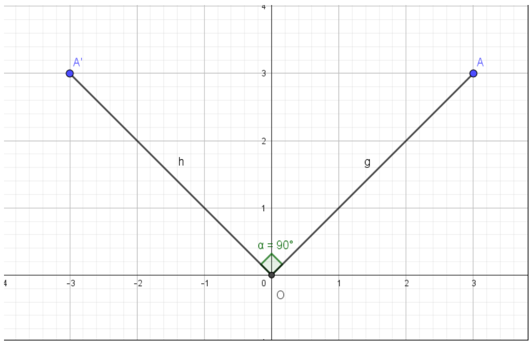

Figure 1. Rotation of the point.

The process of rotating a point (or figure) can be described in the following steps:

1. Select the point or figure to be rotated in the plane.
2. Determine the center of rotation, point O, around which the rotation will occur.
3. Construct the angle α, which defines the amount of rotation.
4. Measure the distance AO and assign the same distance to the new point A'.

In this framework, the angle α represents the amount of rotation, while point O serves as the center of rotation. Regardless of the size of the angle, the rotation always occurs around point O. For example, in a 90° rotation, point A moves to form point A'.

5. Main properties of rotation

Rotation, as a geometric transformation, has two main properties:

1. **Distance preservation:** When a figure rotates around a point, every point maintains the same distance from the center of rotation.
2. **Shape and size preservation:** The figure preserves its original shape and size during the rotation process.

These properties can be illustrated through the following example.

Example 1. Consider rotating a triangle by any angle.

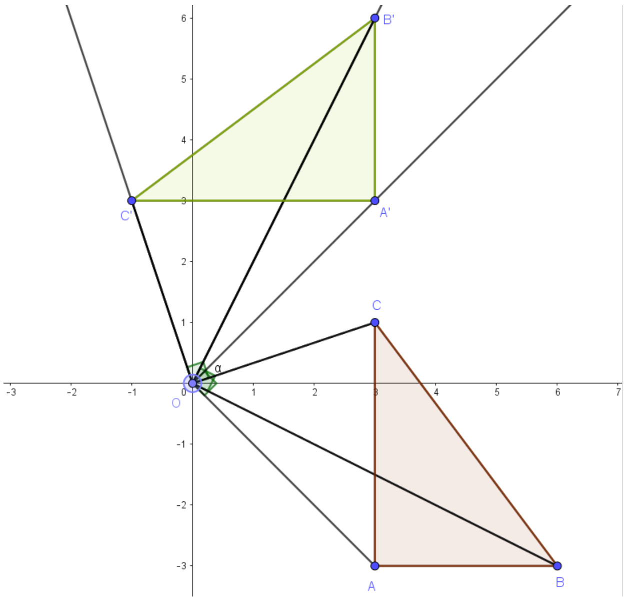

Figure 2. Rotation of the triangle.

In the figure, triangle ABC is rotated by an angle of 90° to form triangle $A'B'C'$. The rotation process is as follows:

1. Each point of triangle ABC is rotated 90° around the center of rotation O.
2. The distances between O and each vertex remain unchanged, satisfying the first property:

$$AO = OA', \quad BO = OB', \quad CO = OC'$$

3. The shape and size of the triangle are preserved. Triangle ABC is right-angled, and after rotation, triangle $A'B'C'$ remains right-angled, confirming the second property.

Thus, this example demonstrates that rotation preserves both the distance from the center and the geometric properties of the figure.

6. Problems of explanation and understanding of rotation and problem solving using GeoGebra

According to the conceptual understanding and visualization framework, students often face challenges when learning rotation. These difficulties include interpreting angles, distinguishing between positive and negative rotation, and maintaining invariance of distances and shapes during rotation.

In this study, understanding is defined as the ability to correctly rotate a figure around a fixed point with the appropriate angle and direction. Visualization refers to students' ability to perceive and manipulate figures dynamically using GeoGebra. Effectiveness is measured through the accuracy of rotated figures and the reduction of common errors compared to traditional instruction.

The following examples illustrate typical challenges students encounter and demonstrate how GeoGebra can support learning [2, 14]. These examples address the research questions concerning conceptual understanding, visualization, and students' ability to correctly interpret positive and negative angles.

Geometry, as a branch of mathematics, often presents difficulties for eighth-grade students, particularly in visualizing abstract transformations. Although students encounter geometric concepts in everyday life, such as in architecture or games, they often struggle to correctly apply these concepts in exercises.

Visualization through dynamic geometry software, such as GeoGebra, provides a practical solution by allowing students to observe figure movements, explore relationships dynamically, and verify properties such as distance and angle preservation.

