The effect of using open-ended problems in primary school Geometry teaching

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Abstract

Geometry is an essential part of mathematics, however numerous studies and international tests indicate weaker student achievements in geometry. Differentiated teaching with open-ended problems has improved learning in other areas of mathematics and it may benefit geometry as well. The goal of this study was to investigate whether the incorporating of open-ended problems can improve students' achievements in geometry. A quasi-experimental study was conducted with students of the fifth and seventh grade of primary school. Results showed improved performance among older students, but no significant effect on younger students. This raises the question of the effectiveness of this approach with younger students.

Keywords

Geometry, open-ended problems, primary school students

Résumé

La géométrie est une composante essentielle des mathématiques. Cependant, de nombreuses études et tests internationaux indiquent des résultats scolaires plus *faibles en géométrie. L'enseignement différencié avec des problèmes ouverts a amélioré l'apprentissage dans d'autres domaines des mathématiques et pourrait également bénéficier à la géométrie. L'objectif de cette étude était de déterminer si l'inclusion de problèmes ouverts pouvait améliorer les résultats des élèves en géométrie. Une étude quasi expérimentale a été menée auprès d'élèves de cinquième et septième année d'école primaire. Les résultats ont montré une amélioration des performances chez les élèves plus âgés, mais aucun effet significatif chez les plus jeunes. Cela soulève la question de l'efficacité de cette approche auprès des plus jeunes.*

Mots-clés

Géométrie, problèmes ouverts, élèves du primaire

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Introduction

Geometry is one of the main components of primary school mathematics (Pasani, 2019). It represents an integral part of national curriculum (see for example, APOSO[1], 2015; Decision on the adoption of the curriculum for Mathematics for primary schools and grammar schools in the Republic of Croatia NN 7/2019; or OECD[2], 2024, for the international perspective of the inclusion of geometry in math curricula), but it is also an obligatory area of international testings (Mullis et al., 2020; OECD, 2019).

Learning geometry can improve logical thinking skills, while geometric shapes are found in objects of everyday life (Hwang et al., 2020; Pasani, 2019). Students' skills in geometry and spatial reasoning are not only crucial for geometry, but also for other areas of mathematics (Clements & Sarama, 2011). Geometry is important for engineering (Velichová, 2002), architecture (Choudhary et al., 2014), physics (Bursill-Hall, 2002) and various other subject areas. However, students' performances in geometry are often very poor (Hwang et al., 2020; Pasani, 2019; Sinclair & Bruce, 2015). This indicates that changes need to be made in the approach to teaching geometry.

A shift in pedagogical approach may involve instruction aligned with the van Hiele levels of geometric thinking (Pasani, 2019), the measurement and observation of geo-

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metric objects in real world (Hwang et al., 2020), or the integration of geometry with visual arts (Schoevers et al., 2020). It is recommended to use interactive teaching methods and strategies that actively engage students and foster interest in learning, as well as to differentiate instruction based on students' individual abilities (APOSO, 2009).

However, the majority of textbook mathematics problems have only one correct solution, which can discourage students from exploring different ideas and becoming more active in the classroom (Mihajlović & Dejić, 2015). In contrast, open-ended problems have different correct solutions and allow different approaches to finding solutions, allowing students who are otherwise struggling with mathematics to find a solution that suits their level of knowledge and abilities. That is why the open-ended problems are especially good for differentiated instruction (Mihajlović & Dejić, 2015).

The goal of this research is to examine the impact of the application of open-ended problems in geometry teaching in primary school, more precisely, whether the application of open-ended problems in geometry teaching in the fifth grade (students aged 10-11) and the seventh grade (students aged 12-13) leads to better student achievements compared to traditional geometry teaching and closed problems.

Geometry teaching in Primary School

In the fifth grade of primary school in Bosnia and Herzegovina, students learn about the concept of angle and triangle, their elements, as well as the types of angles and triangles. Students also learn how to calculate the perimeter and area of a triangle. In the seventh grade, this knowledge is reviewed and deepened, and students gain new insights into angles and triangles. The concept and types of triangles are repeated and they learn about the sum of the interior and exterior angles of triangles. What follows is learning about angles with parallel and perpendicular arms, and construction of angles and triangles (Federal Ministry of Education and Science, n.d.). One of the instructions for mathematics teachers in the seventh grade is to repeat everything students know about triangles (Federal Ministry of Education and Science, n.d., p. 391). This demonstrates how geometric content is interconnected across the fifth and seventh grade curricula.

