Using GeoGebra in Teaching Advanced Geometry: A Case Study

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Abstract: Developing digital skills in schools is essential in the 21st century. GeoGebra is suitable for the development of various digital and mathematical skills. The program provides an opportunity to create visual representations that can facilitate the learning process and motivate students. This article reports on a case study that aims to test an online workbook. The workbook covers the topics of similarity and circle-related concepts at an advanced level and was tested among 10th graders. The workbook contains definitions, theorems, and proofs, as well as related tasks and homework. GeoGebra files are linked to each section to ease the work of both students and teachers. Students learned from the workbook during the experimental classes. Their opinions were collected through two short questionnaires. Based on the students' answers, the visual representations and dynamic figures in GeoGebra helped them understand and acquire concepts related to circles and similarity. Most students could easily use the program and enjoyed the lessons. This case study is part of a larger research, and the workbook will be further developed based on students' opinions and classroom experiences.

Keywords: circle, GeoGebra, geometry, mathematics education, similarity

INTRODUCTION

Digital tools are a part of everyday life. Today's children are digital natives, growing up in an environment where technology-based opportunities are endless. Avoiding these tools and the potential benefits they offer during learning would be unnatural. However, being a digital native does not necessarily mean that they can use these tools effectively. Digital skills must be learned, just like any other skill, and, according to Prievara (2015), they are essential in the 21st century.

The 2020 Hungarian National Core Curriculum (NCC) suggests that digital tools offer numerous methodological opportunities in the teaching and learning process. Teachers must be familiar with and use these tools, as they are indispensable. Technology can foster interaction between teachers and students and transform traditional teaching methods.

Developing digital skills is essential in teaching mathematics. The NCC aims to introduce the use of digital tools at the beginning of primary education. Younger students should be introduced to digital tools through games that enhance problem-solving skills and provide opportunities to practice mathematical operations. In the upper grades of primary school, students are exposed to mathematical software. By the end of secondary school, students should be able to use digital tools to facilitate their mathematical studies and create visual representations (NCC, 2020).

Researchers suggest that several non-digital skills are also developed through the use of digital tools in math classes. Students can become more independent, and collaboration is also possible. They can be innovative and flexible. The development of these skills can prepare them for future challenges (Tomaschko & Hohenwarter, 2017). Technology enables students to perform multiple tasks and receive immediate feedback, which can contribute to a deeper understanding of mathematical concepts (Hollebrands, 2007). Ayub et al. (2010) point out that classroom instruction has improved with the use of digital tools.

Many digital tools can be used in mathematics education. One of them is GeoGebra, which enables users to create visual representations in the field of mathematics. The program allows teachers to reduce the time spent drawing figures on the board and gives students the opportunity to explore mathematical concepts themselves (Haciomeroglu et al., 2009). The creators aimed to provide materials for students everywhere; therefore, the program is free and can be downloaded from the internet. It runs on a wide variety of platforms (Ancsin, 2011) and has been translated into 82 languages to date.

Researchers have found many advantages to using GeoGebra in a classroom setting. It offers new ways of presenting the material (Zöchbauer et al., 2022). By visualizing mathematical concepts, GeoGebra promotes students' understanding and facilitates the learning process (Hohenwarter et al., 2009; Arbain & Shukor, 2015; Joshi & Singh 2020; Adelabu, F. M. et al., 2022; Dahal et al., 2022; Thapa et al., 2022; Zakaria et al., 2024). Saha et al. (2010) examined students with high and low spatial visualization abilities. According to their results, both groups performed better after using GeoGebra compared to the control group. However, simply looking at pictures and figures will not foster conceptual learning. Students must actively engage with GeoGebra to gain a deeper understanding (Haciomeroglu et al., 2009).

