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Enhancing Mathematical Understanding Through Visual Representations in a Hungarian University

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Abstract

For university students of the 2020s, visual experiences play a central role in their daily lives and learning habits. Our experience suggests that traditional teaching methods, such as using lengthy texts, are less effective for this generation. We hypothesize that a curriculum incorporating visual elements, diagrams, and dynamic teaching materials enables more efficient education. Spectacular, interactive learning tools not only make teaching engaging but also facilitate the acquisition of new knowledge through direct experiences and active participation.

To test this, we conducted an experiment at the University of Szeged, comparing two introductory mathematics courses: the Mathematics Teacher Training Program (experimental group) and the Mathematics BSc Program (control group). Our findings indicate that the use of visual and interactive tools significantly improved students' performance. This article presents opportunities for applying visual teaching aids in various topics aiming to enhance the learning process's efficiency and the experiment's results.

To our knowledge, this is the first study in Hungary that comprehensively examines the impact of visual tools on university-level mathematics education over an entire semester, rather than focusing on a short specific topic.

1 Introduction

Today's university students are accustomed to the immediate feedback and visual stimuli of the digital world [12]. Their learning habits significantly differ from traditional approaches, posing new challenges to the education system. Due to the continuous influx of visual stimuli on their smartphones, they are accustomed to receiving and requiring a sequence of short, successive stimuli. A 90-minute lecture, or even a 45-minute class focusing predominantly on textual information, tends to be felt overly long, difficult to follow, monotonous, and fails to maintain their attention.

Taking these challenges into account, we believe that integrating visual elements, diagrams, and interactive teaching aids into the curriculum is necessary to enhance learning efficiency and sustain attention. These types of teaching materials not only make learning enjoyable but also help students acquire new knowledge through direct experiences and active engagement [19], [7].

Numerous studies support the benefits of using visual aids. The role of visualisation is relevant from an early age, as it facilitates conceptual understanding and problem-oriented thinking [4]. However, this impact is not limited to early childhood; later, in higher education, it aids in comprehending abstract concepts while also boosting motivation [11], [14], [17]. The use of diagrams and graphical tools is especially beneficial in mathematics education, particularly when solving complex, multi-step problems. Fortunately, many examples in mathematics education lend themselves to visual representation [6], [3], [7], [19].

This article presents instruction supplemented with visual aids and analyzes its effectiveness in university mathematics teaching. Specific tasks and proposals for utilizing visual aids are discussed in [20].

We tested the effectiveness and applicability of our method through an experimental program at the University of Szeged. During the research, we compared two similar introductory mathematics courses: in the experimental group (Mathematics Teacher Training Program; MT, 16 students), we integrated visual aids into the teaching process, while in the control group (Mathematics BSc Program; BSc, 22 students), traditional teaching methods were applied.

In analyzing the results, we aimed to determine the extent to which visual tools contribute to improving students' performance and how these methods enhance the learning experience. In the following sections, we briefly outline the teaching method, present the methodology and results of the study in detail, and conclude with future plans and tasks.

2 Teaching Strategies and Approaches

The course is a compulsory first-semester subject for both the Mathematics Teacher Training Program (MT; experimental group) and the Mathematics BSc Program (BSc; control group), with content in the two being nearly identical. The course aims to deepen and practice the high school-level intermediate mathematics curriculum while laying the foundation for the advanced knowledge required for university studies. Based on years of experience, we have observed that students entering the BSc program typically possess deeper initial knowledge and have four weekly hours for the course, compared to two in the MT. This additional time allowed the control group to engage in more practice with both a higher quantity and difficulty of problems, enabling them to explore certain issues in greater depth. To address this disparity, we developed visual aids specifically for the MT group, aiming to bridge the knowledge gap and mitigate its impact.

For the experimental group, we created various simple graphics, animations, dynamic, and interactive resources. At least half of the tasks in each topic were supplemented with such visual aids, whether for in-class exercises, homework, or assignments. In this section, we demonstrate, through specific examples, how dynamic visuals and visual aids were integrated into high school mathematics problems for the experimental group. These tools not only added visual appeal but also effectively supported the development of problem-solving and modeling skills while improving text comprehension and problem-solving abilities.

While the control group also made use of traditional visualization tools—such as algebraic tables or graphs drawn on the board—they did not use any digital or interactive tools. The range and intensity of visual methods applied in the experimental group went significantly beyond this baseline.

The experimental group was taught by the second author of the paper, so there was no need to train an external teacher in the methodology associated with the developed approach. The control group was instructed by another qualified high school mathematics educator with a similar professional background and enthusiasm. This ensured consistency in course quality and methodological approach, helping to mitigate potential teacher-related biases.

2.1 Simple Algebraic Visualizations

To address common algebraic errors observed in previous years, we created simple graphics aimed at making algebraic calculations more engaging. Studies (e.g., [17]) confirm that students can more easily organize their knowledge with the help of such visuals, leading to better retention and easier recall of concepts and methods. Our own experiences support these findings as well.

