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Teaching Mathematics and Computer Science

What does ICT help and does not help?

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Abstract. Year by year, ICT tools and related teaching methods are evolving a lot. Since 2016, the author of the present lines has been looking for a connection between them that supports the development of mathematical competencies and could be integrated into Transcarpathian minority Hungarian language education too. As a doctoral student at the University of Debrecen, I experienced, for example, how the interactive whiteboard revolutionized illustration in Hungarian mathematics teaching, and how it facilitated students' involvement. During my research of teaching in this regard, in some cases, the digital solution had advantageous effects versus concrete-manipulative representation of Bruner's too.

At the same time, ICT "canned" learning materials (videos, presentations, ...) allow for a shift towards repetitive learning instead of simultaneous active participation, which can be compensated for by the "retrieval-enhanced" learning method.

I have conducted and intend to conduct several research projects in a Transcarpathian Hungarian primary school. In the research so far, I examined whether, in addition to the financial and infrastructural features of the Transcarpathian Hungarian school, the increased "ICT-supported" and the "retrieval-enhanced" learning method could be integrated into institutional mathematics education. I examined the use of two types of ICT devices: one was the interactive whiteboard, and the other was providing one computer per student.

In this article, I describe my experiences, gained during one semester, in the class taught with the interactive whiteboard on the one hand, and in the class taught according to the "retrieval-enhanced" learning method on the other hand.

I compare the effectiveness of the classes to their previous achievements, to each other, and to a class in Hungary.

Key words and phrases: retrieval-enhanced learning, interactive whiteboard, visualization, development of spatial view with 3D dynamic geometry software.

MSC Subject Classification: 97U70.

Motivation and theoretical background of the research

As a teacher of mathematics and computer science, I thought that the use of ICT tools could improve the efficiency of teaching mathematics, and develop language, technological and mathematical competencies (The European Parlament and the Council, 2006).

Since 2016, I have been consciously looking for the tools and programs (applications) that support certain phases of the learning and teaching process of mathematics, especially those available in minority Hungarian language education.

A direct duty of the mathematics teacher is to let the students acquire the Hungarian vocabulary of the technical language, develop comprehension and interpretation skills, and show the relationship between the curriculum and everyday life.

At the beginning of my career, I thought that "blended learning" (Korenova, 2014) is an effective form of education that promotes the effective acquisition of knowledge. Through online education, I found myself in a life situation (along with many of my peers) where it was not possible to choose a single method. I had to be content with presenting videos and animations reminiscent of this, instead of collecting concrete manipulative experiences. During my online teaching, I tried to replace the missing traditional illustration with dynamic geometry software.

By using the *interactive whiteboard*, we can effectively support any form of work and any phase of learning. We can also create and find digital applications for individual, pair and group work that can help students get involved. The use of an interactive board is particularly effective in the case of a working method based on the intensive involvement of smaller groups (Simon, 2006; Námesztovszki, 2009; Barbarics, Rózsahegyiné Vásárhelyi, & Wintsche, 2019).

The functions of several previous educational tools (board, projector, poster) can be replaced and even expanded with the interactive whiteboard. The screen of the teacher's device (PC, laptop, tablet) can be shown and used as a touch screen, so students can "reach out" to the course of the class. At the same time, the mobility of the teacher increases and unwanted covering can be avoided with the possibility of remote control.

With the help of the interactive whiteboard, the different representations (Bruner, 1968) can be applied in parallel (De Vita et al., 2014). The interactive whiteboard can be used partly with its own software (applications, multimedia learning units), and partly with other external applications (SuliNova, Video Teacher, Geomatech, Okos Doboz, Okostankönyv, Wolfram Alpha, Socrative, Kahoot!, Redmenta, Online Test Pad, EduBase, Liveworksheets). In the case of the latter, the interactive whiteboard essentially functions as a touch screen.