Students find the GeoGebra platform user-friendly, which makes it easy for them to use the program independently (Dahal et al., 2022; Thapa et al., 2022). Active participation (Dahal et al., 2022; Thapa et al., 2022; Zöchbauer et al., 2022) and increased motivation were also observed (Arbain & Shukor, 2015; Dahal et al., 2022; Zakaria et al., 2024). Moreover, students became more confident in their mathematics studies (Arbain & Shukor, 2015). GeoGebra also aids in developing skills such as reasoning, problem-solving, and decision-making (Saha et al., 2010; Joshi & Singh 2020; Zakaria et al., 2024). It provides an opportunity for a student-centered environment (Thapa et al., 2022), promotes discovery learning (Dahal et al., 2022; Hamidah et al., 2024), and gives immediate feedback on students' work (Saha et al., 2010). Teachers can also benefit from the program, as it makes sharing resources easier and faster (Zöchbauer et al., 2022). However, Anwar et al. (2025) emphasize that teachers should not only be familiar with the tool itself, but also with appropriate pedagogical methods that can help make lessons more effective.

As research suggests, the use of GeoGebra can aid in developing mathematical skills, digital skills, and skills that are useful outside the field of mathematics as well. Based on students' opinions, using GeoGebra in mathematics classes is better than traditional teaching methods (Hohenwarter et al., 2009; Saha et al., 2010; Juandi et al., 2021; Nguyen et al., 2023). However, it has been shown to be more effective when used in groups of up to 30 students. Individual work can also be a better option if there are enough devices for each student (Juandi et al., 2021).

Building on these insights, this research aims to explore the implementation of GeoGebra in Hungarian mathematics classrooms through the testing of an online interactive workbook developed as part of a larger educational project. The workbook focuses on the topics of similarity and circle-related concepts. The objectives of this study are:

- To examine how GeoGebra-based materials influence student engagement and motivation.
- To assess the clarity and effectiveness of the developed workbook through classroom application.
- To gather student feedback for improving the workbook's design and pedagogical content.
- To identify any technical or conceptual challenges during implementation.

This case study contributes to understanding how digital tools like GeoGebra can enhance mathematics education, in line with national curriculum goals. Furthermore, by testing a structured, curriculum-aligned digital resource in a real classroom environment, the study extends previous research by offering practical insights into the usability, reception, and impact of GeoGebra-based materials. These findings may inform future material development and support the broader integration of digital tools in mathematics instruction.

While many earlier studies have focused on the general benefits of GeoGebra in fostering conceptual understanding and student engagement, our research specifically investigates its application through a newly developed online workbook focused on similarity and circle-related concepts. Unlike broader interventions, this case study integrates GeoGebra into a structured, topic-specific learning material. Therefore, the study offers insights into both the pedagogical effectiveness and the practical usability of GeoGebra-based resources in real classroom settings.

CASE STUDY

Workbook

The workbook contains definitions, theorems, and their proofs related to the topic, tasks for students, and a project for potential group work. For several exercises, a link to the relevant GeoGebra illustrations is provided, allowing the students to visualize the problem and experiment with it in an interactive way. Additionally, there are tasks that require students to create their own GeoGebra files based on classwork. The following subtopics are presented in the workbook:

- Theorem of Inscribed and Central Angles
- Angle of View
- Cyclic Quadrilaterals
- Tangential Quadrilaterals
- Basic Proportionality Theorems
- Angle Bisector Theorem
- Central Dilations and Contractions
- Similarity Transformations
- Similarity of Shapes
- Some Applications of Similarity (midlines, centroid of a triangle, diagonals of trapezoids, common tangents of two circles)
- Geometric Means in Right Triangles
- Tangent-Secant Theorem
- Ratio of the Areas of Similar Plane Figures

The material can be covered in approximately 21 lessons. The unit concludes with a review lesson and an end-of-unit test. Definitions and theorems are presented, followed by tasks and homework assignments. In some cases, there are more challenging problems that are not compulsory. Solutions to each homework assignment are provided at the end of the workbook. Links to GeoGebra files are included for many of the tasks and theorems.