Unfortunately, many students struggle with understanding and correctly applying the Balance Method, and this also presents a challenge for them. To aid their comprehension, we created the following diagram, which visually illustrates the preservation of equality through equivalent transformations.

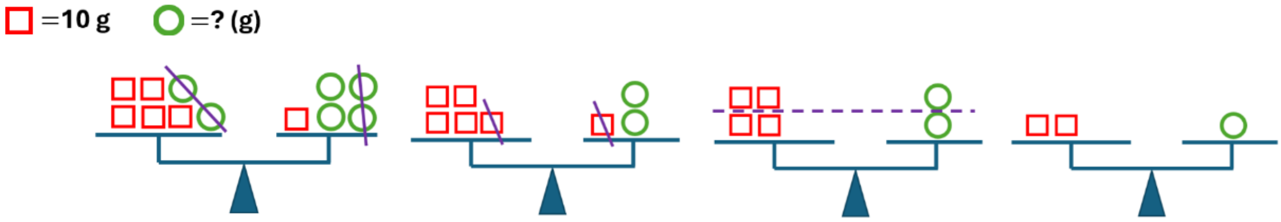


Figure 1: Visual Representation of the Balance Method

2.2 Simple Graphs

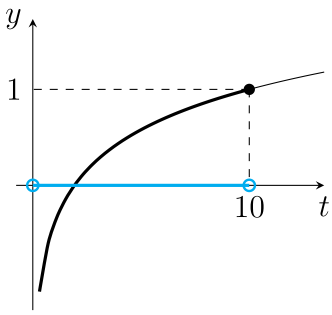
When analyzing inequalities, as well as equations and systems of equations, we find the function-based approach highly beneficial. Students often solve problems algebraically, as this is the method they were primarily taught in high school. However, representing the function's graph in a coordinate system not only makes the solution process shorter but also more intuitive (Figure 2), helping to clarify why a problem has no solution, a single solution, or multiple solutions.

Combining graphical and algebraic approaches enhances understanding, serves as a tool for verifying steps, reduces errors, and strengthens conceptual grasp. This integration encourages students to critically assess their solutions and gain deeper insights into mathematical relationships.

2.3 Animations, Dynamic and Interactive Teaching Materials

2.3.1 Developing a New Perspective

We created numerous visual teaching aids, primarily using the GeoGebra and MS PowerPoint. Unlike static diagrams, dynamic resources help students interpret and understand the role of parameters and



$$\lg(2x+1) < 1$$

$$\lg(t) < 1$$

$$0 < t < 10$$

Figure 2: Graphical Representation of Logarithmic Inequality

solve parameter-based problems correctly. They enable us to present mathematical concepts through novel and illustrative approaches.

The dynamic GeoGebra teaching aid shown in the Figure 3 and accessible via [9] was designed for the topic of inequalities involving absolute values.

In this application, the inequality

$$|x - a| \leq b$$

is examined through the analogy of illuminating with a flashlight. This representation visualizes the solution set of the inequality and its geometric interpretation for different parameter values. The direction of the inequality can also be reversed in the aid, and the right side of the diagram dynamically displays the standard graphical analysis.

This vivid representation of inequalities involving absolute values helps students grasp the concept of distance, which is essential for understanding abstract topics in calculus and avoiding incorrect algebraic solutions, such as $3 < x < -1$.

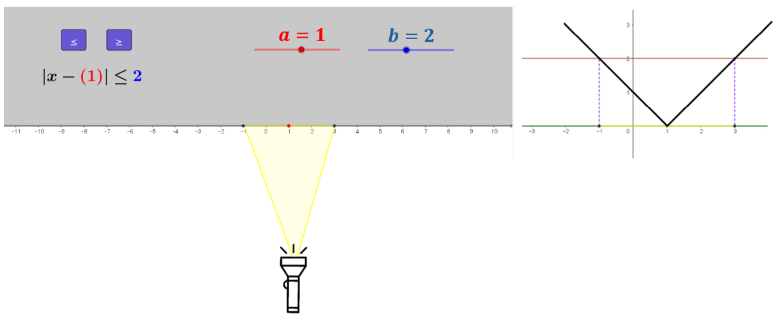


Figure 3: Graphical Analysis of Absolute Value Inequalities

Absolute value problems of this type are traditionally taught using case analysis. When appropriate, the graphical interpretation is drawn on the board by the instructor.

2.3.2 Word Problems

Word problems in mathematics are becoming increasingly challenging not only for high school students, but also for university students. This can be attributed, among other reasons, to the strong correlation between problem-solving processes and reading comprehension skills [18], [3], which, according to PISA studies, are rapidly deteriorating [15]. We employed two alternative methods:

- Word Problem → Visual Aid → Model

It was particularly important to create animations and digital teaching aids for various word problems, as visual representation of the information-such as graphical depiction of the scenarios described in the tasks-significantly aids students in understanding the text. Students can independently interpret the mathematical problems underlying the word problems. Furthermore, dynamic, interactive teaching aids allow students to formulate hypotheses and solution ideas through individual experiments and observations (Figure 4).

