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Improving the efficacy of mathematics education with open-ended problems and technological integration

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ABSTRACT

Nowadays using open-ended problems and technology in mathematical educations is a significant path between theory and its practical applications. Consequently, employing these problems and technological tools in their teaching can transform them into a powerful tool for developing students' mathematical knowledge and critical and creative thinking. This paper treats the impact of open-ended problems and the application of technology in their solutions on the acquisition of students' mathematical knowledge and the enhancement of their creativity. This study included 188 students from two high schools located in distinct cities in Albania. The topics of geometric transformations were introduced to them, followed by a final assessment and a semi-structured interview. The topics of geometric transformations were developed with them, and then, through a final test and a semi-structured interview, the findings were analyzed regarding the impact of open-ended problems and the use of technology in solving them, both on the acquisition of mathematical knowledge and on increasing students' creativity. The analysis of students' attitudes towards these approaches was conducted using questionnaires, through which their motivation to engage in the learning process was analyzed as well as the increase in confidence in their mathematical skills.

Keywords: open-ended problems, technology in teaching, students' creativity, geometric transformations, mathematical skills

INTRODUCTION

The teaching of mathematics has experienced ongoing evolution, adjusting to the requirements and advancements of contemporary society. Teaching mathematics continues to pose a challenge for teachers, necessitating both the conveyance of mathematical principles and the cultivation of students' critical and creative thinking skills.

Innovative approaches in mathematics education in Albania seek to establish a contemporary framework by emphasizing conceptual understanding, cognitive processes, practical problem-solving, and the integration of technology in their solutions.

Digital technologies have created new opportunities for education and specifically for mathematics education, such as representation and visualization, exploration, manipulation, modelling, scenario identification, conjecture encouragement, and justification and generalization support. These technologies facilitate deeper engagement with subjects and foster the development of advanced analytical abilities among students.

Despite the educational reforms in Albania from 2005 to 2018 and the establishment of computer laboratories in numerous schools (Reforma Kurrikulare, n. d.), many teachers continue to use on conventional teaching methods. Students frequently disengage and find it challenging to relate mathematical principles to real-world issues, as well as to utilise technology for solving mathematical difficulties. The PISA 2022 findings indicate that Albanian pupils scored below the OECD average in critical thinking, suggesting that the anticipated standards for mathematics instruction were not achieved (OECD, 2024). From the analysis carried out by the Albanian education authorities, it was emphasized that one of the reasons for the poor performance in the PISA test was the inability of students to adapt to the ways of solving test questions through technology.

Consequently, it is essential to investigate the use of effective methods to improve students' critical and creative thinking abilities, as well as their technological abilities.

One approach involves the utilization of open-ended problems. Such issues not only facilitate the acquisition of problem-solving techniques but also act as a catalyst for enhancing creativity and critical thinking (Stanikzai, 2023). This method may motivate students to analyze a problem from multiple viewpoints and provide diverse solutions, a crucial talent for navigating the challenges of the 21st century employment market (Stanikzai, 2023).

However, while open-ended problems present significant chances for knowledge and problem solving skills progression, they can be difficult to face in traditional educational environments, which often emphasize a singular, standard solution. Conversely, the utilization of technological instruments, such as mathematical software, educational applications, and online platforms, affords several chances for the exploration and resolution of mathematical issues from diverse perspectives, allowing students to freely test, modify, and refine solutions.

This paper attempts to find out if the incorporation of open-ended problems and the integration of technology in their resolution might enhance mathematical knowledge and foster critical and creative thinking skills in students.

Open-ended problems and the integration of technology are the focus of various scientific investigations that examine their objectives and implementation in mathematics education. Innovative approaches are perpetually pursued to enhance students' creativity and adaptability to societal transformations and labor market requirements. "Facilitating the development of young individuals as adept problem-solvers entails equipping them to think mathematically and to confront life's challenges with assurance in their problem-solving capabilities" (McIntosh & Jarrett, 2000).

Problem solving is a fundamental competency within the mathematics curriculum of Albania's pre-university education program, establishing the enhancement of critical thinking and the application of logical reasoning in everyday contexts as the main goal of mathematics teaching (Balliu, 2023). Similarly, Mathematics National Curriculum (1989) highlights that the primary objective of mathematics education is "the cultivation of an individual's capacity to investigate, hypothesize, and reason logically, along with the proficiency to adeptly employ diverse mathematical techniques to resolve non-routine problems".

Stanikzai (2023) defines critical thinking as an intentional and self-regulating judgement that leads to interpretation, analysis, assessment, and conclusions (Stanikzai, 2023). According to Rahayuningsih et al. (2021), creative mathematics ability includes the potential to devise methodologies, inventions, and diverse approaches to problem-solving.

While researchers vary in their definitions of open-ended problems, an understanding exists that these problems possess several techniques of resolution and yield several distinct, yet accurate answers.

Bahar (2015) categorizes mathematical problems as " open or ended" depending on the number of alternatives available to the problem solver. Compared with closed problems, where the solution method is fixed and a singular correct answer exists, open-ended problems may possess an unlimited variety of solving manners (Bahar, 2015).

Conversely, McIntosh and Jarrett (2000) characterizes open-ended problems as those that possess more than one valid outcome and allow various solution methods. The emphasis lies not on the solution to the problem, but on the methodologies employed to get an answer.

In mathematics education, open issues are typically non-routine challenges that allow for interpretative flexibility, accommodate many valid solutions, and permit diverse problem-solving methodologies (McIntosh & Jarrett, 2000).

Open-ended problem solving provides a free and supportive educational atmosphere, enabling students to cultivate and articulate their investigation, collaboration with peers, discovery, and mathematics comprehension (Kosyvas, 2016).

Researchers conclude that the open-ended problem-solving methodology positively influences the improvement of student's knowledge of math. Working with multiple solution strategies can improve students' critical thinking abilities, expand their capacity to utilize diverse approaches, and raise student involvement and motivation (Dreyfus & Eisenberg, 2012).