In teaching this topic, GeoGebra can play a central role in both the discovery process and the development of conceptual understanding. Lessons can begin with a warm-up task. After solving the problem analytically, GeoGebra can be used to visually represent the situation. This allows students to verify their calculations and consider how the problem might change with different parameters. When a theorem is formulated, its consequences can be further explored using interactive models. The interactive construction makes it easier to test hypotheses and visualize hidden symmetries. Additionally, GeoGebra enhances the continuity of learning. Students can access prepared files at home, revisit steps they may not have fully understood during the lesson, and even modify the constructions to explore alternative cases. These files serve not just as visual aids but as interactive spaces for mathematical inquiry. Below, we present some examples from the workbook.

Figure 1 illustrates a theorem related to the angle subtended by an arc. Using the dynamic diagram, we can explore the locations of points P on the plane, from which the segment AB can be seen at the given angle. During the lesson, one student can find the solution for an acute angle and another for an obtuse angle. Students will discover that by moving point P, in such a way that the angle APB equals the given angle β, the path of P forms two circular arcs.

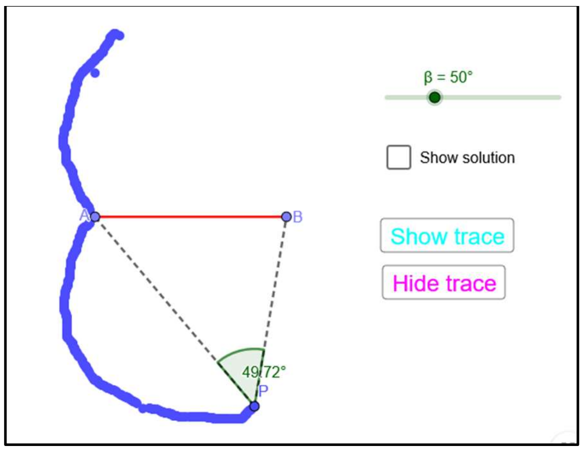

Figure 1: Subtended angle. GeoGebra link:
https://www.geogebra.org/m/ex6vez6c#material/gxrgnsd2

The construction of these two arcs is shown in Figure 2. GeoGebra allows students to follow the construction process step by step for any angle. By pressing the back and forward buttons, the steps and corresponding parts of the figure are displayed one by one.

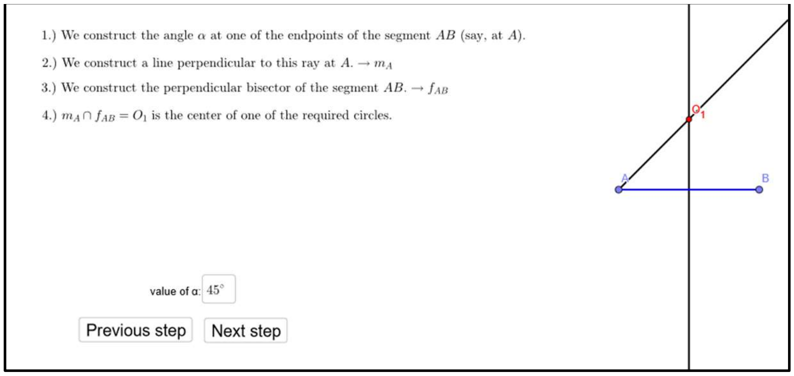

Figure 2: Constructing the arcs from where a segment is seen under a given angle. GeoGebra link: https://www.geogebra.org/m/ex6vez6c#material/z9ueupct

Figure 3 provides a visual representation of the following problem: *"The figure shows the auditorium of a theater from a top view. There are boxes on the longer sides of the auditorium on the ground floor. Find the side box (the point on the longer side of the auditorium) from which the stage can be seen at the greatest angle."* As a first step, students can experiment by moving point P in the figure. Then, by checking the "show solution" box, they can observe the arc, from which the stage can be seen from a given angle α. Using the slider, students can find the largest value of α, where the arc has a common point with the longer side of the auditorium. In this case the arc is tangential to the side, and the two points of tangency (J and K in Figure 3b) give the locations offering the best view.