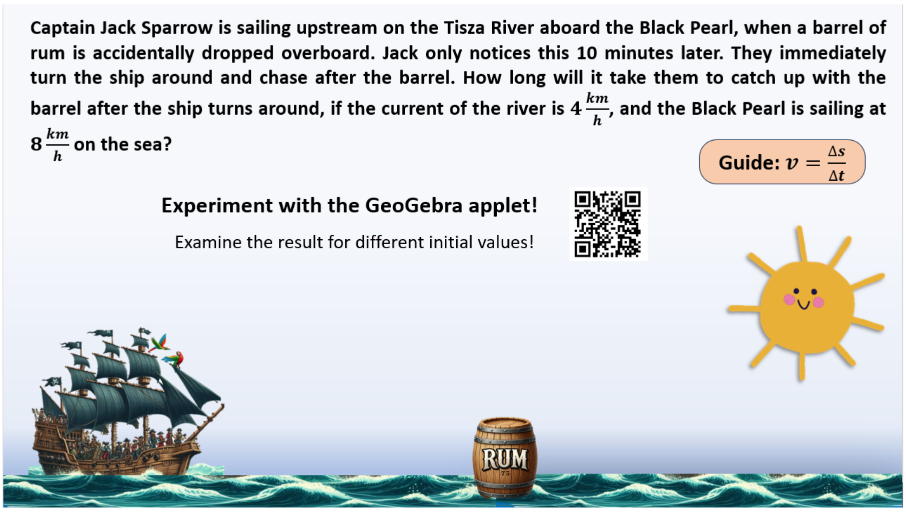


Figure 4: Digital Teaching Aid for a Motion Problem

In this learning environment, the instructor acts as a facilitator who supports students in using the program and helps them organize their solution ideas without dominating the educational process. This approach to word problems greatly encourages independent learning and fosters critical thinking through experimentation [2].

In traditional teaching approaches, word problems are typically processed in a linear sequence, following the Word Problem → Model steps, without the use of visual aids.

- Visual Aid → Word Problem → Model

In traditional instruction, the Visual Aid → Word Problem → Model approach to solving word problems is not applied at all. In relation to word problems, we incorporated creativity-demanding tasks into the teaching process of the experimental group. These tasks required students to create solvable word problems based on an image or animation (Figure 5).

In these types of tasks, students need to formulate and solve mathematical questions based on visual information. This develops their spatial imagination and abstract thinking [1], while also strengthening reading comprehension skills, as describing the problem they devised demands precise and clear text creation [8]. Additionally, visual-based tasks can increase students' motivation

[10], as they create an experiential learning environment that actively involves them not only in the solution process but also in problem creation.

As a homework assignment, students were tasked with formulating and solving a word problem based on the image and data shown in Figures 5 and 6 below.

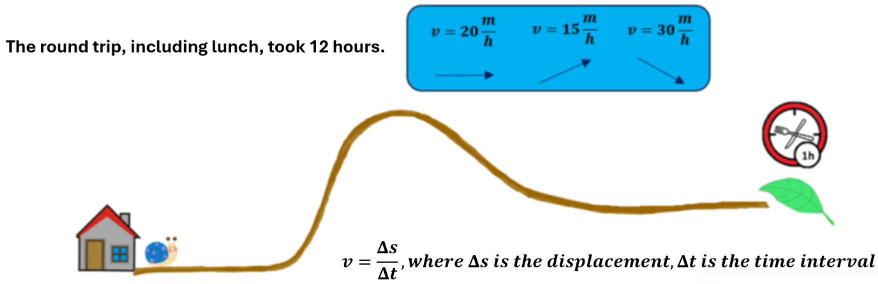


Figure 5: Creating a Word Problem Based on an Image

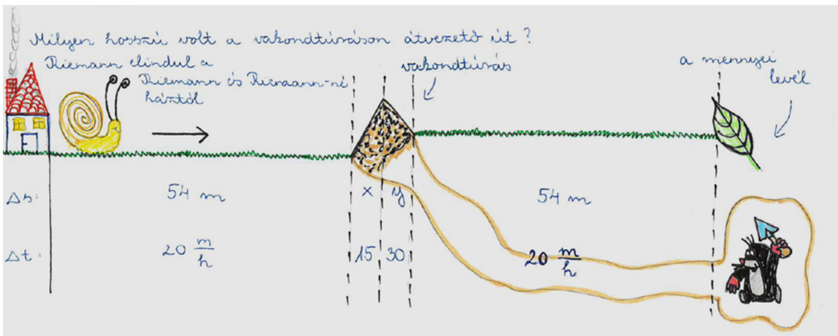


Figure 6: A solution detail submitted by an MT student for the task above

We observed that this processing approach encouraged interest even in more complex motion problems.

