ENHANCING GEOMETRIC CONSTRUCTIONS IN ELEMENTARY EDUCATION USING GEOGEBRA: A CONSTRUCTIVIST APPROACH

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ABSTRACT

This paper investigates the integration of GeoGebra software into lower secondary school geometry lessons using an action research approach. The aim was to explore how the use of GeoGebra affects students' experiences, attitudes, and motivation when solving triangle construction tasks. The study was carried out in two ninth-grade classes in a Czech primary school, drawing on the principles of the constructivist Hejny method. A mixed-methods design was employed, combining classroom observations with open-ended questionnaires and a semantic differential to collect qualitative feedback. The findings indicate that many students found GeoGebra to be a helpful and engaging tool, particularly in terms of visual clarity and flexibility. While some preferred traditional paper-based methods, the digital environment was generally well received. The study provides insights into the practical implementation of GeoGebra in geometry teaching and offers recommendations for supporting students with varying levels of digital competence.

KEYWORDS

GeoGebra, Constructivist Learning, Digital Mathematics Education, Geometric Constructions, Primary Education.

1. INTRODUCTION

In recent years, digital technologies have become an integral part of modern education, transforming traditional teaching methods across various subjects, including mathematics (Prodromou & Lavicza, 2017). GeoGebra, in particular, has emerged as a widely used tool in geometry instruction due to its ability to visualise abstract concepts, promote interactivity, and enhance student engagement (Hohenwarter & Lavicza, 2010; Kaya & Öçal, 2018). Its dynamic environment offers students the opportunity to explore geometric relationships and carry out constructions with precision and clarity (Shadaan & Leong, 2013).

Alongside technological advancements, constructivist pedagogical approaches have gained growing attention. One such approach is the Hejny Method, a scheme-oriented and problem-based teaching strategy widely implemented in Czech primary schools. It encourages students to actively discover mathematical principles through structured tasks, collaboration, and cognitive autonomy (Hejný, 2012).

This study combines the affordances of GeoGebra with the constructivist framework of the Hejny Method in the context of geometry education. Conducted as an action research project, it was implemented in two ninth-grade classes at a Czech lower secondary school. The primary aim was to investigate students' experiences and attitudes toward using GeoGebra when solving triangle construction problems. Rather than measuring academic performance, the research focused on students' motivation, engagement, and practical feedback concerning the use of digital tools in geometry lessons.

The study draws on a mixed-methods approach, integrating classroom observations with open-ended questionnaires and semantic differential scales. The findings are used to identify key factors that influence students' receptiveness to digital geometry tools and to provide evidence-based recommendations for teachers seeking to support diverse learners in a digital classroom environment.

2. THEORETICAL BACKGROUND

Digital technologies are increasingly shaping mathematics education by introducing new opportunities for visualisation, interaction, and personalised learning. In geometry instruction, dynamic digital tools can support students' conceptual understanding and foster motivation, particularly when used in combination with learner-centred pedagogies (Hohenwarter & Lavicza, 2010; Prodromou & Lavicza, 2017).

2.1 The Role of Digital Tools in Geometry Education

Tools such as GeoGebra offer students the ability to experiment with geometric constructions, receive instant feedback, and visualise relationships dynamically (Shadaan & Leong, 2013). Earlier research on digital platforms for Euclidean geometry has highlighted the potential of e-learning environments to support visual and interactive learning (Santos & Quaresma, 2008). Digital environments also contribute to the development of essential 21st-century competencies, including digital literacy and collaborative problem-solving (PISA, 2021). However, successful integration depends on appropriate infrastructure, teacher preparation, and student readiness (Kostolányová & Šarmanová, 2014). Challenges include unreliable internet connections, unequal access to devices, and differences in students' digital competences.

2.2 Constructivist Learning and the Hejny Method

Constructivism posits that learners build knowledge actively through experience and reflection. In Czech educational practice, the Hejny Method embodies this philosophy by encouraging students to discover mathematical ideas through problem-solving and collaboration (Hejný, 2012). It is based on a set of twelve principles, including building on students' prior knowledge and promoting reasoning in social contexts (Žilková et al., 2018).

The teacher's role in this method is to guide exploration rather than transmit procedures. Students are encouraged to develop and test their own solution strategies, leading to deeper conceptual understanding and increased autonomy. This approach is particularly suitable for introducing geometric constructions in a way that is meaningful and engaging for learners.