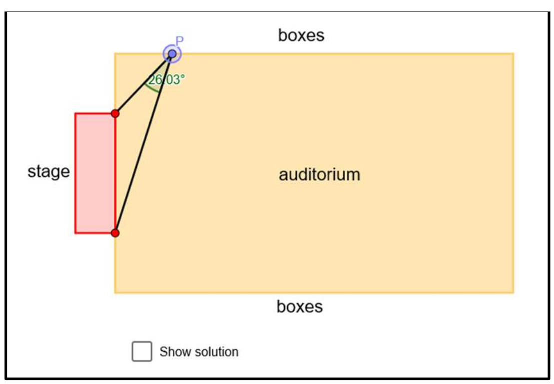

Figure 3a: Where should we sit for the best view? GeoGebra link: https://www.geogebra.org/m/ex6vez6c#material/h598qujw

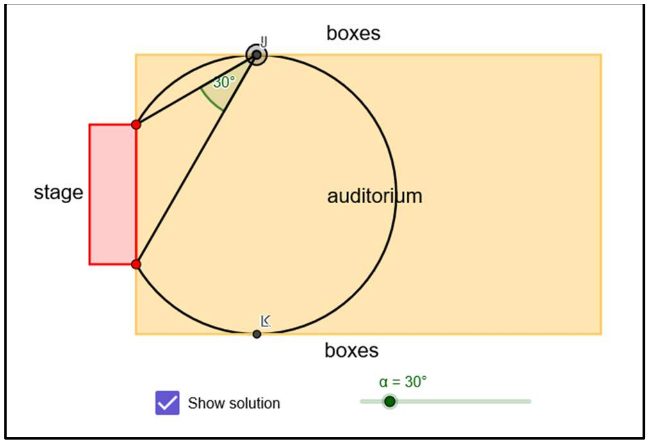

Figure 3b: Where should we sit for the best view? - solution.

GeoGebra facilitates the visual exploration of tasks. A good example is the task illustrated in Figure 4: *"Construct a triangle, given the length of one side and its corresponding median, as well as the size of the angle opposite the given side."* The construction process can be followed step by step. The location of the points C providing a given median is a circle centered at the midpoint F of AB (see the red circle in Figure 4). The prescribed angle at C constrains the location of C to two circular arcs (see the blue arcs in Figure 4). The intersection points of the red circle and the blue arcs give the possible points C. By changing the length of the side, the median, or the angle, students can see how many solutions exist for the problem: there are either 0, 2 or 4 solutions (we have 2 solutions when the blue arcs are tangential to the red circle).

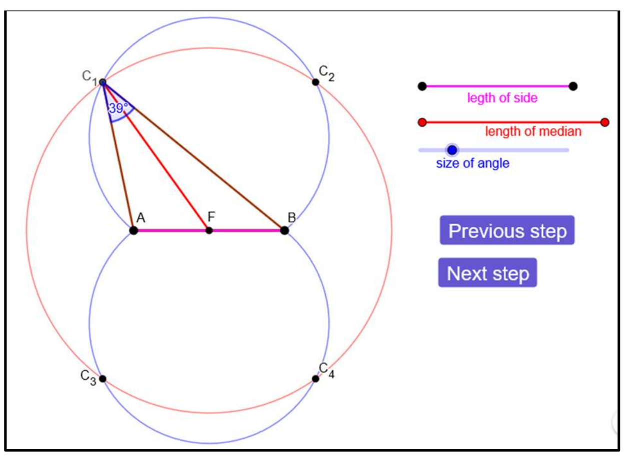

Figure 4: Constructing a triangle from a side, a median and an angle. GeoGebra link: https://www.geogebra.org/m/ex6vez6c#material/m77husfm

Figure 5 presents a task involving the division of a line segment in a prescribed proportion. Students can see, through a dynamic diagram, how a segment can be divided into any given rational ratio. This allows for more visual practice in class and enables students to easily check their homework assignments.