The problem-solving process, as a multifaceted human activity, encompasses significantly more than mere fact recollection or the application of established techniques (Lester, 1994). Therefore, merely memorizing formulas and procedures is inadequate for problem-solving. Bahar (2015) asserts that "cognitive talents, including intellect, creativity, and originality, are significant elements influencing performance in mathematical problem solving during this intricate process" (Bahar, 2015). Research indicates that pupils possess diverse learning styles and needs, so a uniform approach may restrict their involvement and progress (OECD, 2023). Conventional pedagogical approaches, characterized by rote memorization and instructor-centric techniques, frequently do not address the educational requirements of numerous pupils who may be engaged learners. Engaging with challenges that have many solutions enables students to use their knowledge in diverse contexts while also obtaining fresh insights (Niyazova, 2022).

As Stanikzai's (2023) research indicates that "promoting critical thinking enhances academic performance, problem-solving capabilities, and advanced cognitive skills in students asserts" that open-ended problems might stimulate students' creative thinking through critical analysis and assist them in generating novel ideas.

While Forthmann (2019) emphasizes that open-ended problems can encourage students' creative thinking through critical thinking and help them build original ideas. Because when students encounter mathematical ideas that interest and challenge them, they are more likely to experience a kind of personal fulfillment that motivates and keeps them engaged.

Mathematics groups that utilize highly active mathematical thinking skills through open-ended problems effectively cultivate creative problem-solving abilities, thereby better preparing students for real-life situations beyond the classroom, contrasting with many traditional classrooms that emphasize ended problems (Bonotto, 2013).

Technology significantly contributes to the advancement of mathematical cognition, facilitating novel methods of knowledge retrieval. It presents novel paradigms of thought and understanding, resulting in a reconfiguration of cognitive processes (Borba & Villarreal, 2005). Technology's application in education manifests in various forms: students may rely on tools, accepting their outputs uncritically, students may utilize tools to enhance efficiency and productivity; or technological tools may function as collaborators, offering feedback that encourages students to engage further, thereby embedding technology as a crucial component of their mathematical comprehension (Jacinto & Carreira, 2017, 2023). Digital tools are characterized as regulators of human cognition, cognitive and creative collaborators, or extensions of the cognitive self (Koyuncu et al., 2015; Kuzle, 2017).

According to Klančar et al. (2019), the use of digital technologies in the teaching and learning process enables the design of rich learning environments through the use of various digital materials such as simulations, animations and applications.

These tools provide many pedagogical approaches, including experimentation, simulation, modelling, and exploration, thereby addressing both routine and non-routine mathematical challenges.

Technology approaches several methodologies for problem-solving, including visualizations, graphs, and diagrams, which can produce visual representations of answers. These facilitate students' comprehension of the process and enable firsthand observation of how variations in parameters influence outcomes (Santos-Trigo, 2013). Kaput and Thompson (1994) delineated three fundamental features of employing technology to facilitate transformation in the teaching and learning of mathematics:

The first feature is interactivity, facilitated by computers, enables students to observe the outcomes of their activities, interpret them, reflect, and subsequently act again. These fosters enhanced and more vigorous student participation.

The second feature is connected with design facilitates problem-solving and can shape students' mathematics experiences. And the last one is connectivity among teachers and students, and the relationship between education and the external realms of home and work enhances students' mathematics experiences.

Furthermore, the use of digital technologies in mathematics enables students to participate actively and prepares them to address intricate problems (Ayan & Bostan, 2018). In recent years, various research have been undertaken about the application of technology in problem-solving (Hernández, et al., 2019; Minsky, 1961; Santos-Trigo, 2019; Tanjung et al., 2020).

THE ALBANIAN CONTEXT OF USING OPEN-ENDED PROBLEMS AND TECHNOLOGY IN TEACHING AND LEARNING MATHEMATICS IN SECONDARY SCHOOLS

The Albanian preuniversity education system is undergoing a comprehensive reform that encompasses the entire educational framework, including curricular documentation, learning organization and assessment, initial teacher training reform, qualification and professional development of educational personnel, and the physical infrastructure of educational institutions. A fundamental aspect of this reform is the revision of the curriculum, encompassing the mathematics curriculum (Reforma Kurrikulare, n. d.).

The mathematics curriculum for Albanian preuniversity education states that the objective of school mathematics is to facilitate the individual development of students, allowing them to seamlessly apply mathematical knowledge, skills, methods, and reasoning in various other fields of study. It provides students with frameworks of mathematical reasoning, essential concepts and structures, as well as the mathematical knowledge and abilities required for life and advanced education (Reforma Kurrikulare, n. d.).

The high school mathematics curriculum strives to develop essential competencies like problem solving, mathematical reasoning and evidence, mathematical communication, modelling, conceptual connections, and technological application.

The teaching of mathematics in upper secondary school seeks to cultivate students' logical and critical reasoning, to investigate mathematical concepts, and to identify similarities, differences, patterns, and causal connections, between phenomenon, to foster imaginations, encourages problem-solving through diverse methods, and enhances motivation to study mathematics as a field that has significant importance in social and professional life.

In the Albanian secondary education system, mathematics textbooks are modified editions of Oxford and Cambridge publications that conform to the national curriculum. Nevertheless, teachers and textbooks infrequently provide pupils with this expansive viewpoint on mathematics that fosters innovation (Matematika 10, 2021; Matematika 11, 2022; Matematika 12, 2022; Matematika 12 [Me Zgjedhje], 2022).

Teachers sometimes neglect open-ended problems, even when they exist in the textbooks, due to a general lack of familiarity with such assignments. Moreover, despite this reform encouraging the integration of technology in education and the Albanian government's investment in IT laboratories in schools, its application in mathematics teaching is still constrained. This mostly results from instructors' insufficient training in ICT and deficiencies in the use of digital skills.