In classroom instruction, visualization can significantly enhance learning. Rather than relying solely on theoretical explanations and static examples, integrating interactive software like GeoGebra makes lessons more engaging and accessible.

GeoGebra is particularly effective for geometric transformations because it highlights elements of interest, maintains attention through interactive features, and allows students to manipulate figures directly. Technology and internet resources additionally provide supplementary lessons, illustrations, and videos that support mathematical understanding [8].

GeoGebra is an interactive mathematics software application that integrates geometry, algebra, and statistics, suitable for learners from elementary school to university level. It was created by Markus Hohenwarter in 2001/2002 as part of his master's thesis in mathematics education and computer science at the University of Salzburg, Austria.

GeoGebra is available on multiple platforms, including Android, iOS, and desktop environments. The software allows students to solve both geometric and algebraic problems, bringing these mathematical domains together in a single environment that can be applied at all educational levels [10].

7. Some of the mistakes students make when rotating the figures

Although eighth-grade students are often introduced to angles, their construction, and types of angles prior to learning rotation, teachers report that students still encounter difficulties – particularly with the concept of positive and negative angles. One of the main challenges is performing rotations in the negative direction. Students are typically accustomed to working with positive angles, so when asked to rotate a figure negatively, they often make errors despite repeated explanations.

Example 1. Rotate the figure for the angle $\alpha = -60°$.

The solution was made by the students in this form:

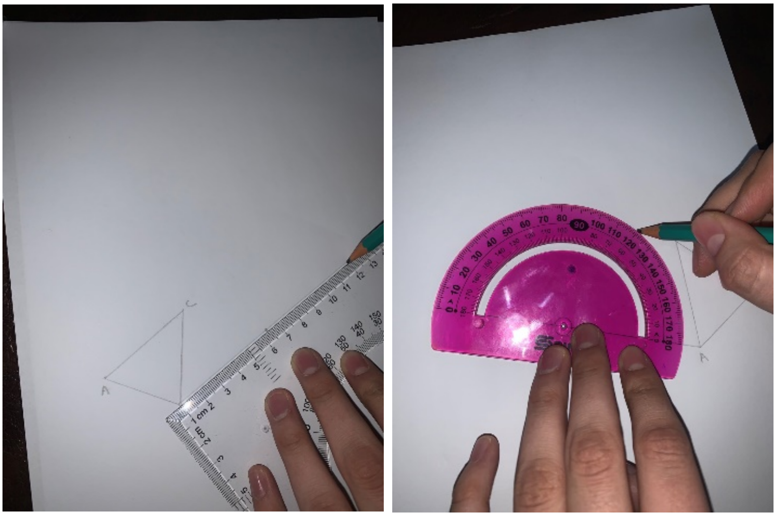

Figure 3. The example solved by the student and their mistakes.

As shown in Figure 3, the student rotated the triangle in the wrong direction. To address this problem, teachers can use the analogy of a clock.

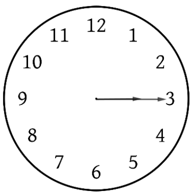

Figure 4. Positive angle of rotation.

Then if the time is 3:15 then both hands are local one above the other where the angle is in this case $0°$. The positive angle is obtained if we move the hand in the opposite direction to the usual movement made by the clock, so the clock will take this view:

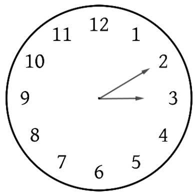

Figure 5. Positive angle of rotation.

So the clock in this case has gone to 3:10, so it has gone backward where the angle that is obtained between the hands of the clock is the required positive angle.

We will do the same with the negative direction. If we have the clock again at 3:15, then:

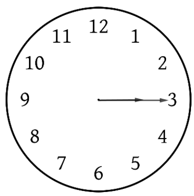

Figure 6. Negative angle of rotation.

To form the negative angle, the hands of the clock should move as usual as the hands move and thus the clock we have is:

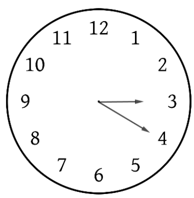

Figure 7. Negative angle of rotation.

So the clock tells us that it is 3:20, so the clock has continued to work as usual and the angle formed between the hands of the clock is the negative angle.

Another common difficulty for students is maintaining the distance between the center of rotation and the points of the figure. Students often do not realize that after rotation, the distance from the center to each point must remain unchanged.

Example 2. Rotate the figure for the angle $\alpha = 120°$.