3 Experimental and Control Groups

All students from the respective programs participated in the study, with no selection process involved. Although advanced-level mathematics exams are not required for admission to either the MT or the BSc Programs, 5 out of 16 students in the experimental group (31%) and 13 out of 22 students in the control group (59%) had completed advanced-level exams. Therefore, we expected the MT students to have a significant initial disadvantage compared to the BSc students.

The curriculum for both groups followed the same problem book [13]. However, the experimental group had only 2 weekly hours compared to 4 weekly hours for the control group. Additionally, the BSc group's deeper mathematical subjects provided better opportunities to develop problem-solving, abstraction skills, and mathematical reasoning. Hence, we considered it a success of our method if the gap between the two groups did not widen.

4 Methodology of the Study

The experimental group engaged with the material using the proposed teaching method, whereas the control group was taught through conventional approaches. Our aim was to determine how visualization affects student performance, measured through a diagnostic test at the beginning of the semester, a final test at the end, and midterm assignments.

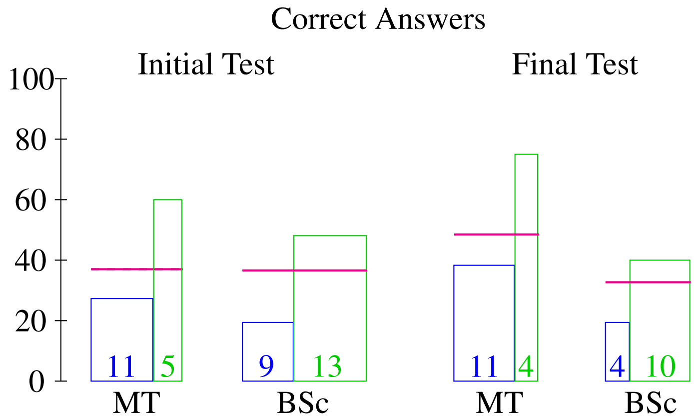
The initial test primarily included tasks from the intermediate-level high school curriculum, while the final test incorporated advanced-level tasks studied during the course. The initial test was completed by 16 students from the experimental group and 22 from the control group, while the final test was taken by 15 students (4 with advanced-level high school mathematics) in the experimental group and 14 students (10 with advanced-level mathematics) in the control group.

Both groups took the same test under identical conditions without the use of any aids. Motivation to perform well was equally encouraged by incorporating test results into the final course grade.

5 Results of the Study

5.1 Comparison of Diagnostic Test Results

The comparison of the initial and final tests is illustrated using bar charts to display the percentage of completely correct answers. The width of the bars corresponds to the group size. The magenta horizontal line indicates the average performance of the respective group, while the blue bars show the averages for students with intermediate-level exams, and the green bars represent the averages for students with advanced-level exams.



Several noteworthy and unexpected results emerged:

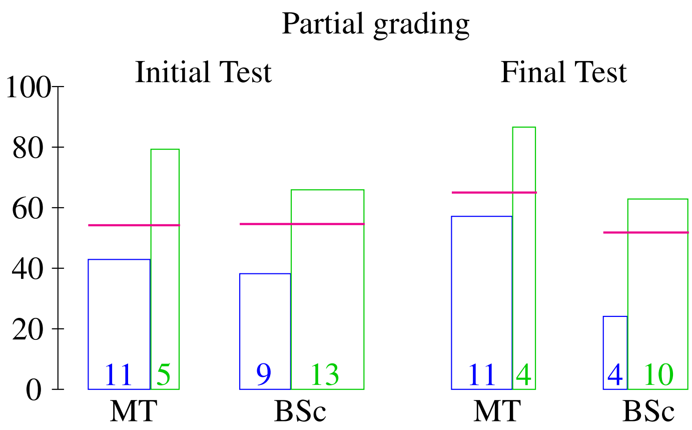
1. At the beginning of the semester, the diagnostic test results showed a minimal advantage for the MT group over the BSc group, based on average performance. However, this difference was minimal because the ratio of intermediate- to advanced-level exams varied significantly between the groups. When comparing students with the same level of high school exams, the MT group's performance was noticeably better.

2. By the end of the semester, despite fewer BSc students taking the final test, and with the ratio of advanced-level students improving (from 13–9 to 10–4), the MT students achieved significantly better average results. Not only did they match the overall average of the BSc group, but their performance clearly exceeded it.

3. Comparing the two tests, the final test was naturally more challenging. This is evident from the weaker average performance of BSc students with advanced-level exams. In contrast, MT students showed significant improvement among both intermediate- and advanced-level exam holders, demonstrating the success of our method.