The results of international student assessments indicate weaker achievements of Bosnian students in mathematics (and geometry) compared to their peers from other countries. During the TIMSS (Trends in International Mathematics and Science Study) survey in 2007, Bosnian primary school students achieved an average of 456 points in mathematics, which is less than the international average of 500 points (APOSO, 2009). It is interesting to notice, that a higher percentage of mathematics classes in Bosnia and Herzegovina is devoted to geometry compared to the international average (35% of all mathematics classes in Bosnia and Herzegovina compared to the international average of 27% of mathematics classes), and still, the results of Bosnian students in geometry are poor (APOSO, 2009). Particularly poor results are identified with problems in the field of application and understanding, and in open-ended problems. The main recommendation of the APOSO study from 2009 is to develop classroom models for active student participation and to differentiate the teaching according to the students' abilities.

Bosnia and Herzegovina also participated in the TIMSS survey in 2019, and Bosnian students achieved an average score of 452 points, which is significantly lower than the international average of 500 points (Džumhur, 2021). The achievements of our students in the field of measurement and geometry are significantly worse than those of the neighboring countries. This again suggests the need to improve curriculum and teaching methods, because one of the important factors influencing student achievement is how prepared the teacher is to teach topics and content from certain areas (Džumhur, 2021).

Students' poor performance in geometry is not unique to Bosnia and Herzegovina. Studies conducted in other countries, along with findings from international assessments, indicate low achievement in this area. Sulistiowati et al. (2019) reported on the difficulties students have when solving geometric problems. Their study found that students at the initial level of geometric reasoning struggled with interpreting and understanding problems, while those at a higher level encounter difficulties during the problem-solving process.

Kwadwo and Asomani (2021) highlight worrying student outcomes in geometry and identify several contributing factors. These include insufficient prior knowledge, a lack of teaching materials and resources, students' fear and poor attitude toward geometry, as well as low teachers' motivation to improve their geometry teaching. Jones (2002) argues that the same elements that make geometry interesting, varied and applicable, also contribute to the challenges of teaching it effectively. Bishop (1986) attributes poor performance in geometry primarily to external factors, such as the greater emphasis on arithmetic over geometry in primary schools, and a weak connection between the geometry curriculum and the real world, which causes students to have little motivation to learn geometry.

Aboagye et al. (2021) identify several possible causes of poor results in geometry, including difficulties in understanding mathematical language, weak connections to prior knowledge, poor understanding of geometric concepts, and a lack of motivation when learning geometry. Their study further suggests that some students are afraid of mathematics because of geometry, i.e., geometry is the reason why they struggle in mathematics.

Numerous students have significant difficulties in understanding and applying geometric principles (Danlami et al., 2025). One important reason is limited spatial reasoning ability, while another one is the challenge of applying abstract geometric concepts to real-world problems.

The reduced number of lessons allocated to geometry in the curriculum, as observed by Jablonski and Ludwig (2023) and Jones (2002), certainly does not help. Other areas of mathematics - such as arithmetic, algorithms, and functions - are given more space in the curriculum at the expense of geometry.

Open-Ended problems

One of the student-centered teaching methods that is becoming increasingly popular in mathematics education is using open-ended problems. Open-ended problems are categorized in two type: problems with only one correct answer, but with several different ways of solving them, and problems with more than one correct answer (Zhu & Tan-Foo, 2005). The possibility of having more than one correct answer allows each student the opportunity to find their own, original solution. Students can compare their solutions and discuss them with their peers, which contributes to creating an interesting and rich dialogue in the classroom (Mihajlović, 2014). When working with open-ended problems, the emphasis is on the process of solving the problem, not the result. Students choose a method, explain how they approached the problem, and when a certain approach can be applied. They explain each step in the process of solving the problem and why a particular solution is obtained (Babić, 2016).

According to Hashimoto (1997), when using open-ended problems, students are first presented with an unfinished problem. The teaching then proceeds by using multiple correct approaches to solve the problem. This method allows students to experience the process of research and discovery, by combining their previous knowledge, skills, and ways of thinking.

Open-ended problems provide the opportunity for all students to develop several possible solutions that align with their individual levels of knowledge and understanding, allowing them to progress at their own pace. Thus, students with stronger mathematical abilities can engage in various activities and propose more sophisticated solutions, while students with lower mathematical proficiency can still participate meaningfully and offer simpler, yet valid solutions (Mihajlović & Dejić, 2015). Students have the opportunity to learn different strategies, deepen their knowledge of mathematics, and develop creative mathematical thinking. All this contributes to connecting students' mathematical literacy and real-life situations (Savić, 2020).