The common feature of the static images in a book and the three-dimensional diagrams as well as the board drawings is that the student can see what he/she wants to show if he/she has previous experience and motivation to process the information. At the same time, it is a scientifically proven fact (Wertheimer, 1912; Koffka, 1935; Köhler, 1959) that the experience of space and movement can be triggered regardless of the will of the observer. The process of movement can be recalled by presenting static images at the right pace. *Dynamic geometry programs* make it easy to create a suitable construction sequence and present it at the right pace. Spatial experience is also possible without complicated procedures (stereogram). Experience of space already can also be created with the help of two-dimensional dynamic geometry programs, but it is much easier to create spatial construction with 3D service, and then display it from appropriately changed perspectives. We can display finished 3D construction in central and axonometric projection. No matter how professional the editing, and how beautiful the vision is, on standard screens or on the surface of the interactive whiteboard appears a two-dimensional, planar figure and it remains so for the observer until we move it by the dynamic feature (tilt and rotate). "The difference between the sight of a still and that of a moving image makes a serious impression on any observer. Spatial experience is also created for those who have not properly interpreted the static image properly" (Vásárhelyi, 2018).

The most expanded dynamic geometry software (AutoCAD, Cabri Geometry 2D-3D, Cinderella, GeoGebra, Euklides, 3DMath,etc.) were written with different philosophies, but they have the same essential functions. I chose GeoGebra for my research and school work. The main content reason for the choice was the possibility to connect the different levels of representation (Bruner, 1968), as well as many areas of mathematics and even different subjects (Geomatech). From aspects of practice, the pros were that it is free and available on several platforms, the communication language of Hungarian is varied, and all of these are important in minority education. An important consideration for the choice was also that it can be easily learned to handle. For didactic purposes, it is advantageous to be able to set the available commands.

Among the several functions of GeoGebra, I see the greatest advantage in the visualization, in the development of the spatial geometry view. In virtual reality, we can take the spatial constructions apart and put them back together more easily than concrete object models in reality (Jakab, 2020).

The completed worksheet can be stored in the cloud and can even be shared, personalized too.

In laboratory conditions, several pieces of research have proved that *retrieval of knowledge is part of the learning process, the antidote to forgetting.* These researches are mainly focused on the learning of language, anatomy, taxonomy, and memory-intensive learning. In Hungary, Mihály Racsmány's research group was the first to publish in this direction (Racsmány et al., 2014). Shortly after the publication of Racsmány's results, the Psychological Research Group on Mathematical Learning Theory of ELTE launched an investigation on the effect of the method in the field of mathematics learning. The new feature of these investigations is that they took place in everyday school teaching practice in mathematics and non-mathematics specialized university and high school education (Szabó, 2018; Bernáth et al., 2018; Dékány, 2019; Yakob (Jakab), 2020; Szeibert et al., 2022).

I also joined this research. My students are new in two aspects compared to the earlier populations: primary school students (6th grade, 12 years old) and they belong to Transcarpathian Hungarian minority.

The essence of the retrieval-enhanced learning method is that we support the integration of the new knowledge element (knowledge, proficiency, skill) into the knowledge network with scheduled retrieval. With the retrieval, we check the existence of the knowledge element on the one hand, and the relationship system on the other. The phases of the scheduled retrieval are:

- *Direct retrieval* – the aim is to avoid misunderstandings and incorrect connections.
- *Short-term retrieval* – early retrieval, supports the correct placement of recently learned material in the expanding knowledge network.
- *Medium-term retrieval* – helps to apply recently learned material and connect it with other areas of knowledge.
- *Long-term retrieval* – multilayer, varied in terms of time and implementation (worksheets, exams, ...).

The focus of the *knowledge-test type worksheet* is to create the opportunity to apply existing and newly acquired knowledge together. This supports differentiated performance feedback, building a knowledge network through positive reinforcement (Vásárhelyi, 2008).

The structure and content of the worksheet guide and direct the students, they help to highlight the essential parts and provides a sample for taking notes in terms of scope and depth.

The worksheet provides *the student* with relative independence, his/her own work pace – either in terms of depth or scope – and autonomy; through independent processing, the student's vocabulary, as well as everyday and professional language comprehension skills develop.

The worksheet can be an information-rich protocol for *the researcher*, even a basis of diagnostic measurement; other researchers can also read out the didactic goals and the depth of processing (Csapó, 1997, 2019, Vári, 2003).

You can use the worksheet to coordinate your schedule (time-locked interactive worksheets). In addition, immediate (or quick) evaluation of interactive worksheets and individual feedback (Gy. Molnár & Csapó, 2019) help the learners track their own learning performance.

