The ICT Usage in Teaching Maths to Children with Hearing Impairment

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Keywords: ICT, Mathematics Performance, Teaching Maths, Mathematical Skills of Students with Hearing Impairment, GeoGebra.

Abstract: The purpose of our research was the modification of teaching strategies of maths for deaf and hard-of-hearing learners. More specifically, we aimed to study the possibilities of optimal use of interactive exercises such as LearningApps and GeoGebra Dynamic Mathematics system in order to provide methodical and didactic support for training sessions, but also to assure independent study and implementation of monitoring activities. The developed visual materials for teaching children with hearing impairments were partially introduced into the educational process in a pilot project for the retraining of 12 school teams working with children with hearing impairments in Kryvyi Rih in educational strategies, for learning mathematics in grades 8-9 of an inclusive type for instructors teaching in a mainstreamed classroom with a mix of hearing, deaf and hard-of-hearing students (students 12-14 years old: $N = 80$ children with hearing impairments; data collected in 2019-2021). In the context of research goals the academic success (algebra, geometry), and mathematical skills of students were analysed. According to the study results, there was a significant increase in the mean score of performance after the intervention than before the intervention. In other words, this increase represents the effectiveness of ICT educational methods. Furthermore, we highlighted some recommendations for using online service LearningApps, GeoGebra Dynamic Mathematics system, and project-based learning technologies in Mathematics, in particular.

1 BACKGROUND CONTEXT

On review of the literature, researchers have stated that deaf and hard-of-hearing learners may lack general vocabulary and the fundamental mathematical vocabulary needed to be able to understand maths concepts/processes such as seriation and classification (Ariapooran, 2017; Barrett, 2005; Nunes and Moreno, 1999; Ray, 2001). It is more difficult for children who are deaf or hard of hearing to acquire the connection between language and maths concepts from their environment incidentally (e.g., from conversations with parents and games with friends about the counting of subjects). Without this type of natural learning, a child with hearing impairment cannot boost beginning maths concepts such as "more/less" or "one/a lot" etc. without educational support (Barrett, 2005).

That is why most children with hearing impairment (HI) have a gap of approximately three years behind their hearing peers in mathematics (Nunes and Moreno, 1999).

Despite the importance of communication with other people as the basis of maths skills, communication with children with hearing impairments may be problematic and poor. That is why these children cannot take part in studying mathematical processes such as problem-solving, developing logic and reasoning, and effectively communicating mathematical ideas without communication skills and maths vocabulary (Le Brun, 2022). Perhaps we can boost maths Ukrainian vocabulary for deaf and hard-of-hearing learners if we use Information and Communication technologies (ICT) for visualisation maths. This is a relatively new area of enquiry, with little research existing in the literature. The current research, therefore, aims to investigate if using ICT for study of maths becomes a booster and helps to improve children's performance on problem-solving tasks in maths, to predict and make observations based on the given information, which requires strong language skills and the ability to critically think.

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2 ANALYSIS OF PUBLICATIONS

The world standard of inclusive education strategy is based on the idea that students with special educational needs require support in getting key life competencies such as cognitive, non-cognitive skills, and "functional literacy" for independent life and socialisation (UNICEF, 2020). Particularly, the success of the students with hearing impairments in the targeted acquisition of these key maths competencies depends on class management, teaching approaches, and methods such as the universal design of learning or differential instruction with ICT (Global Education Monitoring Report Team, 2020). ICT is also a school subject in which students learn to use computers and other electronic equipment to store and send information (UNICEF, 2020).

According to a newsletter prepared by NORAD – Norwegian Agency for Development Cooperation and by AFD – Agence Française de Développement "Information and Communication A technology that supports the inclusion of children with disabilities in education" (National Deaf Center on Postsecondary Outcomes, 2020b). ICTs can support the inclusion of children with disabilities in education, allowing them to overcome some of the barriers that cause their exclusion. ICTs complement other face-to-face communication methods and tools such as teacher training and inclusive pedagogy (de Dinechin and Boutard, 2021). ICT is a tool for both an inclusive and gender-sensitive approach to education, which was introduced over the two years 2020-2022 during the transition to distance education due to COVID-19 pandemics (UNICEF, 2020).