Open-ended problems have a positive impact on improving students' achievement in mathematics (Al-Absi, 2013). Zhu and Tan-Foo (2005) believe that by using open-ended problems in mathematics classes, students could improve their problem-solving abilities while also establishing a more positive view of mathematics. In several studies, it is shown that the use of open-ended problems can exert a positive impact on the ability to solve mathematical problems (Rizos & Gkrekas, 2023; Tanjung et al., 2020).

Boaler (1998) conducted a longitudinal study and followed up with students' work for three years in two schools. While in one school the traditional teaching prevailed and focused on textbook tasks, in the other school teaching was focused on open-ended problems, students' research, and choice of activities. The students of the first, traditional, school developed inert knowledge that they only knew how to use in textbook problems, and struggled with tasks that required more than a simple procedure. Students of the second school were more flexible in their approach to problems, believed in the adaptability of mathematics, and achieved better results. Boaler (1998) emphasized that the students of the second school did not know more than the students of the first school, but they were more prepared to understand situations that they have not been exposed to before, they understood procedures better and had more confidence in their mathematical abilities.

The use of open-ended problems has a positive effect on students' impressions of the lesson and their activities, which is reflected in their self-confidence in work. Kwon et al. (2006) found that open-ended problems foster students' curiosity and collaboration in problem-solving. The research of Ulinnuha et al. (2021) showed that open-ended problems improve the ability of mathematical creative thinking.

The research by Savić (2020) showed no statistically significant difference in mathematical achievements between the experimental and control groups of students when open-ended problems were used with the experimental group, and textbook closed problems were used with the control group. However, the students in the experimental group offered more solutions and demonstrated more creativity in their thinking. These students were also more successful in discussing their solutions and they managed their time more effectively when solving problems. Savić argues that the gradual introduction of open-ended problems in the teaching of mathematics would lead to improvements in mathematical achievements.

With regard to the application of open-ended problems in geometry teaching, Borgersen (1994) believes that geometry is a rich source of these types of problems. Elementary geometry is great for solving problems from the beginning, and it is possible to achieve interesting and meaningful results without much prior knowledge. Borgersen's research (1994) also pointed out that cooperative learning combined with open-ended problems is a particularly good method for developing a positive learning environment.

Research by Irawan and Surya (2017) demonstrated that the application of open-ended problems when teaching about the area and perimeter of triangles and quadrilaterals had a positive effect on students' achievements. Research by Dugay and Pasia (2023) showed significant differences in pre-test and post-test geometry results in students aged 13-14 who were exposed to open-ended problems. Aydogan (2007) investigated the effects of using a dynamic geometry environment with open-ended explorations on sixth grade students' performance in polygons, congruency and similarity of polygons. Her study showed that dynamic geometry environment together with open-ended explorations significantly improved students' performances. Nasution et al. (2021) investigated the effect of using open-ended approach in geometry on students' creative thinking ability. The analysis of their post-test revealed that students in experimental group, where open-ended approach was used, had better results than the students from control group.

Often, open-ended problems in geometry were used as tools in research of different mathematical and cognitive abilities. For example, Simamora and Kamara (2024) explored mathematical creative processes in seventh-grade students while they were solving open-ended problems from geometry. Samphantakul and Thinwiangthong (2019) investigated mathematical conceptual understanding about geometry of eight-grade students using open-ended problems. Shillo et al. (2019) investigated creativity using an open-ended geometry environment, where the platform enabled participants to use discovery, trial and error methods, in order to spark creative problem solving. Taylor (2008) used open-ended geometry problems with high cognitive demand in her study of talented eight-grade students. She explored how they constructed mathematical understanding and meaning through social interactions with their peers.

In all these studies, participants were students aged 12 years or older. The majority of the studies involved participants aged 12-14 years (like in Aydogan, 2007; Dugay & Pasia, 2023; Irawan & Surya, 2017; Nasution et al., 2021; Samphantakul & Thinwiangthong, 2019; Simamora & Kamara, 2024; Taylor, 2008), and some included university students (like Borgersen, 1994 or Shillo et al., 2019). This prompts an inquiry: what about younger students? At the time of writing, the authors found no research examining the impact of an open-ended approach on their learning of geometry.

The primary goal of this research was to examine whether the use of open-ended problems in geometry teaching could enhance achievements among fifth-grade students (aged 10-11 years). Considering the overlap in geometric content between fifth and seventh grades (students aged 12-13 years), this study aimed to investigate the impact of the open-ended approach on seventh-grade students. The additional reason for including seventh-grade students was to enable a comparison of results with findings from existing studies that have explored the use of open-ended approach in geometry teaching among older students.