2.3 GeoGebra as a Tool for Constructivist Teaching

GeoGebra, as a free and open-source software, integrates geometry, algebra, and measurement tools into a single interactive platform (Hohenwarter & Lavicza, 2010). Its dynamic features support discovery-based learning, as students can manipulate geometric objects and test their hypotheses in real time (Shadaan & Leong, 2013). Moreover, GeoGebra facilitates independent and collaborative learning, allowing students to work at their own pace or engage with peers in solving visual tasks (Arbain & Shukor, 2015; Kaya & Öçal, 2018). Previous studies have also confirmed the positive influence of GeoGebra on students' conceptual understanding, especially when applied in carefully structured learning environments (Gurmu et al., 2024).

In the context of this study, GeoGebra was used in the design of a custom-made GeoGebra Book developed by the teacher–researcher and applied during geometry lessons. The digital materials were aligned with tasks from Czech textbooks and adapted to support construction-based learning through the Hejny framework (Gemrot, 2024). Similar approaches have been explored in previous research, where digital applets were developed to support primary students’ understanding of geometric concepts such as symmetry (Žilková, 2020).

2.4 Conceptual Framing of the Study

The conceptual framing of this research is built around the integration of three core dimensions:

- **Digital tools**: their accessibility, accuracy, and visual feedback;
- **Constructivist pedagogy**: guided discovery, peer collaboration, and student agency;
- **Student experience**: affective engagement and usability perceptions.

Rather than predicting learning gains, this study aims to explore how the combination of GeoGebra and the Hejny Method is perceived by learners and what conditions may support or hinder the integration of dynamic geometry in real classrooms. These principles informed both the design of the teaching intervention and the structure of the data collection instruments.

3. METHODOLOGY

This study employed a mixed-methods action research design to explore students’ experiences with the use of GeoGebra during geometry lessons based on the Hejny Method. Mixed-methods research, as defined by Creswell and Clark (2007), combines qualitative and quantitative approaches to provide a more comprehensive understanding of educational phenomena. The research was carried out by a pre-service teacher during her teaching practicum at a Czech lower secondary school. The aim was to examine students’ attitudes, challenges, and feedback related to working with a GeoGebra Book focused on triangle constructions.

3.1 Research Design

The research was framed as a proactive action research project with a positivist orientation, complemented by qualitative data collection tools (Hendl, 2012). The structure of the research followed the iterative cycle of planning, action, and reflection, as commonly defined in action research literature (Phillips & Carr, 2014), allowing the teacher–researcher to respond to classroom realities and adjust instruction accordingly. The researcher implemented four lessons in the subject *Mathematics Exercises* in two ninth-grade classes (9.A and 9.B) at Primary School Příbor (Základní škola Příbor), Jičínská 486, Czech Republic. Each class was taught twice, with the researcher both teaching and observing. The lessons were based on tasks adapted from Hejny's textbooks and implemented through a custom GeoGebra Book (Gemrot, 2024).

3.2 Research Sample

The sample consisted of two intact classes of ninth-grade students. These students were typically 14 to 15 years old, corresponding to the final year of lower secondary education in the Czech system.

- **Class 9.A**: 15 students (no previous experience with GeoGebra)
- **Class 9.B**: 19 students (prior experience with GeoGebra during COVID-19 remote learning)

In total, 34 students participated in the action research. The school was well-equipped with iPads and internet access. Each student worked individually with a device during the lessons (Figure 1.).

Figure 1. Teacher is shown drawing on teacher's PC, students are drawing on iPads. Source: Own Work

3.3 Data Collection Tools

Two main tools were used for data collection:

- **Observation protocol**: The researcher noted classroom dynamics, student interaction, technical challenges, and reactions to digital tasks. Informal reflections and photographs were taken with informed consent.
- **Student questionnaire**: Administered online via Survio after the final lesson. It consisted of:
    - Two filter questions (previous GeoGebra use and class identification)
    - Four open-ended questions (motivation, perceived benefits, likes/dislikes, suggestions)
    - One semantic differential scale (5 bipolar pairs, e.g. "easy–difficult", "fun–boring") rated on a 5-point Likert scale (–2 to +2).