The worksheet can contain a helping question, an explanation, a reminder, and a final result for verification. The solution is also worth reading for those who have been able to solve the task because it reinforces their idea.

Brief description of the research

Among the classes compared in the research, one learned using the retrieval-enhanced method, while in the other class, the visualization of the teacher's explanations and a significant part of teacher-student interactions were realized with the involvement of the interactive whiteboard. During the processing of the new material, it was the teacher who primarily used the whiteboard, while the leading role was assigned to the students during practice.

The teaching research was conducted in the spring semester of the 2019 school year, as part of the morning school sessions, with content appropriate to the class curriculum. The research was not disrupted by the pandemic, so there was attendance-based teaching throughout. In the two parallel classes, we processed the same curriculum using different methods and the same material.

The duration of the research was four weeks, with 16 math lessons divided into four lessons per week. The curriculum focused on the study of perpendicular and parallel lines as well as the coordinate plane. The lesson schedule is included in Figure 1.

Lesson	Topic
1.	Mutual position of two straight lines on the plane. Perpendicular and parallel lines.
2.	Drawing perpendicular and parallel lines with a rectangular ruler.
3.	Solving tasks with worksheets.
4.	Distance between point and line. Distance between parallel lines.
5.	Solving tasks with worksheets.
6.	Rectangle, square.
7.	Spatial elements, perpendicular and parallel planes. Cuboid, cube.
8.	Solving tasks with worksheets.
9.	Skew lines.
10.	Positioning in math class.
11.	The coordinate plane. The cartesian coordinate system.
12.	Representation of points in the cartesian coordinate system.
13.	Solving tasks with worksheets.
14.	Creating and reading tables and graphs.
15.	Solving tasks with worksheets.
16.	Final test.

Figure 1. The topic of the second research

The participants of the research were secondary school students (12 years old) from Transcarpathia. The distribution of headcount by class and gender is shown in Figure 2.

	Boys	Girls	Total
Retrieval class	14	8	22
ICT class	15	12	27
7th grade from Hungary	7	7	14
Total:	29	20	49

Figure 2. Distribution of students by class and gender

In the year before and during the research, I taught mathematics in both classes. The selected classes have all general training systems. There were no students with special needs in either class.

In both classes, I used worksheets which I compiled in accordance with the principle of spirality and Bruner's theory of representation (Bruner, 1968). I often used the different representations in parallel, even if the students were willing to "throw away the crutches". Based on the copies of the completed worksheets, I was able to continuously monitor the individual development of the students and the achievement of the class.

During the lessons, we progressed with the curriculum in a task-oriented manner (not in the phases of handing over the new material, practice, and accountability). Students were able to apply their existing knowledge while solving the tasks and gain new knowledge in the process. If, however, it turned out that the presumed previous knowledge had been forgotten, we discussed it. In both classes, I tried to give students an example of an application when introducing a new concept.

I used input measurements to compare the readiness of mathematics of the two classes and output measurements to examine the efficiency of the methods. There was an end-of-lesson summary in both classes. In the ICT class, the teacher summarized the material with the help of interactive modules; in the retrieval-enhanced class, the direct retrieval was realized with an end-of-lesson short test (see Figure 3).

<table>
<tr><td colspan="2">Input measurements
Comparison of the mathematical readiness of the two classes based on
I1) the grades obtained for the knowledge assessment test, written in the sixth grade at the beginning of the school year
I2) and the math grades of the first semester of the sixth grade</td></tr>
<tr><td>ICT-supported
end-of-lesson summary by the teacher with interactive modules;
home work
summary of a topic
summary of several topics</td><td>Retrieval-enhanced
direct retrieval: end-of-lesson short test
short-term retrieval: home work
medium-term retrieval: knowledge assessment from a topic
long-term retrieval: knowledge assessment from several topics</td></tr>
<tr><td>illustration with increased ICT-support</td><td>illustration with different representations</td></tr>
<tr><td>teacher-student interactions involving the smart board;</td><td>teacher-student interactions verbally</td></tr>
<tr><td colspan="2">Output measurements
O1) Comparison of the achievements of retrieval-enhanced and ICT classes with the students' previous results.
O2) Comparison of the two Transcarpathian classes based on the common geometry knowledge assessment worksheet.
O3) Comparison of the achievement of Transcarpathian and Hungarian students</td></tr>
</table>

Figure 3. Description of research

The interactive learning units used in the course of teaching were partly developed by me, and partly taken from Hungarian educational platforms (SuliNova, Geomatech, Okos Doboz, Okostankönyv, Mozaik Kiadó, GeoGebra, . . .).