4. The diagnostic test also confirmed that students with intermediate-level high school exams generally arrive with inadequate calculation skills. This was already noted in the need to create a visualization for the Balance Method (Figure 1). It is clear that greater emphasis on fundamental calculation skills is necessary at the intermediate level.

A similar conclusion can be drawn if we evaluate the tests using the traditional grading guide applied to national high school exams:



For students who completed both the pre-test and post-test (N=29), we examined the effectiveness of the method using non-parametric statistical tests. First, we used the Wilcoxon signed-rank test to determine whether there was a statistically significant difference between the pre-test and post-test scores of individual students. In the MT group, we found a significant improvement (p=0.0045), indicating that students' performance improved in a statistically verifiable manner over the semester. In contrast, no significant change was observed in the BSc group (p=0.5749), meaning that their results did not show a statistically detectable shift compared to the pre-test.

Next, we used the Mann–Whitney U test to compare the two groups, first in terms of post-test performance and then in terms of the degree of improvement. We found no statistically significant difference in post-test scores between the groups (p=0.1538), suggesting that their final performance levels were similar. However, the difference in improvement was statistically significant (p=0.0415), indicating that students in the MT group demonstrated a significantly greater degree of progress over the semester than those in the BSc group. The effect size measured by Cliff's delta (Cliff's delta = 0.45) indicates a medium effect, suggesting that the instructional method applied in the MT group had a meaningful impact on student development.

These findings suggest that the method used in the MT group supported student learning more effectively than the traditional instructional approach used in the BSc group. While no significant difference was found in the final performance between the two groups, students in the MT group exhibited statistically verifiable greater improvement throughout the semester.

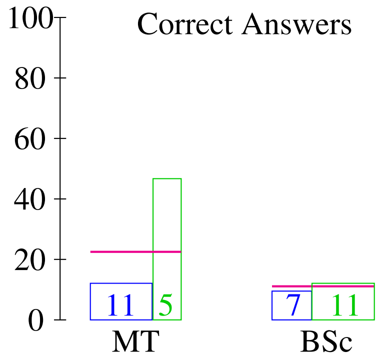
While partial scoring resulted in higher percentages, it masked the severity of the problem. Therefore, in subsequent analyses, we focused exclusively on the percentage distribution of completely correct answers to highlight shortcomings.

5.2 Comparison of Common Tasks in Midterm Tests

Due to the differing number of contact hours and, consequently, the varying depth of content coverage, it was not feasible to fully align the midterm tests, which formed the basis for the students' grades.

Only three common tasks were included, allowing for their comparative analysis.

The percentage distribution of completely correct answers is as follows:



Despite the control group being allowed to use the standard mathematical table during the test, the complexity of the tasks and the aforementioned deficiencies in calculation skills resulted in very poor performance in both groups. Nevertheless, it is evident that the average performance of students with intermediate-level final exams in the MT group matches that of students with advanced-level final exams in the BSc group. In our opinion, this is due to the effectiveness of the visual method, as we will substantiate in the following section.

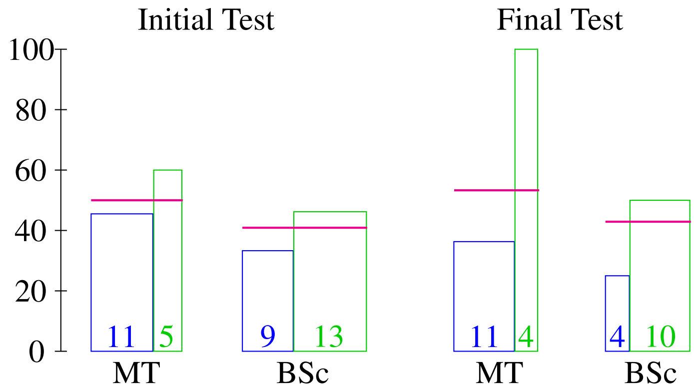
6 Relevant Examples

Due to space constraints, we will detail only the three most illustrative tasks to demonstrate the positive impact of visualization. Alongside the percentage of correct solutions, we will also present the frequency of diagram usage. Furthermore, we will briefly address problem-solving errors and include a selection of diagrams created by students.

6.1 **Task:** *Solve the following inequality:*

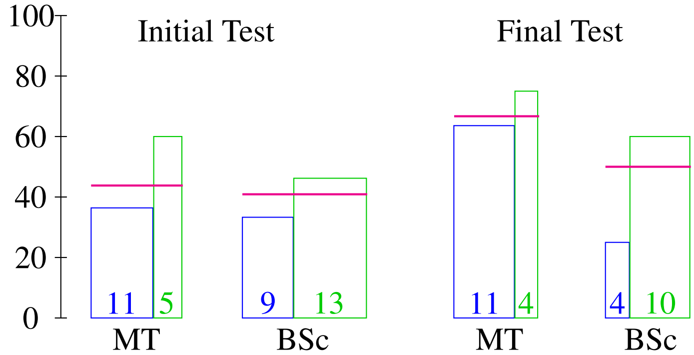
Initial test	Final test
$x^2 - 9 \geq 0$	$x^2 + 2 \geq x$

Correct Answers



Since solving the second task requires more complex reasoning, we neither expected nor observed better average performance. A small portion of the errors stemmed from calculation mistakes, while the majority resulted from incorrect square root extraction, reflecting a reliance on algebraic methods.