The student solved it in this way:

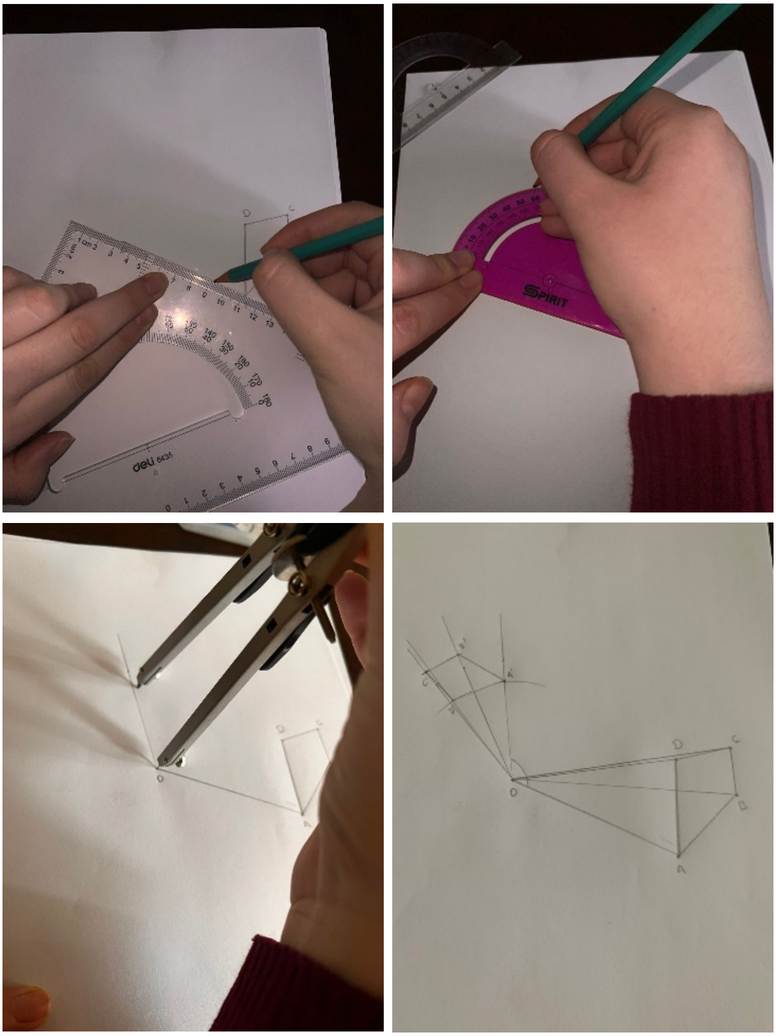

Figure 8. The example solved by the student and his mistakes.

In Figure 8, the student rotated the triangle by 120° correctly in terms of angle, but did not preserve the lengths:

$$AO \neq OA', \quad BO \neq OB', \quad CO \neq OC'$$

To address these challenges, the **GeoGebra program** can be used effectively. GeoGebra allows students to visualize rotations dynamically, providing immediate feedback on both angles and distances. For instance, rotating the segment AB by 60° in GeoGebra clearly shows the equality of lengths AO and OA', which is often a point of confusion for students.

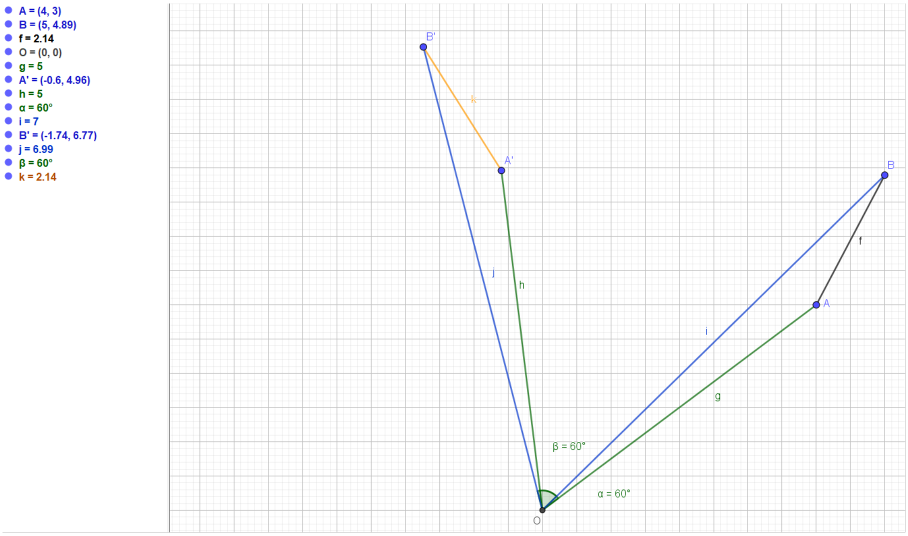

Figure 9. Explanation of the problem.