During the research to be presented here, I used the interactive whiteboard for a "hybrid" presentation both for processing the new curriculum and for practice (A. Molnár & Muhari, 2007).

The difference between the methods can be expressed primarily in depth, frequency, and regularity. During the examination of the results, I used both quantitative and qualitative approaches.

"Retrieval-enhanced" and "ICT-supported" classes' achievements

I1) Based on the sixth-grade assessment test at the beginning of the year, there is no significant difference between the two classes. The average for Class B is 7.57, and 7.64 for Class A (deviation 0.07).

I2) Based on the mathematics grades of the first semester of the sixth-grade, the knowledge of mathematics in the two classes is the same. Class B averages 7.25, and Class A averages 7.18 (deviation 0.07).

I used the results of the O1, O2 and O3 output measurements to compare the progress of the retrieval-enhanced and increased ICT-supported classes.

I examined the reorganization of the two classes according to achievement by comparing sixth-graders' 2nd semester and 1st semester mathematics grades (O1 output measurement). To analyze individual changes, I divided the students into groups with weak (below 34%), medium (34-66%), and good (above 66%) performance using terciles. Figure 4 shows the individual categories and their rearrangement.

		number of persons		
		weak	medium	good
ICT class	1. semester	0	15	7
	2. semester	3	14	5
Retrieval-enhanced class	1. semester	4	15	8
	2. semester	1	18	8

Figure 4. Performance distribution before and after the pedagogical intervention

It can be seen that at the beginning there were students in the middle and good categories in both classes.

In the ICT class, there was no weak performance in the first half of the school year, but at the end of the year, three were placed in this category at the expense of the medium and the good. ICT made demands on these 3 children that they could not meet. The shift toward repetitive learning can be found unaltered in the ICT class.

The categories have also been rearranged in the retrieval-enhanced class. The retrieval-enhanced learning method helped the weak, the number of medium ones increased, and the number of good ones remained unchanged. The method neither harmed nor benefited the good ones in terms of achievement.

The ICT class mastered the use of applied tools and programs beyond the curriculum, which gave them a surplus of knowledge that is not reflected in the results, and despite this, their academic results did not deteriorate significantly.

The fact that tests had to be written in every lesson in the retrieval-enhanced class did not interfere with the work in the mathematics class and the ability to perform.

In the common geometry knowledge assesment test (O2 output measurement), there is no significant difference between the performance of the two classes in terms of the solution of problems. (This is a homogeneous sample, so I performed a two-sample t-test, according to which the difference is not significant, p = 0.15).

A comparison of the percentage distribution of the tasks solved by each class is shown in Figure 5.

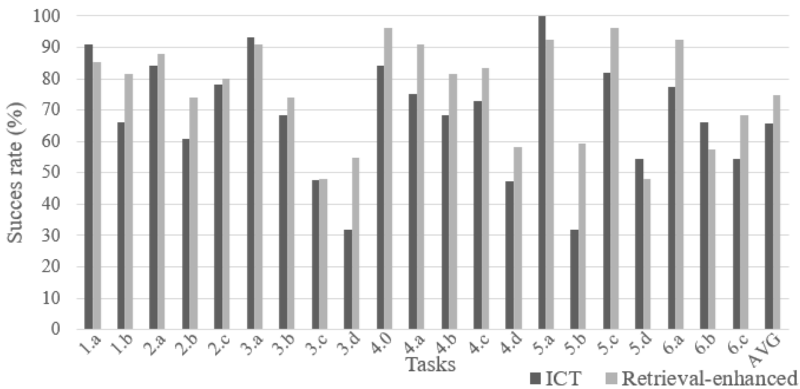


Figure 5. Comparing the solution of the tasks in the knowledge assessment test, divided by task

Of the 20 items, there were five (1.a, 3.a, 5.a, 5.d and 6.b), in which the ICT class performed better than the retrieval-enhanced one (see Figure 6 for differences). In the analysis, I only explain these.