Figures



By the end of the semester, the proportion of students in the experimental group who created diagrams increased significantly, with nearly 70% of them producing some form of visualization for the task. The visualizations took various forms, indicating that the students did not simply replicate a single solution type (Figure 7).

6.2 **Task:** *How many solutions does the following equation have?*

$$|x + 3| + 1 = x + 4$$

This type of problem appeared only in the final test. The following results were obtained:

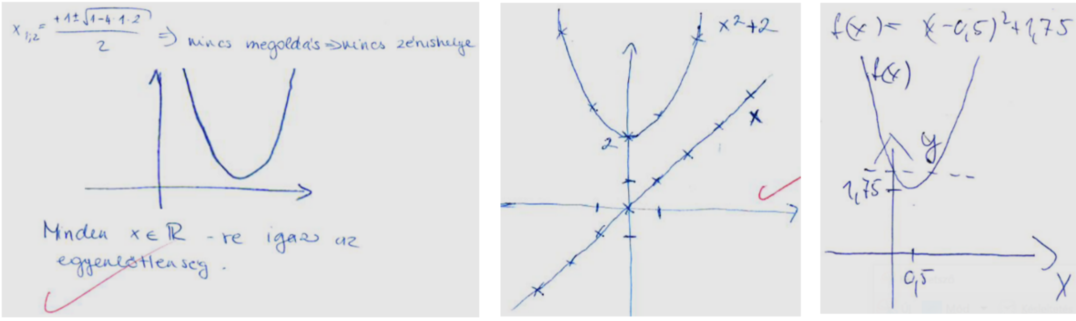
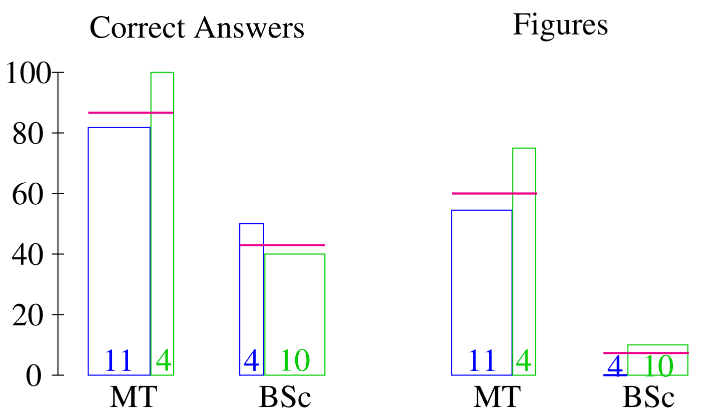


Figure 7: Diagrams created by the experimental group for Task 6.1



The experimental group achieved significantly better and outstanding results compared to the control group, with a much higher proportion of diagrams created. The errors stemmed from the incorrect use of the algebraic method of case separation. Based on this example, the role of graphical representation in providing the correct final result is convincing (Figure 8).