By using GeoGebra, students can directly see which elements of a rotation are preserved, reducing misconceptions and eliminating guesswork. This interactive visualization helps students internalize the properties of rotation and enhances their conceptual understanding.

After clarifying the problems that eighth graders constantly encounter about the meaning of elements that are not very understandable for the student and approach the problem so that they do not have to guess about these issues.

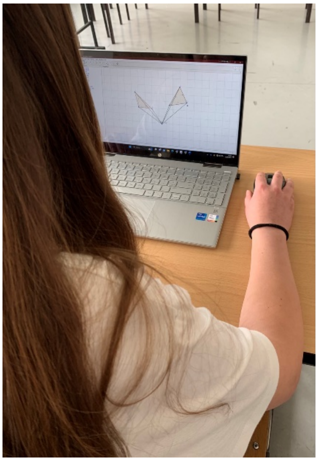

Figure 10. Students while working with GeoGebra software.

In conclusion, the combination of analogies (like the clock) and dynamic geometry software allows students to overcome common difficulties with rotation, including interpreting positive and negative angles and maintaining distance from the center of rotation. These methods provide concrete and visual support, making abstract concepts more accessible and reducing common errors.

8. Comparison of the classical method and the contemporary method in solving different examples related to rotation

The classical method of teaching geometry often proves less effective for students, particularly in eighth grade, where geometric concepts become more abstract. Traditional instruction typically centers on the teacher using chalk, rulers, and compasses, while students follow procedures mechanically.

This approach frequently causes students to lose concentration and overlook important steps, making it more difficult to understand and internalize the concepts being taught. As a result, geometry is often perceived by students as difficult or uninteresting.

In contrast, contemporary methods using dynamic mathematics software, such as GeoGebra, offer an interactive and visual approach to learning.

GeoGebra serves as both a pedagogical and mathematical aid, supporting instruction from elementary school to university level. It enables students to manipulate figures dynamically, observe transformations in real time, and visually verify mathematical results. This immediate feedback enhances understanding and reduces misconceptions [11, 15].

Example 3. Perform the rotation of the figure for the angle $\alpha = 90°$.

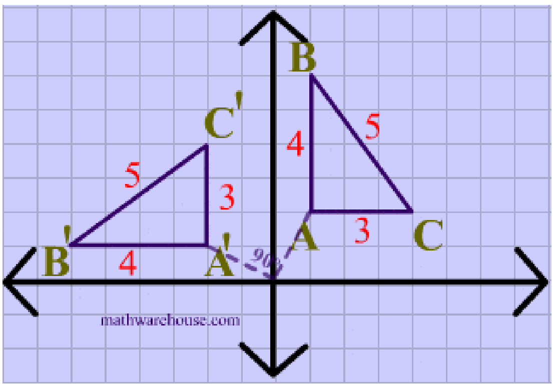

Figure 11. Explanation of the problem.

In a traditional classroom setting, this rotation would typically be performed through manual construction, as shown below:

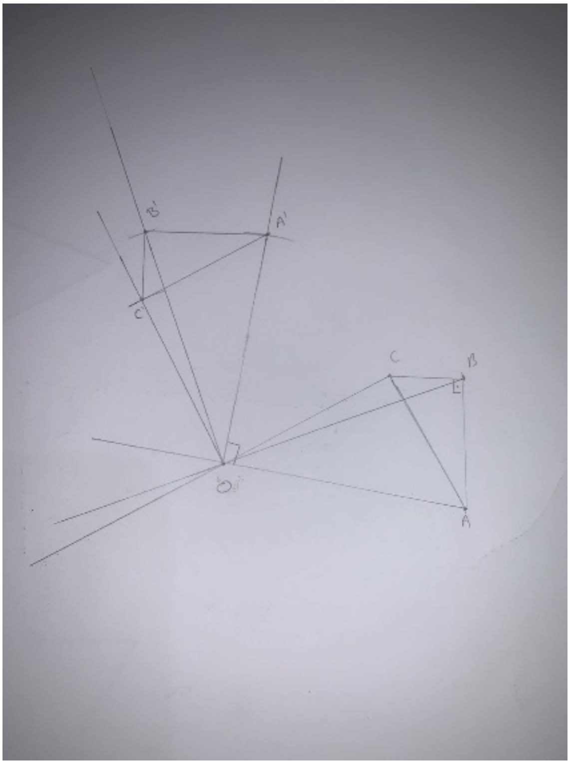

Figure 12. The example solved by the student and their mistakes.