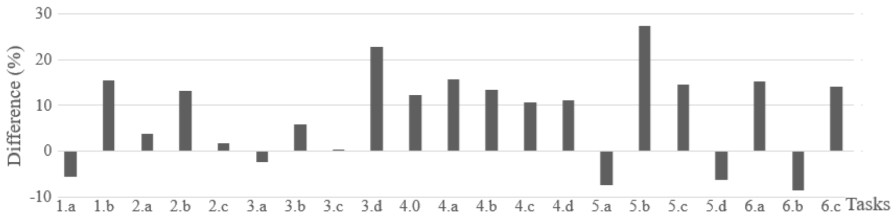


Figure 6. The difference in the solution of the tasks in the knowledge assessment test, divided by task

In part 1.a, the task was to construct a straight line corresponding to several interconnected conditions for concurrency (passing through a certain point, parallel, of a given color). The steps required to solve this task were learned by the ICT class as shown in Figure 7. The two transparent rulers were visible on the image, I only made them invisible to show the final result.

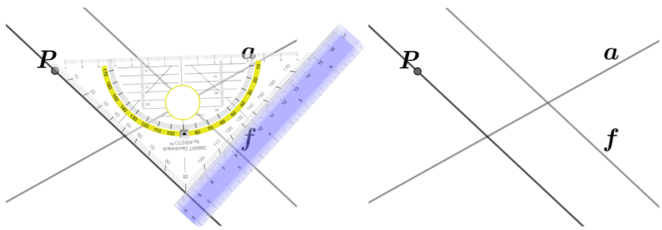


Figure 7. Illustration of the solution of Task 1.a) on a Smartboard

I see the difference between the effectiveness of the two methods in the fact that the "traditional" teacher's ruler and the student's ruler used in the retrieval-enhanced class are very different. Identification, the distinction between the roles of straight and rectangular rulers, was made difficult by the fact that the two rulers were of the same color. In the ICT class, the procedure shown on the Smart Board was more visible, making it clearer which ruler goes where and what to look for when positioning it. This difference was particularly evident in the case of parallel drawing.

Task 3 and its solution are shown in Figure 8.

There was no significant difference in task parts a), b), c), and in part a), the performance of the ICT class improved a bit. I believe that the concrete-manipulative illustration helps to interpret a complex diagram more effectively, as evidenced by the relatively high score of the retrieval-enhanced class in Task 3.d).

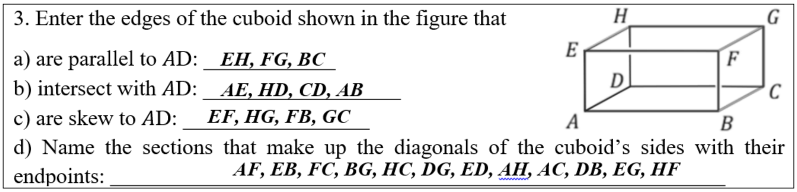


Figure 8. Task 3 and its solution

Despite the fact that, based on the overall results of Task 5, the "retrieval-enhanced" class is approx. 7% better, in addition, part 5.b) showed the largest difference for the whole test, yet the ICT class achieved better results in parts a) and d).

A situation-specific graph had to be analyzed. In parts a) and c), the corresponding values had to be read from the horizontal axis, while in parts b) and d), the corresponding values had to be read from the vertical axis. The scoring was performed according to the method of competence measurement used in Hungary. In part a), I gave the point even if the time spent on the train and the rest were given separately by the student. Concerning answers to d), it was awarded if the student calculated correctly with the wrong answer given in part b). The expected solution to the task is shown in Figure 9.