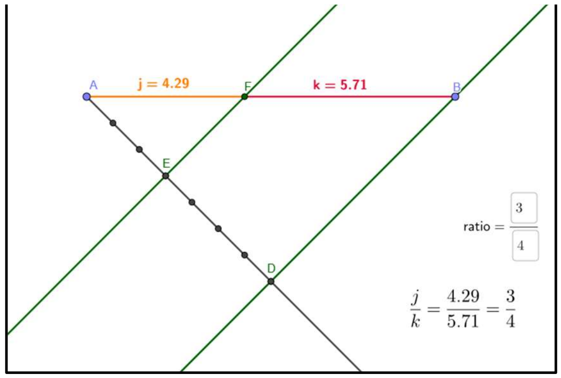

Figure 5: Dividing a segment. GeoGebra link:
https://www.geogebra.org/m/ex6vez6c#material/ey9qhqwh

The inequality between the arithmetic and geometric means is illustrated in Figure 6. It proves the inequality with the help of the altitude theorem of right triangles. In the figure, the altitude of triangle ABE is shown in pink, while the radius of the circle is shown in orange. By moving point C, students can observe that segment CE will always be shorter than segment OD, except when they coincide – this happens when the length a of the red segment AC is the same length b of the blue segment CB .

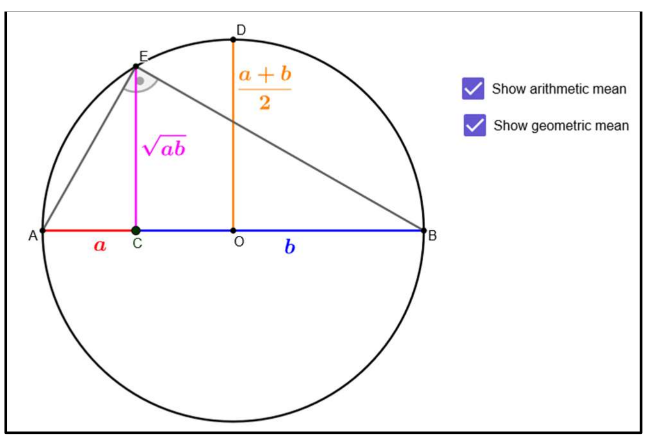

Figure 6: Inequality of arithmetic and geometric means. GeoGebra link: https://www.geogebra.org/m/ex6vez6c#material/xk9cjbkt

Methods and Participants

During the case study, 21 lessons were conducted using the workbook created for this purpose. Students received the workbook via the school's social platform, allowing them to access it on their mobile phones during lessons. Unfortunately, computers were not available in class, so individual tasks requiring the creation of GeoGebra files were assigned as homework. In a few instances, students were able to complete the tasks during class using the GeoGebra app on their phones. In other cases, the teacher demonstrated the process of creating the files during the lessons.

The workbook was tested with 10th-grade students studying mathematics at an advanced level. They had three math classes per week. The group consisted of 14 students – 6 boys and 8 girls. Students completed a short online questionnaire twice during the experimental period. The first questionnaire included 6 statements with 5-point Likert scales, 3 open-ended questions, 1 preference question, and a box for additional suggestions. The second questionnaire included 4 statements with 5-point Likert scales, 2 open-ended questions, and a suggestion box. The statements were formed based on the questionnaire that Arbain and Shukor (2015) used in their study.

At the end of the observation period, students completed a final test covering the main topics. The test assessed their conceptual understanding of similarity and circle-related mathematical concepts, as well as their ability to apply mathematical reasoning in problem-solving. In addition to the test, homework assignments were used to evaluate students' independent use of the software. During classroom activities, attention was paid to the clarity and accuracy of student responses, particularly their use of precise mathematical language and the correct application of definitions. The questionnaires measured student motivation and to gather feedback on their experience with GeoGebra — including how much they enjoyed using it, what their general opinion of the software was, and what difficulties or positive experiences they encountered during the activities.