Methodology

Participants

A quasi-experimental approach was used in the research at hand, with an experimental (E) and control group (C) of fifth and seventh-grade primary school students. A total of 85 students participated in this research (Table 1).

Table 1

Distribution of the sample by group and grade

	E	C	Total
Fifth grade	22	21	43
Seventh grade	20	22	42
Total	42	43	85

Prior to this research, the students were taught in the traditional way (the frontal form of classroom work dominated, without many experimental or independent activities of the students) and through this research, the students of the experimental group were introduced to open-ended problems for the first time.

Teaching and intervention in Experimental and Control Group

During the research, there was no change in the curriculum, which means that all content areas and units planned by the curriculum were covered within the planned time frame. Thus, it was ensured that the transition through the new content was the same for the students of the control and experimental groups. In the control group, teaching was carried out in the traditional way, and in the experimental group, an open-ended approach was applied. The following describes the differences in the approach to teaching mathematics between these two groups.

1. Classes intended for the teaching of new content mostly used frontal form of work in both groups, with teacher leading students through the new content. Classes ended with homework assignments that students did independently. The experimental group students were given one to two open-ended problems for homework, while the control group students were given one to two closed problems.
2. During practice classes, students solved homework assignments and other problems together, under the teacher's supervision. This sparked discussion in both groups. However, in the experimental group, where the problems were open-ended and required deeper mathematical thinking and a creative approach, the discussion was much more open and meaningful. The students proposed different problem-solving strategies, which contributed to the development of critical thinking, communication of their solutions, and collaboration. In contrast, in the control group, the discussion was more focused on finding the correct answer, without much reference to the alternative methods of problem-solving.
3. During classes that focused on content revision, students were mostly given problems for independent work, to check and revise the previously acquired

knowledge. Sometimes, this approach would be partially changed and discussion among students was encouraged, with a focus on the exchange of ideas and mutual problem-solving. The experimental group students addressed a combination of problems: one or two open-ended problems, as well as traditional textbook problems. The control group students solved only closed problems, focusing on the application of the learned procedures.

It is important to note that open-ended problems were not used during the explanation of new content, but rather during review and assessment of the students' understanding of the new content, as homework assignments and problems during review lessons. When using open-ended problems, the guidelines from Babić (2016) were followed: write and present the problem to students clearly, and if necessary, further explain what is expected of them; make the problem attractive – interesting so students remain motivated to solve it (for example, by connecting it to real-world experiences); prepare in advance several possible responses; ensure enough time for students to explore the problem; record all student responses; summarize their solutions.

According to the curriculum, the content areas that were covered with the fifth-grade students during the research were: angles, types of angles, triangles, perimeter, and area of the triangle. A typical example of a closed problem from this content area is: *Triangle sides have lengths $a = 12$ cm, $b = 3$ cm, and the perimeter of this triangle is $0 = 27$ cm. Calculate the length of the triangle side c*. The experimental group students, in addition to the classical closed problems, solved problems such as the following: *Draw a triangle with a perimeter greater than 5 cm and smaller than 8 cm. Explain in words how you know that its perimeter is between 5 cm and 8 cm.*

The content areas covered with the seventh-grade students during the research were: triangles, types of triangles, the sum of interior and exterior angles of triangles, angles with parallel sides, angles with perpendicular sides, and constructions of some angles. An example of the closed problem from this content area is: *Triangle ΔABC has angle measures $a = 57^o$ and $\beta = 60^o$. Determine the measure of angle γ.* Besides closed problems, the experimental group students solved open-ended problems like the following one: *One angle in a triangle has a measure of 67^o. Write at least two combinations for the remaining two angles. What type of triangles do we get with these combinations? Explain.*

Testing

Before dividing students into control and experimental groups, a test of knowledge was performed (pre-test). Before this test, all students were taught in the same, traditional way. After the intervention, another test was performed (post-test). It is important to note that both tests were classical in the sense that they did not favor the experimental group students with the problem setting.

Results and discussion

Given the differences in age and content that were covered in the fifth and seventh grades, the analysis and discussion of the results will be conducted separately.

Fifth Grade Students

The study involved 43 fifth-grade students: 22 students in the experimental group and 21 in the control group. These students took the pre-test, and then the post-test after the intervention, the content of which covered the geometry taught during the intervention. Table 2 shows the results of the pre-test and post-test for both groups.