For students, the GeoGebra animation shown in Figure 11 is generally easier to understand than the classical method presented in Figure 12. Dynamic visualization allows students to observe the entire rotation process, including the movement of points and the preservation of shape and size.

By contrast, the classical approach often depends on procedural memorization, which students may forget, resulting in weaker conceptual understanding.

Example 4. Rotate the quadrilateral by the angle $\alpha = 45°$.

The solution was completed by the student using the GeoGebra program. The student solved it in the following way:

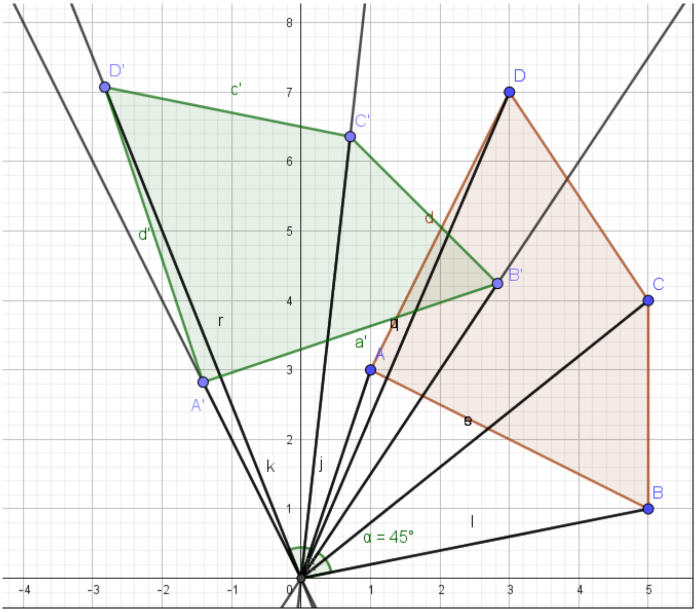

Figure 13. The graph of the results of the students in the test.

Using GeoGebra, the student successfully completed the rotation without errors. The quadrilateral preserved both its shape and size, demonstrating the correctness of the rotation.

This example illustrates that contemporary teaching methods, especially those involving interactive software, provide clear visual feedback that strengthens conceptual understanding and reduces errors.

9. The influence of illustrations, visualization, and animations on the understanding of rotation

The questionnaire was administered to 34 eighth-grade students from the experimental group to investigate their perceptions of understanding while learning geometric rotation supported by GeoGebra.

The purpose of this instrument was not to directly measure achievement, but rather to explore students' self-reported understanding, clarity of concepts, and confidence when using dynamic visualization tools in learning geometry.

Questionnaire

1. Whether students felt they understood the lesson better with the help of GeoGebra:
   A) Yes B) No

2. Whether students felt they understood how the process of rotating a figure is performed:
   A) Yes B) No

Since both questions refer to related aspects of perceived understanding, a chi-square test of independence was applied to examine whether there is a relationship between general lesson comprehension and understanding of the rotation process.

Table 1. Observed frequencies.

	Rotation Understanding: Yes	Rotation Understanding: No	Total
Lesson Understanding: Yes	22	5	27
Lesson Understanding: No	4	3	7
Total	26	8	34

Table 2. Expected frequencies.

	Rotation Understanding: Yes	Rotation Understanding: No	Total
Lesson Understanding: Yes	20.6	6.4	27
Lesson Understanding: No	5.4	1.6	7
Total	26	8	34

The observed frequencies show that most students who reported understanding the lesson better with GeoGebra also reported a clear understanding of the rotation process.

To formally test this relationship, a chi-square test of independence was conducted. The analysis produced the following result:

$$\chi^2(1, N = 34) = 5.43, \quad p < 0.05$$

To determine the strength of the relationship, Cramer's V was calculated:

$$V = 0.40$$

This value indicates a moderate association between students' perceived lesson understanding and their perceived understanding of rotation.

10. Interpretation of test results and their discussion

Classroom observations supported the questionnaire findings. Students in the experimental group:

- engaged actively with the software, experimenting with rotations dynamically;
- made fewer mistakes in rotating figures, particularly in distinguishing positive and negative angles;
- demonstrated better preservation of distances and shape properties during rotation exercises.

In contrast, students in the control group often required repeated explanations from the teacher and made more errors when performing rotations manually.

These findings suggest that GeoGebra supports students' conceptual understanding of rotation by providing dynamic visualization and interactive exploration. The chi-square test confirms a significant positive association between software use and perceived understanding, while observational data highlights improved accuracy, engagement, and confidence in performing rotations.

The understanding of rotation is an essential part of the understanding and expansion of knowledge related to transformations as well as in the understanding of geometry in general.