Results

Based on students' responses to the open-ended questions, we can draw the following conclusions about the benefits of using GeoGebra in our case study. The GeoGebra figures offer students with weaker motor skills the opportunity to analyze accurate diagrams of any size during home study. Additionally, it can be challenging for some teachers to draw precise figures on the board, so providing students with well-drawn examples is beneficial. Visual representations of the concepts make it easier for students to grasp the material.

> *"Since the figure is accurate, it's easier to understand and more transparent."*

> *"It helps us think not only based on theory but also with the help of figures."*

With dynamic diagrams, students can quickly and easily explore multiple examples. By manipulating the diagram, special cases can be generated effortlessly, something that would require drawing separate figures with the traditional paper-pencil method. This provides an opportunity to address any doubts students may have by seeing proofs or solutions in various forms.

> *"It illustrates the theorems—for example, when we move a point, the theorem still holds. It's much harder to imagine this on paper."*

> *"By creating the diagram together, I understand the material more easily, and it encourages me to think rather than just accept everything."*

Despite teachers' best efforts to actively plan lessons, there are times when students are tired and fall behind during class. In such cases, as well as during home preparation, the figures can be reviewed step by step.

> *"It's much more transparent, and it can be broken down into steps that can be revisited. If someone unintentionally zones out in class, it's harder to follow the steps of a task [without GeoGebra]."*

GeoGebra helps students become more motivated and confident when experimenting with geometry.

> *"I like to start my homework with it, and even in my free time I often feel like doing geometry. I open it up to create simple things, although the functional part is still somewhat unfamiliar."*

While some students were quite confident, others needed more support during individual work.

> *"I get completely lost in GeoGebra on my own and just end up confused. It would be enough for me if it were just there as a tool, nothing more."*

Students filled out the first questionnaire after the topics related to the circle. The second questionnaire was at the end of the research period. Table 1 shows three items that appeared in both of the questionnaires. The means of the responses to these items slightly decreased. It seems that students enjoy using GeoGebra and believe it is helpful. However, the second half of the workbook did not contain as many GeoGebra exercises as the first one. This could be a possible reason for the decrease in the scores. A second reason could be that using the same software for a longer period can become boring for the students. Thirdly, GeoGebra allows more interactivity in exercises related to circles than in the topic of similarity, hence its advantages compared to traditional teaching methods are less prominent in the latter topic. During further developments of the workbook, we will create more exercises and better examples for the second part. In our future research, we will concentrate on the long-term use of GeoGebra.

A fourth possible explanation for the decline could be the increasing complexity of the tasks in the second part of the workbook. As the mathematical content becomes more abstract, students might find it harder to explore concepts through GeoGebra, especially without sufficient guidance or scaffolding. This suggests that not only the quantity but also the variety and structure of GeoGebra activities play a crucial role in maintaining students' interest and engagement. In future revisions of the workbook, we plan to diversify the types of interactive tasks, for example by including more exploratory challenges, and real-life applications, to better align with students' varying levels of motivation and skill.

Item	First questionnaire	Second questionnaire
GeoGebra helps to learn mathematics concepts.	4.25	4.00
GeoGebra can help to increase my achievement in mathematics.	3.92	3.36
I am happy if the teacher uses the GeoGebra in teaching mathematics.	4.47	4.46

Table 1: Means of the same questions in the two questionnaires.

Based on the responses to the questionnaires, the majority of students felt that GeoGebra helped them understand the concepts better. They were more motivated to learn the material using digital tools in addition to traditional methods. Students appreciated the teacher's demonstrations of how to use the platform during class and how to create different figures, which not only helped them understand the topic but also allowed them to learn how to use GeoGebra. However, some students found the pace too fast or would have preferred to always have ready-made figures available.

