The impact of the GeoGebra dynamic program on the learning of functions in lower secondary school

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Learned Custos, my esteemed Opponent, honourable members of the audience

It is my great honour to present today the main ideas of my doctoral research. My work explores a topic that concerns many teachers and students: how we can support young learners in understanding functions in mathematics, and how digital tools — especially the dynamic geometry program GeoGebra — can assist in this process.

Computers have been used in schools for more than sixty years. From early on, there was a strong belief that computers would transform learning and automatically improve students' results. Yet research has shown that these hopes have not always been fulfilled. Sometimes technology has a clear positive effect, sometimes very little effect, and sometimes even a negative one. The key question, therefore, is not whether computers should be used, but how they should be used so that they truly support learning.

My dissertation focuses precisely on this question.

Functions are one of the central topics in the mathematics curriculum in lower secondary school. They describe relationships between quantities in everyday life: for example, how distance changes with time or how price changes with weight. Although the idea sounds simple, functions are difficult to understand for many students.

One reason is that functions can be represented in many different ways. A function can appear as an equation. It can appear as a graph on a coordinate plane. It can appear as a table of values. These different representations are, in fact, different ways of describing the same relationship. However, for students, they often seem unrelated. An equation looks abstract, a graph looks like a picture, and in a table the connections between numbers remain hidden. Students must learn to move between these representations and see how they are connected.

Many studies have shown that this is one of the biggest sources of difficulty. Students may learn how to calculate, how to draw a graph, or how to fill in a table, but they may still fail to understand the deeper meaning of the function. They know the steps but not the idea.

Traditionally, graphs are drawn by hand using pencil and paper. This practice is important: it helps students see how a graph emerges from another representation, such as an equation or a table. But drawing by hand takes time and requires accuracy. If a mistake happens, the student must start again. And once a graph is drawn, it is static. It cannot be easily changed, moved, or explored.

Dynamic software such as GeoGebra offers something that pencil and paper cannot. It shows the equation and the graph at the same time. When a student changes a number in the equation, the graph changes instantly. This allows students to experiment freely. Through such exploration, students begin to see the connection between the equation and the graph much more clearly.

Technology can also take over some routine tasks. When a computer draws the graph, students can use more of their mental capacity to think about what the graph actually means. Previous research shows that this can lead to a deeper understanding — especially when teachers guide students to explain what they observe.

However, technology alone is not enough. Without thoughtful guidance, students may look at the screen without really thinking. Therefore, teachers remain central in helping students use digital tools in a meaningful way.

The aim of my dissertation was to investigate how the use of GeoGebra influences students' learning and attitudes towards mathematics when studying linear and quadratic functions.

The research focused on three main questions:

The first research question was what is the impact of the use of the GeoGebra dynamic program on the learning outcomes of students who learn functions in lower secondary school?

The second was how do students participating in GeoGebra-assisted intervention and students in traditional instruction explain their answers when they match the equation of a linear function to the graph? Are there differences in these explanations?

The third research question was what are students' attitudes towards mathematics when using the GeoGebra dynamic geometry program in two different contexts – inside the school and outside school?

To answer these questions, we conducted two empirical studies involving seventh- and ninth-grade students in Estonia. Also, we organised three creative student competitions. The studies combined tests, questionnaires, analysis of students' written explanations. Together, they form the four studies presented in my dissertation.

The first finding of my research concerns test results. In both the seventh and ninth grades, students who used GeoGebra did not achieve significantly higher scores in the final tests compared to students who learned only with traditional methods without using GeoGebra.

However, one important exception emerged. When students had to match a function equation with the graph — an activity that requires recognising the relationship between the coefficients and the position of the graph — the students who used GeoGebra performed significantly better. This suggests that GeoGebra supported a deeper understanding of how equations and graphs are connected.

Interestingly, students themselves often reported that GeoGebra helped them understand functions better, even though this was not visible in their test scores. This observation aligns with earlier research, which suggests that test performance does not always fully capture what students have learned.