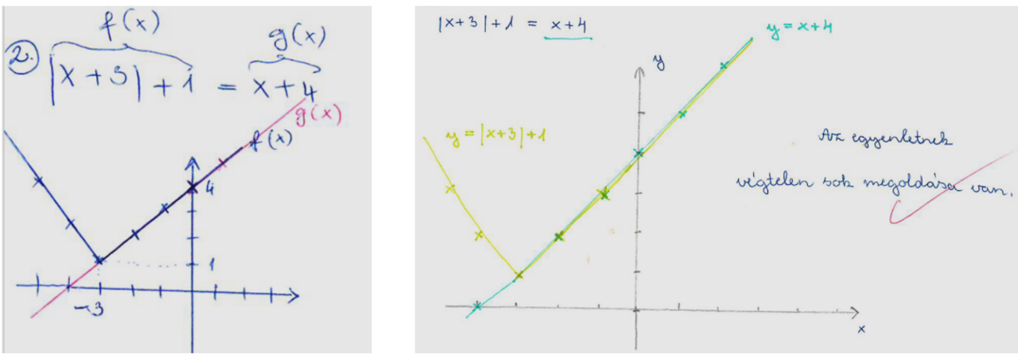


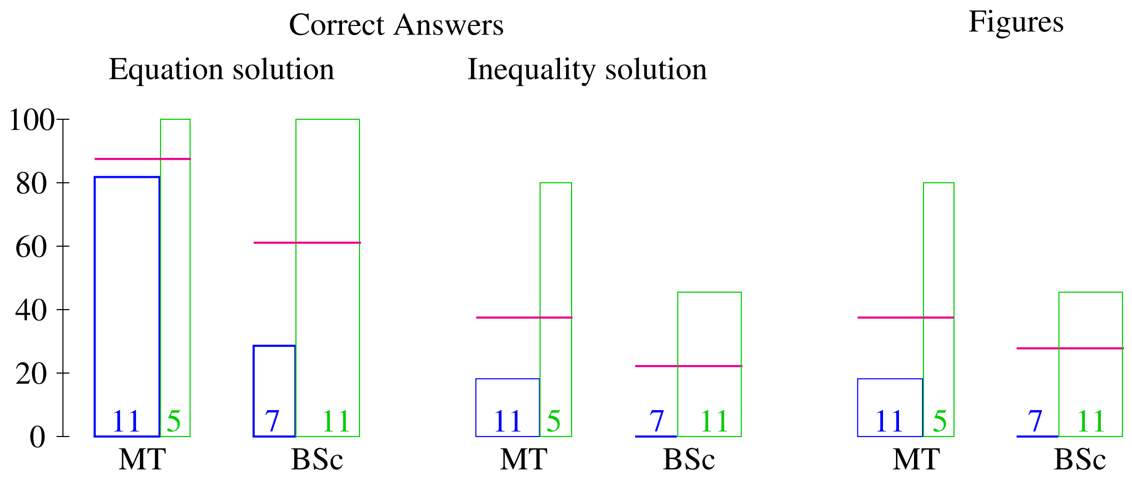
Figure 8: Diagrams created by the experimental group for Task 6.2

6.3 **Task:** *Solve the following inequality:*

$$2\cos^2 x - 5\sin x - 4 \leq 0$$

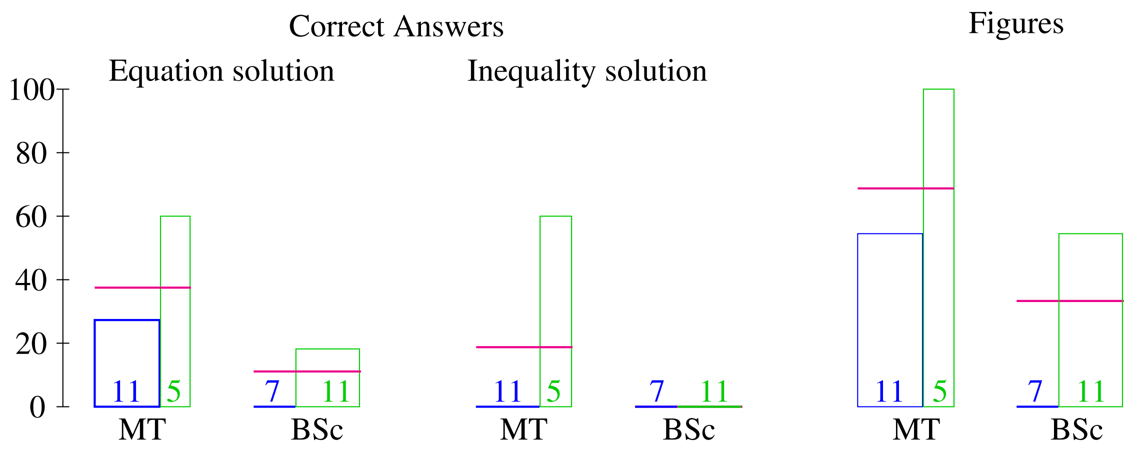
Finally, we analyze in detail the task from the mid-term test on which students performed very poorly, in order to better understand which steps posed difficulties and where visualization provided support. For this purpose, the solution of the task was divided into two parts.

- **Part 1:** Based on the trigonometric identity $\cos^2 x = 1 - \sin^2 x$, the formulation of the quadratic inequality by introducing a new variable, followed by the correct solution of the equation and then the inequality.



The experimental group performed better even in the first part of the task. Both groups were able to correctly formulate the quadratic inequality at a similar rate; however, the use of the quadratic formula posed slightly more problems for the control group. It was evident that transitioning from the equation to the inequality remained a challenge for students, and unfortunately, no BSc student with an intermediate-level high school graduation exam managed to complete this step successfully. Furthermore, it is crucial to note that all students who created diagrams solved the inequality flawlessly.

- **Part 2:** The correct solution of the trigonometric equation and inequality.



The experimental group not only created visualizations for the task at a significantly higher rate, but, presumably with the help of the diagrams, were also able to solve the trigonometric equation at a higher rate. The solution to the trigonometric inequality was successfully achieved only by the MT group, who either read it off from the unit circle or from the graph of the function (Figure 9). This again demonstrates that graphical representation plays a key role in providing the correct final result.