According to the teacher, GeoGebra led most students to participate in lessons with much more enthusiasm, even though many of them had disliked geometry in primary school. The group enjoyed working together to create files, and some students even began exploring the program further, either as a computer or phone application. These topics are mostly found in the advanced-level curriculum of the Hungarian two-level matura exam. Although the topics are challenging, these visual representations make it easier to understand them.

LIMITATIONS

One of the limitations of this study is the small number of participants, which limits the generalizability of the findings. No control group was used in this pilot phase, as the primary aim was to test the functionality of the workbook and gather initial feedback on its structure, content, and the integration of GeoGebra. As such, the focus was not on comparing digital and non-digital teaching methods, but rather on evaluating the digital material itself.

We acknowledge that the limited sample size and the lack of a comparison group may restrict the broader applicability of our findings to different topics, educational levels, or international contexts. In future phases of the project, we aim to test the workbook in more classrooms and with larger, more diverse groups of students.

The workbook is still in progress. More GeoGebra files will be added to the workbook, and students' feedback will be taken into account during further development of the teaching material. The case study presented here is part of a larger project in which we aim to create an online workbook that can be useful for students. Since it is time-consuming to collect suitable tasks for a topic and create visual representations in GeoGebra, we hope that teachers can profit from this workbook as well.

CONCLUSION

This study highlights the importance of using digital tools in mathematics education. Based on the literature review, GeoGebra is a suitable platform for use with students. It can be used for creating visual representations in different fields of mathematics, which can ease the learning process for students and motivate them during the lessons. Besides digital and mathematical skills, GeoGebra can also be useful in developing skills that are relevant for the 21st century.

A case study related to an online workbook was performed. The workbook was created for advanced-level 10th graders to study similarity and circle-related concepts. It consists of definitions, theorems, proofs, tasks, and homework assignments related to the topic. Several links can be found in the workbook that lead to GeoGebra files with visual representations. A teacher tested the material with a small group of students and asked for their opinion about it with two short questionnaires.

Based on students' answers, this workbook seems to be on a good track. Students enjoyed the lessons with GeoGebra and became more motivated to study geometry after successfully creating different figures. The visual representations and the dynamic figures provided more opportunities than traditional paper-pencil methods. This helped students with conceptual learning and gaining a deeper understanding of the topic. Most students could easily use the program individually; however, some of them needed more help. GeoGebra promoted student-centered teaching, as creating files together during classes encouraged students to participate actively. Individual work was mostly done at home; however, a project for group work is also provided in the workbook. It would be useful to create groups based on students' levels of GeoGebra knowledge, allowing those who are better at it to help others.

During the research process and the development of the workbook, we gathered several practical insights that can be useful for mathematics teachers who wish to integrate GeoGebra or other digital tools into their lessons. When introducing GeoGebra in the classroom, it is advisable to start with simple tasks that help students become familiar with the interface and basic functions of the software, such as plotting points or using sliders. These initial steps support students in navigating the digital environment with greater confidence and gradually prepare them for more complex constructions.

It is important to recognize that technical difficulties are a natural part of the learning process. Some students may initially struggle with certain GeoGebra tools, especially when working with transformations or custom tools. To maintain motivation, it is useful to incorporate a variety of task types. In addition to discovery-based activities such as mini-projects. Alternating task formats helps sustain students’ interest and engagement throughout the lessons. If students encountered difficulties while using GeoGebra, they could post their questions on a forum hosted on the school’s online platform. This allowed all students to view both the questions and the teacher’s responses, creating an opportunity for shared learning and collaborative problem-solving.

Finally, it is beneficial to provide a brief opportunity for reflection at the end of each lesson. Ask students to write down one thing they learned during the lesson and one part they found difficult or confusing. These reflections offer valuable insight for planning future lessons and help identify students who may need additional support.

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