In general, when teaching mathematics, ICT for deaf and hard-of-hearing learners can be divided into three main categories:

- educational content and digital media, the purpose of which is to convey lessons/skills to the student (for example, a learning video on stochastics with translation into sign language). An example would be the development of Best Practices at the Secondary Level of DeafTEC: Technological Education Centre for Deaf and Hard-of-Hearing Students (National Deaf Center on Postsecondary Outcomes, 2020b).
- Software that serves as an intermediary to make certain educational content/activities available (e.g., GeoGebra for geometry or LearningApps) (Rochester Institute of Technology, 2022a).
- Accessibility features that make the hardware accessible to everyone (e.g., software to convert maths problem text into sign language) (National Deaf Center on Postsecondary Outcomes, 2020a).

The main goal of the strategies of using ICT in inclusive education is designed to promote access to mathematics content based on the Standards of instructional strategies and should be based upon current and accurate information about the child's sensory functioning. Most researchers agree that access to appropriate ICTs can reduce differences in inclusive education, and deaf and hard-of-hearing learners must have access to ICT-based programs being a part of the schedule of school (Rochester Institute of Technology, 2022b). That is why digital inclusion in maths education as a process is a system of a student's empowerment through participation in education processes with ICT-programs (de Dinechin and Boutard, 2021); individual curricula of studying maths (Ray, 2001); providing reasonable accommodation of materials (Ray, 2001). However, despite the huge potential benefits of ICT usage in inclusive education, it only rarely worked in Ukrainian schools.

2.1 The Principles and Methods of Mathematics with the Instruction of Deaf and Hearing Students in Mainstream Classes

We need to highlight that for teaching deaf and hard-of-hearing learners, the same methods as for other children are used. However, the peculiarities of the psychophysical development of the students lead to other ways of applying these methods. In particular, the methods of teaching are remedial and developmental, and they stimulate deaf and hard-of-hearing learners to work independently and to take initiatives (Fritz et al., 2019).

The principles and methods of maths education in an inclusive class of the middle school are based on the determination of needs of deaf and hard-of-hearing learners:

Step one – to determine the current level of maths knowledge, communicative skills, and maths vocabulary of the children who are deaf or hard of hearing.

Step two – to determine the effective teaching style (visual, kinesthetic, poly-sensory and another one, especially if one of the styles dominates). For mainstream classes it is important to use multimedia approaches for a visual representation of maths course content (e.g., GeoGebra for geometry or LearningApps for particular stochastics is to achieve strong mastering of knowledge, the formation of practical skills to solve problems on the basics of combinatorics, probability theory, and mathematical statistics) (Kidd, 2018). Using LearningApps is especially important for students who are relying on speechreading for receptive communication as it reduces eyestrain. Also, there is an appropriate language model that can effectively provide not only the vocabulary to label objects but also a language model for expressing concepts and ideas, using the child's mode of communication in maths.

Step three – to identify specific aspects of the child's learning activities; where he or she needs outside help during the educational process. For example, use more than one mode of presentation for maths concepts. These may include manipulatives, verbal, gestural, pictorial, and symbolic modes. Encourage students to translate between modalities, particularly the language of mathematics, to make connections (Kollosche et al., 2019). For example, instructional strategies of using GeoGebra visualisation to provide an enriched learning environment that promotes a wide range of real world, meaningful mathematical experiences with opportunities for exploration and problem-solving in geometry. Initially introduce word problems as informal stories with maths facts through dramatization, using pictures, drawings, and manipulatives, and then translating the action into a maths sentence. Students can use images, objects, and visualise or pantomime the action in a problem to move from the concrete to more abstract representations of the problem.