As for the exam in general, it contained exercises that were explained in class, the exam also contained other exercises related to transformations. We will focus on the exercises related to rotation, since their main difficulty in transformations is rotation.

Although teachers tried to explain and make this topic clearer, the expectations regarding student mistakes were partially confirmed. Students who were active in homework, regularly attended classes, and participated in extra hours generally did not encounter problems. In contrast, students who were less active, irregular with homework, and less engaged during class experienced greater difficulties in solving rotation exercises.

Regarding homework, students completed four homework assignments. Classroom activities were mainly based on pair work, where students solved rotation exercises together. This method showed satisfactory results, as students supported one another while solving the exercises. Another activity included the use of GeoGebra to explain and interpret rotations and then solve exercises on the table.

Although eighth-grade students were not very familiar with GeoGebra at the beginning, they adapted quickly and performed successfully while solving exercises with the software.

All these activities formed part of the mathematics lesson. The test was similar to homework tasks, although some additional requirements were included.

Below are exercises solved from the test related to rotation, where comparisons between classes are presented. In total, there were two exercises involving rotation.

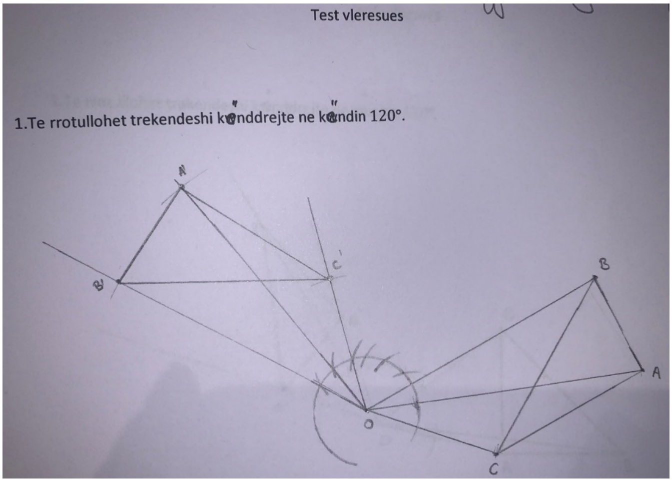

Figure 14. The first exercise of the test was solved by a student of the class where GeoGebra was included.

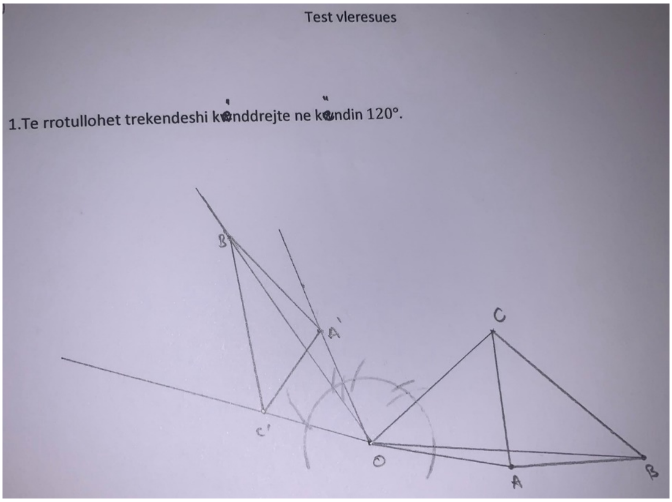

Figure 15. The first exercise of the test was solved by a student of the class where GeoGebra was not included.

In the first figure, the exercise was solved by a student who was moderately active in the classroom as well as regular with exercises. In this class, the modern method of explanation was used, where the exercise was solved correctly and understood clearly and logically.

In contrast, the second figure presents an exercise solved by a good student from another class, where the traditional teaching method was used without GeoGebra software. As observed in the image, the student made an error during the rotation of triangle ABC. The student constructed the angles correctly but failed to preserve the lengths. Therefore, the rotation was not correct and the exercise was solved incorrectly.

Now we will examine the second exercise of the exam in both classes.

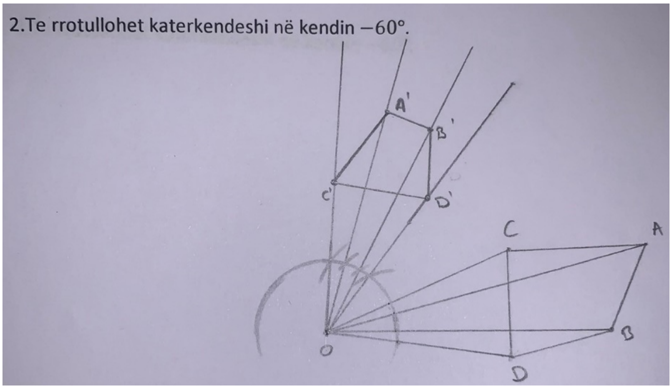

Figure 16. The second exercise of the test solved by a student of the class where GeoGebra was not included.