A study conducted by the department of mathematics at the faculty of natural sciences, University of Tirana, reveals that teachers' perceptions of technology use in mathematics necessitate immediate attention, despite efforts by governments and stakeholders to tackle certain challenges. Technological instruments are ineffectual if users lack the requisite skills or appreciation for them (Dara et al., 2024).

Prior research conducted by Albanian scholars about the application of technology in mathematics education, specifically with open-ended problems, is virtually absent. This study examines the application of open-ended problems and the incorporation of technology in their teaching.

The common opinion of the authors of the studied literature is that the use of open-ended problems not only stimulates students' creativity and critical thinking but also helps them improve their academic knowledge. Also the use of technology in teaching mathematics enables simulations and visualizations that help students see and understand how different results can be achieved through different methods. So, in this paper, we will study the effect of the use of open-ended problems and technology in solving them on the level of knowledge, in stimulating creative thinking and in motivating high school students in Albania. Furthermore, considering the examined literature's deficiency in addressing students' attitudes and perspectives towards open-ended problems and the integration of technology in their learning, our study also examines this dimension (Mohd & Mahmood, 2011; Sturm & Bhndick, 2021; Zakaria & Ngah, 2011).

MATERIALS AND METHODS

This study, undertaken as part of a project named "*The impact of using information technology in teaching and learning mathematics in Albanian secondary education"* by the department of mathematics at the faculty of natural sciences, University of Tirana, with the support of the National Agency for Scientific Research and Innovation, focused on two primary aspects: first, to analyze the influence of open-ended problems and the integration of technology in their instruction on students' acquisition of mathematical knowledge; and second, to figure out how the application of open-ended problems and technology in their resolution impacts the enhancement of students' creativity, assessed through a parameter derived from the Torrance (1969) tests of creative thinking method.

The purpose of this study was to examine how open-ended problems and the application of technology to their solutions affect Albanian high school students' subjective attitudes toward these kinds of problems and this teaching method, as well as how they improve their mathematical knowledge and develop critical and creative thinking.

The research questions used in this study are as follows:

1. How do open-ended problems and the use of technology in solving them affect the acquisition of mathematical knowledge among upper secondary students?
2. How do open-ended problems and the use of technology in solving them influence the development of students' mathematical creative thinking in upper secondary education?
3. What are students' attitudes toward open-ended problems and the use of technology in solving them?

Based on the research questions above and the reviewed international literature, the following hypotheses are proposed. The use of open-ended problems and technology in solving them:

(1) enhances students' mathematical knowledge,

(2) improves students' creativity and critical thinking, and

(3) encourages interest and motivates students to learn mathematics.

The method used in this study is the quasi-experimental approach. This methodology allows for the comparison of results between an experimental group (EG) and a control group (CG), assessing the effectiveness of a teaching intervention based on the use of open-ended problems and technology integration in their instruction.

The research **population** consists of high school students. As part of the study project *"The impact of the use of information technology in the teaching and learning of mathematics in Albanian secondary education",* an initial analysis was conducted on the availability and use of technology in mathematics teaching in Albanian high schools. For this specific study, a sample of 188 students (six 10th grade classes) was selected from two Albanian high schools located in Tirana and Shkodër. This age group was chosen because students' critical and creative thinking skills are still in development at this stage (Insel et al., 2022; Konrad et al., 2013). The experiment involved the implementation of lessons on geometric transformations, which are part of the curriculum for this grade level.

The students were divided into two main groups:

1. **The EG**, which consisted of two subgroups: one (62 students) followed a teaching methodology based on open-ended problems, and the other (66 students) followed a methodology that integrated the use of technology in teaching and in solving open-ended problems.
2. **The CG** (60 students) followed the same lessons but taught through the traditional teaching method by their teachers.

The division of students into groups was carried out in such a way that the average grade in mathematics and its standard deviation were approximately the same across groups, in order to minimize the impact of prior knowledge on the results of the final test. The 10th grade mathematics curriculum includes six lessons on geometric transformations, which review and deepen knowledge on axial symmetry, central symmetry, rotation, parallel translation, homothety, and the composition of two or more transformations. In the two classes of the CG, these lessons were taught using traditional methods (teacher-centered teaching). In the two classes of the first experimental subgroup, these topics were covered using open-ended problems adapted from the mathematics textbook to illustrate the concepts. In the second experimental subgroup, the same topics were taught using GeoGebra to solve open-ended problems, as in the first experimental subgroup. The classrooms used for the second experimental subgroup were equipped with computers and smart boards.

To collect reliable and comprehensive data, three main research instruments were used:

1. **Final test:** A test consisting of three problems. The first two problems, related to transformations, are closed problems assessing standard knowledge of geometric transformations. Both problems were selected from the official 10th-grade mathematics textbook. The third problem is an open-ended problem, offering various solution methods and multiple correct answers, focused on geometric transformations. The test was administered to all students in the sample and was graded based on the accuracy of the solutions and the level of knowledge acquired regarding geometric transformations. (see **Appendix A**).
2. **Semi-structured interviews:** Interviews were conducted with students from each group who worked on solving open-ended problems in the test, in order to better understand their reasoning, the flexibility with which they moved between solutions, their responses to guidance, and the originality of their solutions. From the CG, 30 students were interviewed; from the first experimental subgroup, 30 students; and from the second experimental subgroup, 34 students.