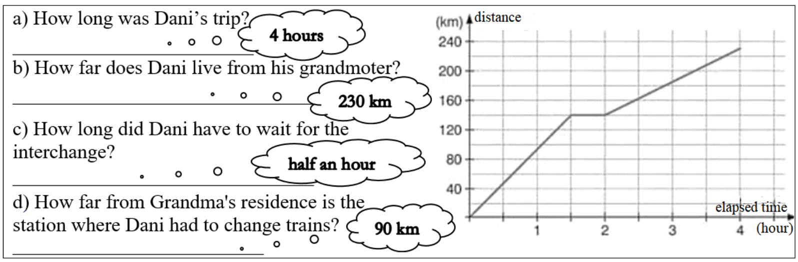
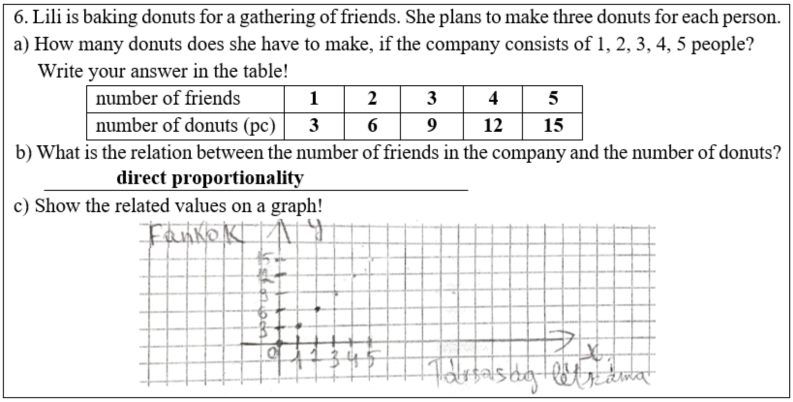


Figure 9. Task 5 and its solution

In part a), the students of the examined classes successfully read the requested data from the graph (ICT 100%, retrieval-enhanced 92.59%). From the answers given in part b) in the ICT class, it can be seen that everyone understood the task and read the distance and step intervals well from the appropriate axis, but 15 students did not realize it's not being a grid point. The discrepancy was considered an inaccuracy in the image and an integer was given. The fact that the value was usually read from the y-axis could be confusing in this task, and both directions were included. On ICT tools, there is not as much difference between the two axes, the coordinate system looks more accurate than in a booklet, worksheet, or book, even if the book's coordinate system is projected. As a result, the label and layout of each axis receive less attention than necessary. In part c), reading the waiting time proved easy with a solution rate above 80% in both classes. In part d), a change of perspective and a backward conclusion are required to determine the remaining section. The Smart Board seems to use reversal of operations and thought (the so-called 'crab method').

Task 6 and its solution by a student are shown in Figure 10.



6. Lili is baking donuts for a gathering of friends. She plans to make three donuts for each person.

a) How many donuts does she have to make, if the company consists of 1, 2, 3, 4, 5 people? Write your answer in the table!

number of friends	1	2	3	4	5
number of donuts (pc)	3	6	9	12	15

b) What is the relation between the number of friends in the company and the number of donuts?

direct proportionality

c) Show the related values on a graph!

Figure 10. Task 6 and a student's solution

The result of the ICT class was better in part b) of Task 6 as well. Here, I expected the students to describe the relationship between the quantities in the task. ICT encourages students to express their thoughts, and, in an environment supported by an interactive whiteboard, students were more actively involved in classroom dialogues, which was also reflected in the responses. In the "retrieval-enhanced" class, several students did not complete this assignment.

In part a) of Task 6, the solution rate of both classes is high, but both the finding of the related quantities and their depiction in a table (6.a) and on a graph (6.c) were more successful in the "retrieval-enhanced" class.

The average of the "ICT-supported" class in the end-of-topic test was 65.54%, and the average of the class with the "retrieval-enhanced" learning method was 74.55%. The difference between the two Transcarpathian classes is 9.01%, which according to the results of the two-sample t-test is not a significant difference;

it is only a tendency. The effect of the "retrieval-enhanced" learning method is more favorable for most of the tasks.

The Transcarpathian and Hungarian students' achievements

At the end of the research, we compared the performance of two Transcarpathian 6th-grade classes and a Hungarian primary school 7th-grade class on the basis of the same test (O3 output measurement).