The second focus of my research was on how students explain their thinking. In one task, students had to match an equation with a graph and then explain their choice.

The explanations were different in the two groups:

- Students who used GeoGebra often based their reasoning on the coefficients in the equation — the slope and the y-intercept.
- Students who did not use GeoGebra more often made a table of values, substituting numbers into the equation and made their decisions based on this table.

This difference reflects the different learning experiences of the two groups. In the GeoGebra using group, some lessons focused on exploring how changing a coefficient in the equation changes the graph. In the control group that did not use GeoGebra, using a table was more familiar and natural. Some mistakes were common in both groups. For example, several students thought that the coefficient of x shows where the graph crosses the x-axis. This is, of course, incorrect. About one quarter of all students gave explanations that were unclear or missing entirely. This suggests that explanation skills need more attention in mathematics lessons.

The third major finding concerns attitudes. Students were asked about their opinions toward mathematics before and after learning functions. They were asked how necessary, difficult, interesting, and enjoyable they rate mathematics.

In both seventh and ninth grades, students rated learning functions more difficult and less interesting, necessary and enjoyable than mathematics in general. This is not surprising: functions introduce many new ideas and can feel abstract.

However, something very positive emerged. A considerable proportion of students in the experimental classes reported that using the GeoGebra program improved their attitude towards mathematics. Among seventh graders, 42 per cent and among ninth graders, 33 per cent said their attitude became more positive.

Students explained that using GeoGebra made learning easier, more interesting, and more enjoyable. They felt they understood the content better. Some simply enjoyed working with computers.

Thus, even though GeoGebra did not improve test scores, it played an important role in creating a more positive and engaging learning experience.

My research also explored learning outside school. Over three years, we organised competitions for students all over Estonia. When creating these competition works, the participating students needed to deal with line equations and graphs in the GeoGebra environment. The competition entries had to be created on the following topics: Patterns from Function Graphs, Movement, and Fireworks for the Anniversary of the Estonian Republic.

Students reported that through these projects they learned more about GeoGebra and also more about mathematics — especially functions. They discovered connections between mathematics and art. They saw mathematics as something present around them. They learned patience and persistence. Many felt proud of their work.

These experiences show that digital tools can bring mathematics to life in new and creative ways.

The findings of my research contribute to earlier theories in several ways. They show that dynamic software may not always improve test scores, but it can change **how** students think. Students learn to view equations and graphs as connected. Their ways of reasoning shift toward more conceptual explanations.

The research also highlights the importance of explanation. Students in both the experimental and control groups needed support in expressing their reasoning. This is consistent with findings from the Estonian PISA results, which showed that students who regularly explain their thinking perform better.

The results also confirm that students' attitudes matter. Positive feelings toward mathematics are linked to better learning. For many students, GeoGebra served as a source of interest and enjoyment, helping them feel more positive about the subject.

From a practical perspective, the findings suggest several possibilities for teachers.

Firstly, dynamic geometry software can support exploration. By showing multiple representations at once, GeoGebra helps students discover how functions behave.

Secondly, explanation tasks should be used more often. Asking students to explain their thinking gives teachers valuable insights and strengthens students' understanding.

Thirdly, teachers should consider students' attitudes. Enjoyable experiences, such as creative projects or real-life applications, can help students develop a more positive relationship with mathematics.

Finally, technology use does not need to be limited to the classroom. Competitions, and creative explorations can connect mathematics to students' lives in meaningful ways.

In conclusion, my research shows that technology alone does not guarantee better results. But when used thoughtfully and combined with traditional teaching and motivating competitions, dynamic tools like GeoGebra can enrich learning, support deeper understanding, and make mathematics more enjoyable for students.

I hope that this work will encourage teachers to explore digital tools with curiosity, to value students' explanations, and to create learning experiences that are both meaningful and joyful.

Honoured Custos, honoured Opponent, dear audience, thank you for your attention.

I respectfully ask you, esteemed Docent Anu Laine, as the opponent appointed by the Faculty of Education for the public defence of my doctoral dissertation, to present your criticisms of my doctoral dissertation.