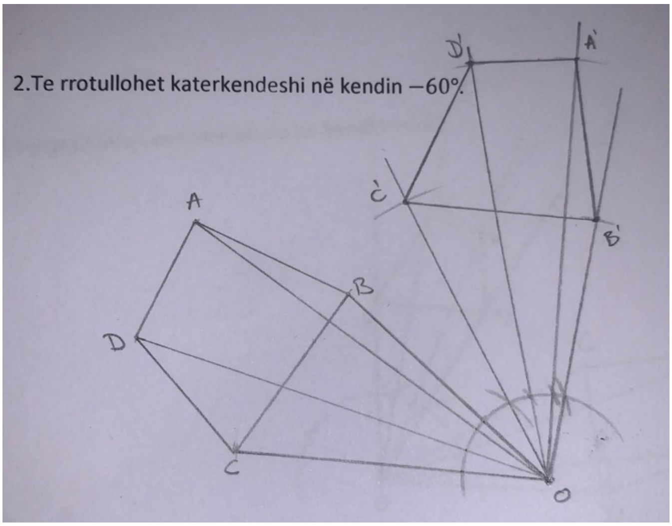

Figure 17. The second exercise was solved by a student of the class where GeoGebra was included.

The second exercise of the exam, related to rotation, was more difficult than the first because students had to rotate a quadrilateral.

In the first image, the exercise was solved by a student from the class where the traditional method was used. At first glance, it can be observed that the student made mistakes in preserving lengths and also incorrectly determined the negative direction of rotation.

In the second figure, the exercise was solved by a student from the class where the modern method using GeoGebra was applied. The student solved the exercise correctly and without errors.

11. Results

The performance of students in four eighth-grade classes (VIII/1, VIII/2, VIII/3, and VIII/4) was analyzed to examine differences in understanding rotation in geometry. Classes VIII/1 and VIII/3 used GeoGebra (experimental group), while VIII/2 and VIII/4 followed traditional instruction (control group).

Table 3. Table of results of students in the test.

VIII/1	VIII/2	VIII/3	VIII/4
100	85	100	65
100	0	89	50
85	52	100	0
90	86	68	10
82	90	95	88
73	65	65	90
84	53	85	95
92	20	87	60
87	30	84	52
86	55	96	20
94	58	66	80
99	54	84	82
66	62	82	55
50	68	92	20
62	75	30	65
90	55	66	57
81	65	52	85
82.6	57.2	78.1	49.47

Table 3 presents the individual test scores of students in each class. The maximum possible score was 100 points. The mean scores for each class were as follows: VIII/1 = 82.6, VIII/2 = 57.2, VIII/3 = 78.1, and VIII/4 = 49.47.

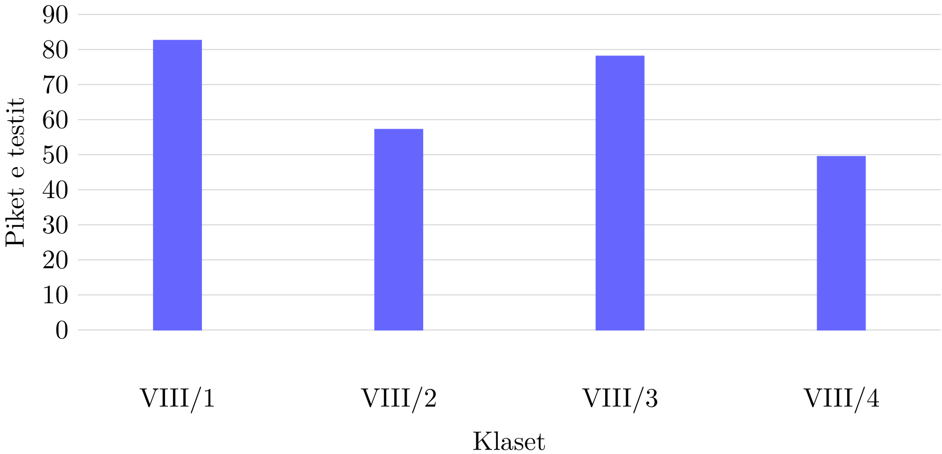

Figure 18. The graph of the results of the students in the test.