3.4 Digital Materials: GeoGebra Book

The teaching material was a digital collection entitled *Triangles with the Hejny Method*, designed by the researcher in the GeoGebra platform.

- The book was shared via QR code and Teams.
- Each lesson focused on triangle construction using tools such as perpendicular bisectors, altitudes, and Thales' circle.
- Students worked at their own pace with semi-guided interactive applets.

Technical challenges (e.g. login issues, device connectivity) were noted and addressed between lessons.

3.5 Ethical Considerations

The study was conducted with the approval of the host school and in collaboration with the class teacher. No personal data were collected. Students were informed about the purpose of the activity and participation in the post-lesson questionnaire was voluntary.

3.6 Data Analysis

The qualitative data from the questionnaire were analysed thematically (Hendl, 2012), focusing on:

- Students' attitudes toward GeoGebra
- Reported benefits and challenges
- Perceptions of motivation and usability

The semantic differential responses were summarised using frequency tables. The analysis did not aim to generalise, but to understand learners' individual experiences and perspectives in context.

4. RESULTS AND DISCUSSION

This section presents the findings of the action research conducted in two ninth-grade classes at a Czech lower secondary school. The results are based on qualitative and quantitative data collected through post-lesson student questionnaires and classroom observations.

Analysis focuses on two main areas:

(1) **students' perceptions of the GeoGebra learning experience**, and
(2) **challenges and suggestions for improving the implementation of digital tools in geometry education**.

4.1 Student Perceptions: Semantic Differential Analysis

A semantic differential scale was used in the post-intervention questionnaire to evaluate students' subjective experiences with GeoGebra. Students rated five pairs of contrasting adjectives on a five-point scale ranging from −2 (negative) to +2 (positive). The categories included: Easy–Difficult, Fun–Boring, Clear–Unclear, Useful–Useless, and Motivating–Demotivating.

Table 1. below summarises the distribution of responses and weighted mean scores for each category.

Table 1. Student Responses to Semantic Differential Scale (N = 32). Source: Own Work

Category	**-2**	**-1**	**0**	**+1**	**+2**	**Mean Score**
Easy–Difficult	1	2	6	15	8	**+0.9**
Fun–Boring	0	2	3	13	14	**+1.2**
Clear–Unclear	1	2	6	14	9	**+1.0**
Useful–Useless	0	2	2	15	13	**+1.2**
Motivating–Demotivating	2	1	3	15	11	**+1.1**

The results indicate an overall positive reception of GeoGebra across all categories. Students found the environment generally useful, fun, and motivating, and they rarely described the experience as boring or useless. The highest positive score was observed for *Fun–Boring* (+1.2), suggesting a high level of engagement.

4.2 Qualitative Feedback from Open-Ended Questions

Open-ended questionnaire items provided further insight into how students perceived GeoGebra during geometry lessons. The following key themes were identified through thematic analysis:

- **Ease of Use and Visual Feedback**:

"GeoGebra helped me because I could easily see if my construction was correct without having to erase and start again."

- **Increased Efficiency**:

"It was faster and more convenient than using a ruler and compass."

- **Learning Curve Challenges**:

"I didn't know how to log in at first and spent time trying to access the book."
"The tools were sometimes confusing, especially when I had to go back a step."

- **Requests for Improvement**:

"It would help if the tasks were explained more clearly at the beginning."
"A colour-coding of task difficulty would make it easier to choose what to solve."

Although the majority of students expressed positive attitudes, several responses noted the importance of technical preparedness and interface clarity—particularly for students unfamiliar with GeoGebra on tablets.

4.3 Interpretation and Pedagogical Implications

The results suggest that GeoGebra, when integrated with structured pedagogical methods like the Hejny framework, can enhance student engagement, usability perception, and autonomy in solving geometric construction problems. Despite occasional technical difficulties (login issues, tool limitations), students appreciated the interactive and exploratory nature of the software.

These findings align with previous research emphasising the motivational and cognitive benefits of dynamic geometry environments (Arbain & Shukor, 2015; Kaya & Öçal, 2018; Shadaan & Leong, 2013). Similar findings have been observed in other geometry domains, such as stereometry, where action research studies report increased student engagement and deeper understanding when GeoGebra is used in combination with constructivist strategies (Korenova et al., 2024).