2.2 Methods of Maths Teaching to Children with Hearing Impairments

There are specific methods of class management and teaching where children with hearing impairment (Kidd, 2018; National Deaf Center on Postsecondary Outcomes, 2020b; Nunes and Moreno, 1999; Ray, 2001; Singh, 2019). Firstly, teachers need to use alternative forms of communication and the strategy of studying maths based on non-verbal intelligence and competences (seriation, analogy, systematisation) (Fritz et al., 2019). The adaptation of the education maths content to the cognitive abilities of the students for children with HI, this is the removal of complex verbal material.

Secondly, it is visual learning. Taking into account the specificity of the HI, the types of showing objects are additionally selected. For example, for children with hearing impairment, the visual manuals should be specific, with details that concentrate on the perception of main things. The teacher needs some tips for classroom management: slowing down the educational process. Communication of the information for deaf and hard-of-hearing learners is carried out with consideration of the slower perception of the verbal information. For deaf and hard-of-hearing learners, more time is given to think about the answer (Kidd, 2018).

Thirdly, repeatability in teaching. The repetition variability should be used to fill the gaps in the perception of children with hearing impairment especially if we use ICT (Kidd, 2018). The optimization of the work pace and fatigue dynamics of deaf and hard-of-hearing learners. This tool is aimed at activation of the students' cognitive activities, support of their ability to work and includes, in particular: switching the students to different types of activities to prevent fatigue (gamification, visualisation, modelling, extrapolation examples in classroom space); using interesting facts, examples, and details in the process of presentation of the material; emotional presentation; organising the minutes of rest at the lessons; creating success situations for the deaf and hard-of-hearing learners (Shestopalova et al., 2019). Conceptually, difficulties of deaf and hard-of-hearing learners in middle school in maths class depend on the expression of disorders and manifest themselves in the following areas: fundamentally, it's understanding of spoken language and formation of active speech (Barrett, 2005).

Generally, the main purpose of studying maths is the formation of verbal-logical thinking children with HI and well as the formation of the auditory-visual-tactile perception of mathematical concepts (child with HI asks questions to clarify details; makes decisions on the use of approaches and materials learned earlier; can explain decisions and establish logical connections; knows how to systemize features; plans activities) (Rochester Institute of Technology, 2022a; Kidd, 2018).

3 CURRENT RESEARCH AND HYPOTHESIS

We have a goal of comprehensive estimation of if using ICT for the study of maths became a booster and helps to improve HI children's performance on problem-solving tasks in maths and their ability to predict and make observations based on the given information, which requires strong language skills and the ability to critically think.

Learning difficulties in this category of children are related to speech delay and specific problems in conceptual and figurative thinking (Barrett, 2005). In particular, the peculiarity of the formation of visual-action thinking is that it occurs almost without speech, which makes it imperfect and does not contribute to the transition to the visual image level. In turn, the formation of formal-logical thinking is also difficult

(Le Brun, 2022).

That is why the purpose of our research is the modification of teaching strategies for deaf and hard-of-hearing learners. More specifically, we aim to study the possibilities of optimal use of interactive exercises such as LearningApps and GeoGebra Dynamic Mathematics system in order to provide methodical and didactic support for training sessions, but also to assure independent study and implementation of monitoring activities. Consequently, some aspects of the problem of teaching maths to students with hearing impairment can be eliminated through the use of ICT as a provider of training materials through adapted, assistive devices, information and communication technologies, and support. However, there are some problems with ICT for children with hearing impairment. ICT as a provider of training materials adapted for maths teaching to deaf and hard-of-hearing learners is not firmly established and needs further research and testing.

The research question that guided the present study was: does ICT boost the maths skills of hearing impaired teenagers? The current research hopes to extend on the work of previous research by investigating that all three methods LearningApps, Geogebra, and STEM boost maths skills.