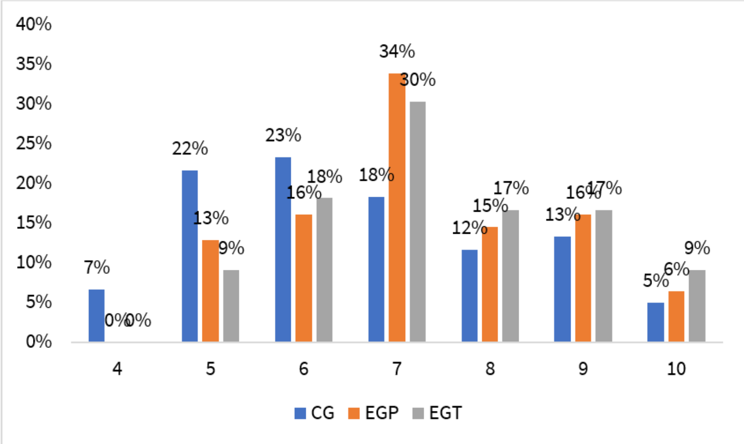

Figure 1. Relative frequency distribution of grades by group (Source: Authors' own elaboration)

Table 1. Characteristics of first study group

	Groups	N	Mean	Standard deviation	Standard error mean
Grades	CG	60	6.67	1.654	0.213
	EGP	62	7.26	1.425	0.181

Table 2. Student's t-test results-1

Test	t-statistics	df	Critical value (α = 0.05)	Critical Region	Result
CG < EGP	-2.01	116	-1.658	t < -1.658	Reject H_0

3. **Questionnaires:** These were designed to evaluate students' perceptions regarding the enhancement of their creativity, their motivation, and their attitudes toward open-ended problems and the use of technology in solving them. Two separate questionnaires were developed: one for the first experimental subgroup and one for the second experimental subgroup.
   a. **The first questionnaire** included questions related to students' attitudes toward open-ended problems and the impact of this method on their creativity and motivation to learn mathematics.
   b. **The second questionnaire** included questions about students' attitudes toward the use of technology in solving open-ended problems, and its impact on their mathematical knowledge acquisition, creativity, and motivation (Avila-Toscana, 2025; Galbraith, 1998).

The study assessed final test assessment scores to evaluate the effects of the open-ended problem teaching style and technology utilization on students' knowledge acquisition, comparing the average scores across groups.

Students' creative thinking, as proposed by Guilford (1967, 1973) and Torrance (1969), was evaluated through four components: elaboration, flexibility, originality, and fluency.

The data for these four components were obtained via test results and structured interviews with students from all three groups who attempted to solve the third problem (the explanation of identifying these components concretely is defined here at "the analysis for increasing student creativity").

Data regarding students' views towards open-ended problems and technology in mathematics instruction were gathered via questionnaires distributed to the two experimental subgroups.

Data Analysis

The impact of the method of using open-ended problems and technology in solving them on increasing students' knowledge acquisition

Figure 1 displays the distribution of grades after the evaluation of the test for each of the three groups.

The average grade of each group on the test was used as an evaluator of student knowledge acquisition. First, we compared average grades of the CG with those of experimental subgroup's that had used open-ended problems, establishing the hypothesis: H_0: $\mu_{CG} = \mu_{EGP}$ and H_a: $\mu_{CG} < \mu_{EGP}$ with $\alpha = 0.05$.

Table 1 shows the characteristics of the first study group.

Table 2 presents the results of the student's t-test with one-tailed test, assuming that the variances are not equal.

Since the criterion value falls in the critical zone, we reject the hypothesis H_0 and accept the alternative hypothesis. So, the average score of the EG, which used open-ended problems during teaching, is statistically higher than the average score of the CG. This means that teaching through open-ended problems increases the acquisition of mathematical knowledge among students.

Table 3. Characteristics of second study group

	Groups	N	Mean	Standard deviation	Standard error mean
Grades	EGP	62	7.26	1.425	0.181
	EGT	66	7.42	1.458	0.179

Table 4. Student's t-test results-2

Test	t-statistics	df	Critical value (α = 0.05)	Critical Region	Result
EGP < EGT	-0.76	120	-1.658	t > -1.658	$\mathbf{H_0}$ not rejected

Table 5. Matrix correlation of parameters

	S	T	F	O
S	1	0.855	0.902	0.516
T	0.855	1	0.755	0.472
F	0.902	0.755	1	0.449
O	0.516	0.472	0.449	1

Calculating the average grade of the EG utilizing technology for open-ended problems, we have that $\underline{x_{EGT}} = 7.424242 > \underline{x_{EGP}} = 7.258065$. This leads us to the conclusion that increased use of technology in teaching geometric transformations through open-ended problems enhance students' acquisition of mathematical knowledge.

To analyze the impact of technology use on students' knowledge acquisition, we also tested the hypothesis H_0: $\mu_{EGP} = \mu_{EGT}$ and H_a: $\mu_{EGP} < \mu_{EGT}$ with $\alpha = 0.05$.

Table 3 shows the characteristics of the second study group.

Also with the assumption that the variances are not equal, using student's t-test with one-tailed test, we have the results in **Table 4**.

Since the criterion value falls over the allowed region, hypothesis H_0 is not rejected. So, there are sufficient data that their average grades of these two EGs could be different with same level of confidence $\alpha = 0.05$.

Analysis for increasing student creativity

The analysis of creativity focused on the subgroups from three the initial groups (CG, EGP, and EGT), that had answered the third test problem, an open-ended problem. The elements of creativity, as defined by the Torrance (1969) creative thinking tests methodology, are specified as follows:

1. **Elaboration** was measured through the number of problem solution methods and their accuracy, the argumentation of the problem solution steps, and the connection between the mathematical concepts addressed in the problem, which was marked with **S**. The accuracy of the solution was measured through three values: incorrect (1), partially correct (2), and correct (3).
2. **Flexibility**, defined as an individual's capacity to transition between various cognitive frameworks, was assessed by the quantity and composition of distinct transformations employed by the student across all solution modalities, in addition to an interview denoted by a **T**.
3. **Fluency**, defined as an individual's capacity to respond to and elaborate on a proposed notion while further developing the solution based on these enhancements, was assessed during the interview utilizing a Likert scale (1-5). This parameter was designated with **F**. An instance of the interview is located in **Appendix B**.
4. **Originality** is an individual's capacity to take on a specific problem in an innovative and distinctive manner, yielding several acceptable solutions, was assessed using diverse problem-solving results and during a structured interview to evaluate the students' problem-solving technique, denoted by the letter **O**.