The most common mistake resulted from incorrect diagram or graph creation, but several students also made errors when converting the angle from degrees to radians. Unfortunately, some students from the MT group, despite providing the correct graphical solution to the inequality, incorrectly wrote the interval of the solution set. These were naturally not included in the correct solutions, though it was simply a minor oversight.

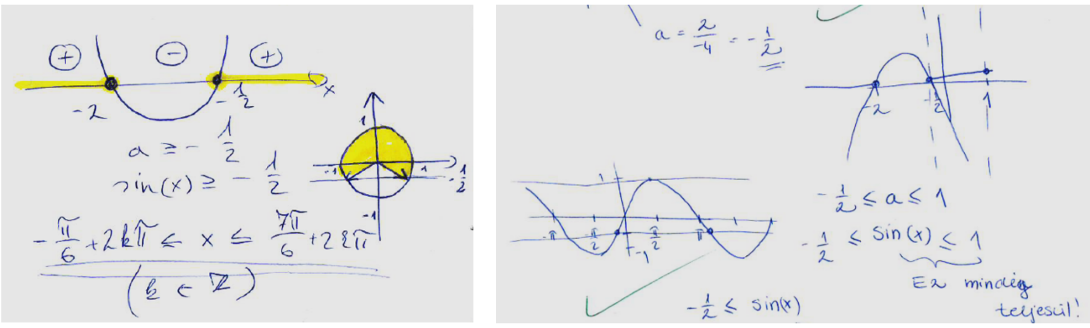


Figure 9: Diagrams created by the experimental group for Task 6.3

7 Student feedback

We assessed the impact of visualization on student attitudes based on classroom work, as well as through assignments and homework, and students were also able to provide anonymous written feedback about the course at the end of the semester.

The attitude change was clearly indicated not only by the significantly better classroom engagement than usual, but also by the fact that even those students who otherwise struggled to follow the solution process began to think through the problems using graphs and diagrams. This suggests that the method stimulated creative problem-solving, and the students focused not only on traditional algebraic solutions. It is particularly important to note that by the third lesson, every student in the experimental group started tasks independently, without exception. In contrast, the control group still left several tasks incomplete in the last test.

The quality and detail of the submitted tasks and homework clearly showed that students effectively and enthusiastically used the supplementary materials. After the class, they were already interested in what visual materials they would receive or what they would need to prepare themselves. They looked forward to the upcoming tasks with sincere anticipation. The effectiveness of the supplementary materials is further supported by assignment data: the average submission rate for the five mid-semester assignments was 88.75%, and students achieved an average accuracy of over 70% based on partial scoring.

The above conclusions were also reflected in the end-of-semester feedback:

“The classes were good, especially the GeoGebra animations were really cool.”

“The idea is great, and it would be good to have a course like this in several semesters.”

“The course helps expand and deepen high school material.”

“Very important course, it helped bring students with different levels of prior knowledge to the same level.”

“It was my favorite class.”

“Very enjoyable, we made good progress, clear and fair expectations.”

8 Conclusion

Surprisingly, the average of the pre-semester assessment showed a minimal advantage for the experimental group over the control group. In the case of the experimental group, we supported the review and expansion of high school knowledge with visual aids and new presentation methods. This engaging, visually appealing approach not only made learning more motivating but also encouraged students to engage in independent learning. Our primary goal was achieved: the experimental group’s results, due to the differing number of lessons and the varied depth of mathematics subjects, did not fall short of the control group’s level.

Despite the small sample size, the presented data clearly demonstrate that we not only met the minimal expectations but also achieved results far surpassing our goals. The performance of the experimental group significantly increased, further extending its advantage over the control group. Furthermore, the increased use of visualizations clearly demonstrates that students in the experimental group adopted a new, creative approach to problem-solving, confirming the method’s validity, practicality, and effectiveness, along with its positive influence on student attitudes.

While we did not find studies specifically addressing the impact of visualization over a full-semester university course, particularly in the context of mathematics teacher education versus mathematics training, several studies have demonstrated the significant effect of GeoGebra in comparison to traditional teaching methods at the university level [5] [16]. These findings are in line with our own observations, which show that visual tools, such as GeoGebra, not only have a significant impact on academic results but also positively influence student attitudes.

9 Future Directions

Following the completion of the article, we plan to further revise the curriculum of the Practical Courses, adapting it to the lower knowledge level of students studying under the 2020 National Core Curriculum. Based on the results of the research, the aim is to further develop and align the methods so that future students can apply visual tools and methods more effectively in their mathematical studies.

Later this year, we aim to repeat the testing of our method within a larger course of over 100 students. We plan to refine the methods, such as expanding the types of visualizations and tailoring them to meet students' individual needs.

Last but not least, a key task is the detailed description of the teaching methodology, which we believe is an essential part of the method's success, alongside the tasks equipped with visualizations. This will also help our colleagues successfully adapt our method to their own teaching fields.

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