A comparison of class averages shows that students in the GeoGebra-supported classes (VIII/1 and VIII/3) achieved higher mean scores than students in the traditional-method classes (VIII/2 and VIII/4). The experimental-group averages (82.6 and 78.1) were notably higher than those of the control group (57.2 and 49.47), indicating a tendency toward better performance in classes where GeoGebra was used.

The graphical representation of the results (Figure 18) further illustrates this pattern, showing consistently higher scores in the experimental group compared to the control group.

In addition to overall performance, student errors were analyzed in two rotation exercises.

In Exercise 1 (triangle rotation), students in the GeoGebra classes generally completed the task correctly, preserving both distances and angles. In contrast, some students in the traditional-method classes made errors in maintaining distances between points and in constructing angles, resulting in incorrect rotations.

In Exercise 2 (quadrilateral rotation), students using GeoGebra were able to rotate the figure accurately while preserving its geometric properties. Students in the traditional classes, however, showed more frequent errors, particularly in maintaining correct distances and identifying the correct direction of rotation.

Overall, the results suggest that the use of GeoGebra may support students' understanding of rotation by improving accuracy and reducing common conceptual errors. However, these findings are based on descriptive comparisons and should be interpreted within the limitations of the study design.

12. Discussion

The results of this study indicate that the use of GeoGebra has a positive effect on students' understanding of geometric rotations. This improvement can be explained by the role of dynamic visualization in supporting spatial reasoning and conceptual clarity in geometry learning.

12.1. Accuracy and conceptual understanding

Students who used GeoGebra demonstrated fewer errors in constructing angles and preserving distances compared to students in the traditional group. The dynamic nature of the software allowed students to visualize rotation processes in real time, which supported a deeper understanding of both positive and negative rotations and the invariant properties of geometric figures. These findings align with previous research emphasizing the importance of visualization tools in developing conceptual understanding in geometry.

12.2. Engagement and motivation

Classroom observations indicated that students in the experimental group were more actively engaged in the learning process. The interactive nature of GeoGebra encouraged exploration, experimentation, and collaboration among students. In contrast, students in the control group relied more on teacher explanations and showed lower levels of active participation. This suggests that technology-enhanced learning environments may increase student motivation and classroom interaction.

12.3. Collaborative and independent learning

Pair-based activities combined with GeoGebra supported both collaborative and independent learning. Students were able to test ideas, verify results instantly, and correct their mistakes without waiting for teacher feedback. This immediate feedback mechanism appears to strengthen conceptual understanding and reduce persistent misconceptions in rotation tasks.

12.4. Blended learning approach

Student feedback suggests that combining GeoGebra with traditional instruction could further improve learning outcomes. A blended approach may provide the structure of traditional teaching while maintaining the benefits of dynamic visualization. This combination could be particularly effective in ensuring both conceptual clarity and procedural understanding.

12.5. Student feedback and observations

To complement quantitative results, student feedback was analyzed to better understand learning experiences. **High-performing student (A.R., VIII/1)** The student who achieved the highest score reported that GeoGebra significantly supported his understanding of rotation. He emphasized that the dynamic visualization helped him understand angle direction and distance preservation, which contributed to his strong performance in tests. **Less engaged student (VIII/1)** A student with lower classroom participation reported difficulties in understanding rotation, indicating that limited engagement with GeoGebra reduced learning effectiveness. This suggests that the benefits of the software depend on active student involvement rather than passive observation. **Across-group perspectives** Students in the experimental group generally perceived GeoGebra as helpful for understanding and motivation. Students in the control group expressed interest in using similar tools, suggesting that integrating technology into traditional teaching could improve engagement and performance.

13. Conclusions

The findings of this study demonstrate that the integration of GeoGebra significantly improves students' understanding of geometric rotations. The use of dynamic visualization supported students in developing more accurate spatial reasoning, particularly in preserving distances, angles, and correct rotational direction. Compared to traditional instruction, students exposed to GeoGebra showed a clearer conceptual understanding and reduced frequency of common errors in rotation tasks.

In addition to cognitive improvements, the study also found increased student engagement and motivation during the learning process. Interactive and collaborative activities enabled students to actively explore geometric transformations, which contributed to stronger conceptual learning. The results also suggest that even students with limited prior experience in technology can successfully adapt to and benefit from GeoGebra-supported instruction.

Overall, the study highlights the pedagogical value of integrating dynamic geometry software into mathematics teaching. It is recommended that educators adopt a blended instructional approach that combines traditional teaching methods with interactive digital tools such as GeoGebra. This approach can enhance students' conceptual understanding, support long-term retention, and improve overall learning outcomes in geometry and related mathematical topics.

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