In the reviewed literature, there is no analysis of the weight of each of these variables on student creativity. The researcher determines them based on their teaching experience.

To measure the creativity we have defined the parameter $K = \omega_1 S + \omega_2 T + \omega_3 F + \omega_4 O$, where S, T, F, and O are mentioned above. To define weights of each component, we followed the method of the analysis of correlation. Three groups which take part in this study were mixed into one, and then with the data for $n = n_1 + n_2 + n_3 = 100$ students, we made the analysis of correlations of four parameters, where we have obtained the matrix correlation in **Table 5**.

Normalized weights determined by the formula $\omega_i = \frac{\sum_j corr(x_i, x_j)}{\sum_{i,j} corr(x_i, x_j)}$ are $\omega_1 = 0.275088250126072$, $\omega_2 = 0.25903513195495$, $\omega_3 = 0.26105227769373$, $\omega_4 = 0.204824340225248$ and creativity parameter is $K = 0.275088250126072 \cdot S + 0.25903513195495 \cdot T + 0.26105227769373 \cdot F + 0.204824340225248 \cdot O$. Creativity K was calculated for each student according to the above formula.

Following that, we investigated the hypotheses regarding the equality of creativity mean between the CG (referred to group 1) and the experimental subgroup using open-ended problems (referred to group 2), as well as the equality of creativity mean between group 2 and the EG utilizing technology for solving open-ended problems (designated as group 3).

Table 6. Characteristics of third study group

	Number of groups	N	Mean	Standard deviation	Standard error mean
Creativity	1	32	2.2836	0.88180	0.15588
	2	32	3.4014	1.10645	0.19559

Table 7. Comparison between group 1 and group 2

		Levene's test for equality of variances		t-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	MD	SED	95% CI of the difference	
									Lower	Upper
Creativity	Equal variances assumed	2.832	0.097	-4.469	62.000	0.000	-1.11783	0.25011	-1.61779	-0.61786
	Equal variances not assumed			-4.469	59.060	0.000	-1.11783	0.25011	-1.61829	-0.61737

Note. MD: Mean difference; SED: Standard error difference; & CI: Confidence interval

Table 8. Characteristics of fourth study group

	Number of groups	N	Mean	Standard deviation	Standard error mean
Creativity	2	32	3.4014	1.10645	0.19559
	3	36	4.1527	1.17502	0.19584

Table 9. Comparison between group 2 and group 3

		Levene's test for equality of variances		t-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	MD	SED	95% CI of the difference	
									Lower	Upper
Creativity	Equal variances assumed	0.060	0.807	-2.705	66.000	0.009	-0.75135	0.27778	-1.30595	-0.19675
	Equal variances not assumed			-2.715	65.767	0.008	-0.75135	0.27678	-1.30400	-0.19870

Note. MD: Mean difference; SED: Standard error difference; & CI: Confidence interval

Initially, we analyzed the hypotheses on equality of variances through the Levene test between group 1 and group 2. Then, we analyzed the creativity means of both groups, and the results are presented in **Table 6** and **Table 7**.

Since for the equality of variances between group 1 and group 2, the value F is 2.832 and p (significance) = 0.097 > 0.05, we supposed that the variances are equal. So, to analyse the hypothesis of equaling the creativity mean between group 1 and group 2, we used t-test. We have $t = -4.469, p - value = 0.000 < 0.05 = \alpha$ (security level), we conclude that there is a statistically significant difference between the creativity means of group 1 (CG) and group 2 (EGP). Therefore, the use of technology in solving open-ended problems further increases students' creativity.

We did the same thing to compare the creativity of group 2 and group 3 (EGT). The results for them are presented in **Table 8** and **Table 9**.

Again, since for the equality of variances between group 2 and group 3, the value F is 0.060 and p (significance) = 0.807 > 0.05 (security level), then we accept that the variances between these two groups are equal. To verify the creativity mean between the variance, we used t-test, its values are represented in **Table 9**. So, we have $t = -2.705, p - value = 0.009 < 0.05 = \alpha$ (security level) and we conclude that there is a statistically significant difference between the creativity means of groups 2 and 3, where group 3 is having a higher creativity mean compared with group 2. Therefore, the use of technology in solving open-ended problems further increases students' creativity.

Students' attitude towards open-ended problems

To assess students' attitude towards the use of open-ended problems and the use of technology in their solution, two questionnaires were used, which were distributed to the two subgroups of the EG, respectively. The questionnaires are presented in **Appendix C**.

Figure 2 and **Figure 3** displaying the questionnaire results indicate that students exhibit interest for using open-ended problems and technology in the teaching of mathematics, the students are enthusiastic for using these methods in teaching of mathematics. They evaluate that these strategies increase motivation, promote critical thinking and intuition, and facilitate comprehension of topics in mathematics and their connections with one another and the real world.

RESULTS

The results achieved show the followings:

1. The implementation of open-ended problems in the teaching of mathematics significantly improves students' knowledge acquisition. This gap is greater in comparison to students who take part in traditional educational techniques. Consequently, the application of these strategies enhances the efficacy of the teaching. These methods allow the teacher to approach every aspect of the educational issue from various perspectives, hence encouraging more student involvement.