To support successful implementation, future lessons should:

- Include time for onboarding and orientation,
- Provide printed QR codes and simplified login procedures,
- Differentiate tasks by complexity and student digital readiness,
- Encourage reflection on both process and mathematical reasoning.

4.4 Comparison Between Classes (9.A vs. 9.B)

Although both classes followed the same instructional sequence and used the same digital materials, a comparison between Class 9.A and Class 9.B revealed notable differences in digital fluency and perception of the learning experience.

- **Prior Experience with GeoGebra**:
  - Class 9.B had used GeoGebra during earlier remote learning sessions (COVID-19 period).
  - Class 9.A had no previous experience with the software.
- **Initial Technical Barriers**:
  - In 9.B, students struggled with login issues, forgotten passwords, and slow connectivity during the first lesson.
  - In 9.A, a printed QR code was introduced by the teacher to simplify access, resulting in significantly fewer delays.
- **In-Class Behaviour and Engagement**: The teacher–researcher observed that students in 9.A demonstrated higher enthusiasm and more frequent spontaneous cooperation, perhaps due to the novelty of the tool and the smoother start.
- **Learning Outcomes and Tool Mastery**: By the second lesson, the difference in digital fluency between the two groups was no longer apparent, indicating a steep learning curve and fast adaptation by 9.A students.

This comparison underlines the importance of instructional scaffolding and technical support, especially when introducing new technologies to inexperienced students. Well-prepared onboarding (such as QR codes or simplified interfaces) can offset initial disadvantages and create more equitable learning conditions.

5. CONCLUSION

This study examined the implementation of GeoGebra software in lower secondary geometry education through a classroom-based action research project. Conducted in two ninth-grade classes, the research focused on student motivation, usability, and engagement while solving triangle construction problems using a custom-designed GeoGebra Book.

The results of the semantic differential scale and open-ended feedback indicate that students generally perceived GeoGebra as useful, engaging, and motivating. Positive responses prevailed in all five evaluated categories—especially in terms of ease of use and task clarity. Students appreciated the software's interactive interface, visual precision, and ability to undo actions, which facilitated a smoother construction process compared to traditional paper-based methods.

Despite these positive perceptions, some technical and pedagogical challenges emerged:

- **Technical difficulties** in the initial sessions (login issues, connectivity delays),
- **Variability in digital readiness**, particularly among students with no prior exposure to the tool,
- **Interface limitations**, such as missing or unclear functions on mobile versions of the app.

The action research also revealed that instructional scaffolding, such as using printed QR codes and shared digital displays, played a crucial role in overcoming entry barriers. Moreover, students without prior experience adapted quickly when provided with structured support—highlighting the importance of inclusive onboarding strategies.

Drawing on these findings and previous studies (e.g., Arbain & Shukor, 2015; Kaya & Öçal, 2018; Prodromou & Lavicza, 2017), we offer the following practical recommendations:

1. **Initial guidance and differentiated support** are essential for students with varying digital fluency. Grouping by experience level may be helpful in early sessions.
2. **Blended instruction** that combines GeoGebra with traditional tools should be maintained, both to reinforce manual construction skills and to accommodate diverse learning preferences.
3. **Teachers need professional development** that goes beyond technical usage—focusing instead on pedagogical integration of digital tools into constructivist teaching frameworks such as the Hejny Method.
4. **Digital lesson materials** (e.g., GeoGebra Books) should be carefully designed to avoid interface obstacles and provide toolbars tailored to the structure of each task.

This case study reaffirms the value of combining dynamic digital tools with inquiry-based pedagogies. While the research was limited to a small sample and focused on a specific topic within geometry, it contributes to a growing body of evidence that well-designed digital integration can support deeper engagement and more accessible mathematics learning for diverse student populations.

For future research, we recommend:

- **Extended implementation** over a longer time frame to examine sustained effects,
- **Replication in diverse educational settings**, including rural schools or schools with limited digital infrastructure,
- **Investigations focused on teacher development**, examining how digital tools shape instructional strategies and professional growth.

Ultimately, GeoGebra—when thoughtfully integrated into constructivist frameworks—has the potential to modernise mathematics education, empower learners, and provide inclusive opportunities for mathematical exploration.

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