Although the Hungarian class had a slight advantage due to the higher number of mathematics lessons, their performance is still a good comparison basis for evaluating my classes. On the other hand, Hungarian students in Transcarpathia compare their performance with that of Hungarian children in Hungary, which makes it completely natural if we do the same. As the curriculum and requirement level of the 7th grade of Hungarian primary schools and the second grade of the Transcarpathian secondary schools are close to each other, the performance of the students can be compared. According to the teacher, Eszter Rózsahegyi, Hungarian students studied the curriculum in a similar way.

Figure 11 illustrates the solution distributed by class and task.

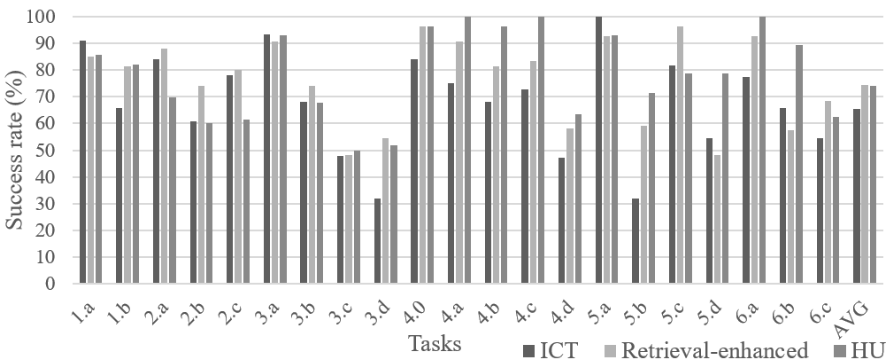


Figure 11. Solutions of the problems of the geometry test

Surprisingly, the performance of the "traditional" Transcarpathian 6th-grade and the Hungarian 7th-grade classes with an increased number of lessons correlate in a relatively large number of instances. The result of the 6th-grade class in Transcarpathia was not worse than that of the 7th-grade class taught with the Hungarian "traditional" method, there was no significant difference between the two classes.

It can be concluded that the classes are the same not only in terms of comparability, but also in terms of effectiveness.

Factors hindering the success of the research

According to Csíkos, a sample size of between 50 and 100 people can be recommended as the number of student groups for empirical pedagogical studies (2004, p. 199). However, due to the minority environment, the number of Hungarian schools, and therefore also the number of classes participating in the research, is low.

The ICT infrastructure in Transcarpathia has prevented modern devices (tablets, smartphones) from being integrated more organically into the learning-teaching process. A significant barrier to the use of existing ICT tools and educational software is that they are available limited in time. For example, the homework given as part of the scheduled retrieval could be better placed at the service of the learning process by digitizing the worksheets, setting interactive worksheets, and submitting the solutions electronically, so that students could also receive personal feedback from the teacher. A serious obstacle in the implementation of this is students' uneven provision of devices and access to the Internet.

Summary

Based on the comparison, studying according to the method supported by the use of the interactive board and interactive teaching materials proved to be very useful for the students, regarding either the construction of concepts or the direct application of the definition. Using the interactive whiteboard requires a certain level of dexterity in addition to knowing the program (Csiba, 2019, p. 130), but, for example, the line will be infinite and will not be bent, or parallel lines will not intersect, which can be perceived by scrolling.

With ICT tools, it is easier to have a spectacular, interesting lesson, making sure that the teacher does not cover the board. Without ICT, it will take more effort to provide a sight comparable to ICT.

At the same time, the introduction of ICT support cannot be postponed. For example, the changes that occurred due to the worldwide coronavirus epidemic warned of this.

There are two misconceptions about the retrieval-enhanced learning method inspected during the research: the antidote to forgetting is repeated learning;

the time spent on tests of knowledge, retrieving, and questioning is wasted. I hope that with this article I will contribute to breaking them down.

In order for retrieval and testing to be a full part of the learning process, a change of attitude is needed both among teachers and students. Effective application of the retrieval-enhanced method requires appropriate timing, and questions and tasks to help build the knowledge network.

As the two methodological solutions examined (the retrieval-enhanced learning method and ICT) have different advantages, it is worth testing whether they can be used together. The retrieval-enhanced method can also be supported with ICT tools in the class with ICT support, which does not mean a loss of time or energy.

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