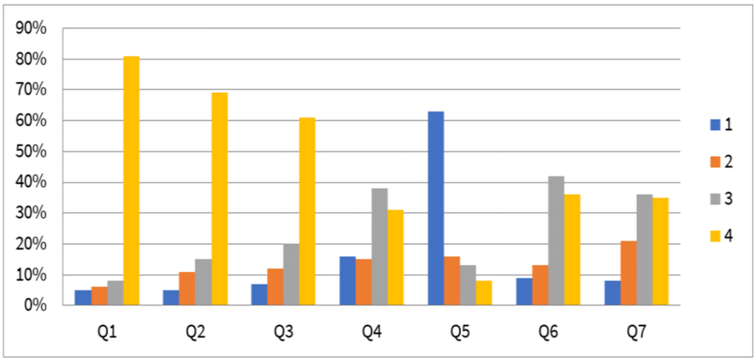

Figure 2. Results of a questionnaire regarding the implementation of open-ended problems in the teaching of geometric transformations (Source: Authors' own elaboration)

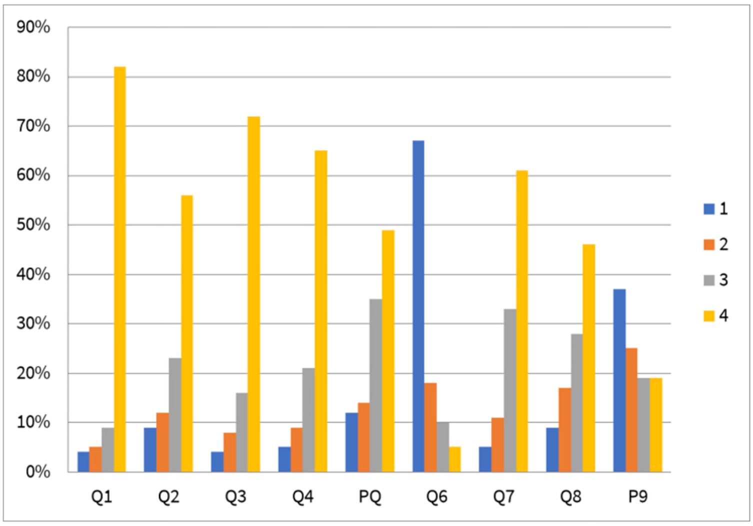

Figure 3. Results of the questionnaire on the use of technology in teaching open-ended problems in geometric transformations (Source: Authors' own elaboration)

2. Using open-ended problems in teaching mathematics improves students' creativity and critical thinking. But also using technology in teaching open-ended problems significantly increases students' creativity and critical thinking. Among the reasons for the statistically significant difference in the creativity of students who used technology in solving open-ended problems, compared to the other two groups, we think assume: simulation of geometric transformations through technology, the assumption adopted for solving the problem and the simplest verification of the ideas employed in its solution and simpler visualization of different solution results.
3. The use of open-ended problems and the use of technology in their solution boost students' motivation and desire to learn mathematics. As can be seen in the students' responses regarding their motivation for the experimental problem group, in both groups we have 61% and for the experimental technology group 65% of the second group they think that these methods greatly increase their motivation to learn mathematics.

CONCLUSIONS

This study has achieved its main objective by explaining the role of open-ended problems and the use of technology in their solution in better acquisition of mathematical knowledge by students and in promoting critical and creative thinking of secondary school students. However, it has several limitations that are worth discussing.

First, the sample includes only 188 students from two gymnasiums, which limits the generalizability of the findings to the entire population of secondary school students.

Secondly, the intervention was applied only to the topic of geometric transformations, so the observed effects cannot be extrapolated to other mathematics topics.

And the last limitation is related to the uneven exposure of students to technology, as well as the relatively short duration of the intervention (only 6 teaching hours), which may not reflect long-term effects on learning and creativity.

Due to the limitations of the study, both in the number of students involved and in the topic of the mathematics program included in it, we believe that the results of this study will be a starting point for continuing with other studies in the Albanian and broader context, to evaluate the effectiveness of mathematics teaching methods through problem solving in the acquisition of knowledge, as well as in increasing creativity, critical thinking and motivation of students in learning mathematics.

An important component in teaching is the teacher, whose role should be considered in further studies. It is concluded that their training is necessary for both the methodologies of teaching mathematics through problem-solving and the application of technology and software in its education.

Author contributions: ES, EH, VV: writing–review & editing; **ES & EH:** conceptualization; **ES & VV:** formal analysis and writing–original draft; **ES:** data curation; & **EH:** supervision. All authors agreed with the results and conclusions.

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AI statement: The authors stated that they used AI-assisted tools only for language editing and text refinement. All scientific content, analysis, and conclusions are entirely the responsibility of the authors.

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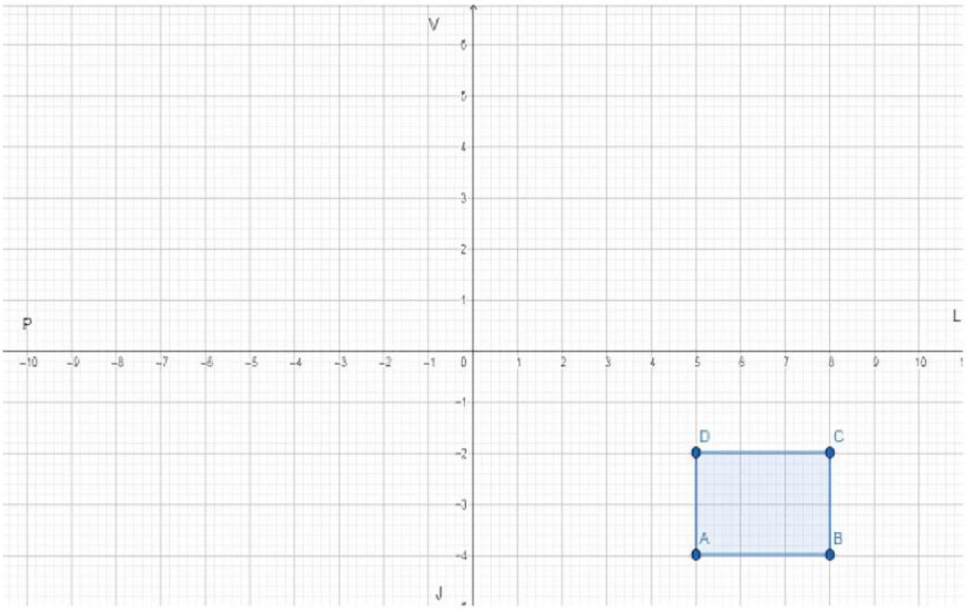
APPENDIX A: TEST ON GEOMETRIC TRANSFORMATIONS