Table 2

Descriptive statistics of the pre-test and post-test for the fifth-grade students

Group	No.	Test	$\bar{X}$	St. Dev.
Experimental	22	Pre-test	3.18	0.85
		Post-test	3.59	0.85
Control	21	Pre-test	3.61	0.80
		Post-test	3.66	1.11

To compare the students' results on the post-test, taking the results of the pre-test as a covariate, the plan was to use the ANCOVA test. By testing whether the assumptions of the ANCOVA test were met, the p-value of Levene's test of 0.694 was obtained (equal variances can be assumed). However, while testing the normality of residuals, the Shapiro-Wilk test gave values of $p=0.013$ for the experimental group and $p=0.012$ for the control group, so the normality of residuals cannot be assumed. We decided to use the non-parametric ANCOVA, because it proved to be a better choice with the violated assumptions of normality (Cangür et al., 2018). Non-parametric ANCOVA showed that there was no statistically significant difference in the student's results on the post-test when the results of the pre-test were taken as a covariate: $F(1,41)=0.776$, $p=0.38$.

Despite various studies pointing to the benefits of using open-ended problems, our results with younger students did not show a significant difference in geometry achievements when using open-ended problems. One possible cause of this is the age of the students: fifth-grade students are younger students, aged 10-11 years, while studies indicating the advantage of open-ended problems have usually focused on somewhat older students. For example, Dugay and Pasia (2023) conducted a study with students aged 13-14, Boaler (1998) observed the work of students from the age of 13 up to the age of 16, while Irawan and Surya (2017) also worked with 13-year-old students. One may question whether students aged 10 or 11 are sufficiently cognitively mature to benefit from open-ended problems, especially if one keeps Piaget's theory of cognitive development in mind. According to this theory, students aged 10 and 11 still belong to the concrete operational stage, and only in the next stage are they able to think abstractly without relying on concrete objects (Oogarah-Pratap et al., 2020).

Seventh Grade Students

The study involved 42 seventh-grade students: 20 students in the experimental group and 22 in the control group. They also had the pre-test, and then following the intervention the post-test, the content of which covered the geometry taught during the intervention. Table 3 shows the results of the descriptive statistics of the pre-test and post-tests for both groups.

TABLE 3

Descriptive statistics of the pre-test and post-test for seventh-grade students

Group	No.	Test	$\bar{X}$	St. Dev.
Experimental	20	Pre-test	3.55	0.89
		Post-test	3.90	0.97
Control	22	Pre-test	2.91	0.92
		Post-test	3.00	0.93

Levene's test had a p-value of 0.648, but the assumptions of normality of the residuals were not met for this group of participants either. Shapiro-Wilk test gave values for the experimental group $p=0.009$, and for the control group $p=0.002$, and again the non-parametric ANCOVA was applied. The results showed that there was a statistically significant difference in the results of the post-test between the control and experimental group when the results of the pre-test were taken into account: $F(1,40)=4.149$, $p=0.04$.

So, there was a difference in the achievements of seventh-grade students in geometry, in favor of those who used open-ended problems in classes. This is in accordance with research by some other authors on the use of open-ended problems with students of similar ages (e.g., Dugay & Pasia, 2023 or Irawan & Surya, 2017).

Conclusion

This research demonstrated that the application of open-ended problems in geometry teaching can have different effects, depending on the age and cognitive maturity of the students.

The primary objective of this study was to examine the effect of the open-ended approach in geometry teaching on fifth-grade students. The results indicated no statistically significant difference between the experimental and control groups, which may suggest that students at this age may not yet be cognitively developed enough to take full advantage of this approach.

Given the similarities in geometry content taught in the fifth and seventh grades, the study also investigated the effect of the open-ended approach on seventh-grade students' achievement. The implementation of open-ended problems with seventh-grade students revealed a positive impact on their performance in geometry. These results are consistent with those of previous studies that explored the use of open-ended problems among participants of a similar age group, for example studies by Aydogan (2007), Irawan and Surya (2017), Nasution et al. (2021), and Dugay and Pasia (2023). The results observed in fifth-grade students differ from those reported in these studies. However, it is important to consider the age difference, as fifth-grade students are typically 2 to 3 years younger than the participants in the existing studies.

This study demonstrated that open-ended problems in geometry have significant potential when applied with older students; however, educators should be careful when implementing such approach with younger students.

The study has certain limitations: it focused on the use of open-ended problems within one specific area of geometry (angles and triangles) and was conducted over a relatively short duration. Future research should consider investigating a broader range of geometric topics and potentially employ a longitudinal design to track student outcomes over an extended period (like Boaler, 1998).

While the results for seventh-grade students have been positive, further research is needed to better understand how and why open-ended problems work for different ages and how they can be adapted to be more effective for younger students. In addition, it is necessary to consider other factors, such as how the problems are implemented, what methods were used by teacher, and individual differences among students, which can affect the outcome of the lesson.

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