Name and surname: ____________________ Date: __________

1. **(20 points)** A given triangle with vertices $A(2,1)$, $B(4,3)$, and $C(3,5)$, is reflected according to the $y = x$ axis. What are the coordinates of the new figure?
2. **(30 points)**
   a. A square with vertices in $(1,1)$, $(1,3)$, $(3,1)$, and $(3,3)$ rotates **90° in a clockwise** direction around the origin. What are the new coordinates of the square?
   b. If the square were transformed through homothety with coefficient $k = -2$, would the shape of the figure be preserved? If so, what would be the new length of the side of the square?
3. **(50 points)** The playground is situated in the southeastern section of the city park, as illustrated in the figure. The region housing the playground will be transformed into a tennis court, while the playground will be constructed in the area situated between the west and north relative to the city park.
   a. Describe all the ways of geometric transformations or their composition that lead the playground to the required area.
   b. What are the new coordinates of the new park according to the transformations chosen by you?



APPENDIX B

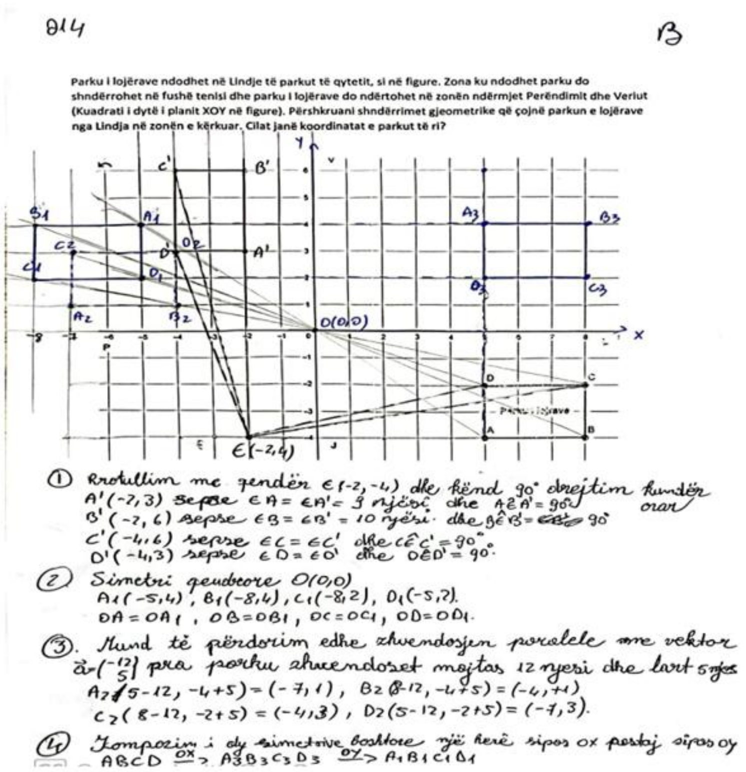
Semi-Structured Interview

1. Which geometric transformation did you use?
2. In how many positions can the park be located in the area between West and North, through the geometric transformation you chose?
3. Can the transition of the old park to the area between West and North be done with any other geometric transformation (different from the one you chose in question "2")?
4. How many transformations in total can you use?
5. In how many positions can the park be moved? Does this depends onthe number of transformations you use?
6. Is the shape and size of the park preserved during the transformation you chose?

Example of a Structured Interview

Two students were randomly selected: Student A from the control group and Student B from the experimental group, with whom a structured interview was conducted to primarily evaluate parameter F (fluency), as well as parameters T (flexibility) and O (originality).

Interview With Student A



Interviewer (Int): Which geometric transformation did you use?

Student A: "The park can be transformed in four distinct manners: rotation, central symmetry, parallel translation, and axial symmetry. I considered executing a rotation about the origin $O(0,0)$ at an angle of $90°$, but I saw that it would ultimately reside in the first quadrant. Consequently, I selected point E to be further away from point A than from the Ox axis, as EA' equals EA, and A' must reside in the second quadrant. The others were easier."

Int: In how many positions can the park be located in the area between West and North, through the geometric transformation you chose?

Student A: Based on the transformation I selected, there exists only one solution; however, alternative solutions yield different configurations for the park.

Int: What about with the rotation transformation you chose, could you have gotten a different park position in the second quadrant?

Student A: Maybe if I had taken a different center of rotation?!

Int: You have employed four distinct solutions to the problem: rotation about the center $E(-2,-4)$, central symmetry with respect to the origin $(0,0)$, parallel displacement using the vector $\vec{a}=(-12,5)$, and the composition of two axial symmetries, first along the Ox axis and later along the Oy axis. Do you believe that alternative compositions could be used in instead of axial symmetry? (to measure the fluence and flexibility)

Student A: ”Yes, it can be done with a rotation with center $(0,0)$ and angle $90°$ clockwise and symmetry along Ox, or rotation with center $O(0,0)$ and counterclockwise and then symmetry along the Oy axis, because in the end it will be in the required area.”

Int: How many positions can the park pass through? Does this depend on the number of transformations you use?

Student A: In my proposed solution, there are three distinct positions; nevertheless, it is possible that additional locations may exist.

Int: Is it possible for distinct transformations to yield the same position?

Student A: Actually, the location of the park in the second solution is identical to that in the fourth solution.

Int: Is the shape and size of the park preserved during the transformation you chose?

Student A: Yes, in my solutions the shape and size of the park are also preserved.

Int: Could we have chosen a transformation that did not preserve the size?

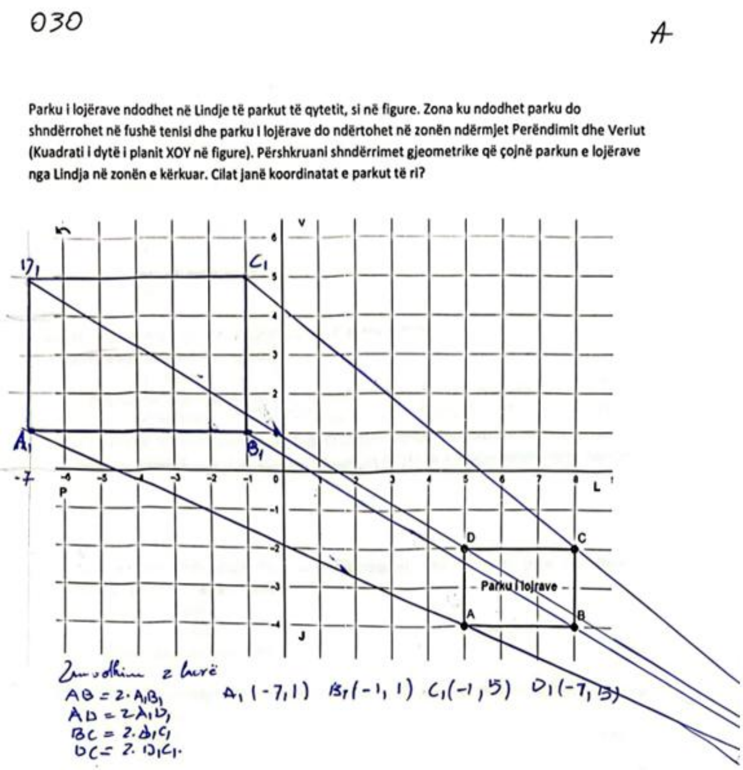
Student A: It is not stated in the problem, however, if it were allowed, we could solve for homothety, but I would have to determine the center and the coefficient.

Notes

We note that student A, in addition to having solved the problem correctly, has presented several different ways of solving it and responds very well during the interview.

He is open to other ways of solving and other results for the location of the park, which rates him higher in terms of the number of transformations used in the solution, for a good response to suggestions given for other transformations, for different solution results, etc. According to Likert scale, this student is evaluated by scale 5.

Interview With Student B



Interviewer (Int): Which geometric transformation did you use and why?

Student B: “I used homothety since there is no requirement that the park must keep the same dimensions, and the enlargement guarantees it will occupy the required area.”

Int: What is the center and the enlargement coefficient?

Student B: ”I know that the center should be to the right of the old park, so that when it is zoomed in it passes into the required area, because I remember it from the exercises we did in class, but I’m not sure about the coordinates. While the enlargement coefficient that I took was 2.”

Int: Is the shape and size of the park preserved during the transformation you chose?

Student B: The shape is, but the size is not, because I enlarge it by 2.

Int: Can the old park be converted into the requested area with any other transformation?

Student B: “I believe so.”

Int: What could be another transformation?

Student B: “I think reflection, but I can’t remember how it’s done.”

Int: Would the size be preserved with other transformations?

Student B: I believe so, because only homothety changes the size.

Int: How many positions can the park pass through? Does this depend on the number of transformations you use?

Student B: Maybe more than 1. Maybe, I don’t know.

Notes

We note that student B, beyond some errors in the calculation, has tried to enlarge the figure to move the quadrilateral to the second quadrant. But he has not presented other methods of solution and has limited himself to only one way, that of enlargement. During the interview, he does not react well to suggestions for using other transformations to find other ways of solutions, but also for other results of the solution, he is suspicious. According to Likert scale, this student is evaluated with scale 1.

APPENDIX C

Questionnaire 1. Assessing Students' Attitudes Towards the Use of Open-Ended Problems in Teaching Geometric Transformations

Instructions: Please read each statement carefully and click on the box that best represents your opinion.

Likert scale: 1–Completely disagree, 2–Partially agree, 3–Agree, and 4–Totally agree

Questions

1. Using open-ended problems helped me better understand geometric transformations.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
2. Open-ended problems make me think creatively and use intuition when solving tasks.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
3. I am more motivated to learn when open-ended problems are used in class.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
4. I feel more confident in my mathematical abilities when I encounter problems that can be solved in more than one way.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agre
5. I prefer problems that have a single solution rather than open-ended problems.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
6. The teacher should use more open-ended problems in teaching other topics as well.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
7. Open-ended problems help me see the connections between different geometric transformations.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree

Thank you for your participation!

Questionnaire 2. Assessing Students' Attitudes Towards the Use of Technology in Solving Open-Ended Problems in Teaching Geometric Transformations

Instructions: Please read each statement carefully and click on the box that best represents your opinion.

Likert scale: 1–Completely disagree, 2–Partially agree, 3–Agree, and 4–Totally agree

Questions

1. Using open-ended problems and technology to solve them helped me better understand geometric transformations.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
2. Using technology in teaching geometric transformations helped me see the connections between different geometric transformations.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
3. Technology makes it easier for me to solve open-ended problems and makes me think creatively and use intuition when solving them.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
4. I am more motivated to learn when technology and open-ended problems are used in the classroom.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
5. I feel more confident in my math skills when I use technology on problems that can be solved in more than one way.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
6. I prefer problems that have a single solution rather than open-ended problems.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
7. The teacher should use more open-ended problems and technology in teaching other topics as well.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
8. Using technology to solve open-ended problems helps me explore transformations and simulate their composition.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree
9. I prefer to solve problems without using technology.
   ☐ Completely disagree ☐ Partially agree ☐ Agree ☐ Totally agree

Thank you for your participation!