4 METHOD

4.1 Design

The design of the study includes a model of ICT application and the impact of effective inclusive education strategies and methods on the process of learning mathematics for children with hearing impairment. The study utilised a within subject design with one IV (intervention: pre vs post) and the DV being the maths performance (as outlined in the Materials section).

4.2 Procedure

The study consists of three stages:

The first stage was to collect data for diagnosing the level of mathematical abilities by analysing the level of spatial thinking of the Raven's Progressive Matrices (Raven, 2020), Rey-Osterriet Composite Figures Test (ROCF), Gottschaldt's Hidden Figure Test (GHFT) and the educational achievements in algebra and geometry of potential ICT users (students with hearing impairments). Purpose: at this stage, information was collected on the level of performance of a sample of students with hearing impairments, and their spatial skills were analysed using diagnostics.

The second stage consisted of an analysis of existing ICTs for teaching mathematics (algebra and geometry) classes, their usefulness, limitations, requirements, etc., which served as the basis for reflection in the analysis stage. Purpose: to study the possibilities of optimal use of interactive exercises LearningApps and the GeoGebra dynamic mathematics system for methodological and didactic support of training sessions, independent study, and control activities.

The third stage is the processing and analysis of data in order to make recommendations on the appropriateness of using ICT technologies in schools in Kryvyi Rih (taking into account the usefulness of ICTs, their cost, ease of use, impact on school inclusiveness, etc.). In addition, the main problems in the implementation of ICT and inclusive education programs were identified and recommendations were given.

4.3 Participants

Implementation of ICT programs in educational strategies signed in USL and voiced for learning mathematics in grades 8-9 of an inclusive type for instructors teaching in a mainstreamed classroom with a mix of hearing, deaf and hard-of-hearing students.

Table 1: Demographics of the sample ($N = 80$, mean age = 12.5; SD = 1.06).

Total of the Year	deaf students	hard-of-hearing students
2019 ($N = 30$)	8	22
2020 ($N = 21$)	6	15
2021 ($N = 29$)	10	19
Total	24	56

Overall, 80 participants took part in the study (40 females, 40 males; mean age = 12.5; SD = 1.06). Thirty participants were deaf from birth and 70 with hearing loss in early childhood (on average diagnosed at the age of 3; SD = 1.5). Tables 1, 2 present the detailed demographics of the sample.

Table 2: Demographics of the sample ($N = 80$, mean age = 12.5; SD = 1.06).

Mainstream class (N)	Special class (N)
24	56

There was no significant difference in intelligence score between different educational levels, $F(5.49) = 2.46$; $p = .05$. Participants were recruited through the Department of Education and Science of the Executive Committee of the Kryvyi Rih City and advertising in Non-Governmental organisations.

The work of the research team was aimed at developing a concept for supporting inclusive mathematics education in Kryvyi Rih in cooperation with the Department of Education and Science of the Executive Committee of the Kryvyi Rih City Council and Kryvyi Rih State Pedagogical University. The developed visual materials for teaching children with hearing impairments were partially introduced into the educational process in a pilot project for the retraining of 12 school teams working with children with hearing impairments in Kryvyi Rih using STEM methods and in the course of the Suziriya Mathematical Multidisciplinary Educational and Rehabilitation Centre for children with hearing impairments in 2019-2021.

4.4 Materials

4.4.1 Academic Success

In the system of Ukrainian education, educational success is assessed by summing up current grades in the classroom, and test works on the topic on the basis of a 12-point scale (max 12). The rating of grades is available to all students in the class. In the context of conducting mathematics lessons (algebra, geometry), the mathematical skills of students were analysed.

4.4.2 Stereotype Threat

For our study, situational factors that increase stereotype threat may include expectations of difficulty in maths, and the expectation of discrimination due to one's identification with a negatively stereotyped group of children with special educational needs. To reduce the repetitive experience of stereotype threat in teaching mathematics using ICT, we used a preliminary diagnosis of the Rey-Osterriet Composite Figures Test, the Raven's Progressive Matrices and the Gottschaldt's Hidden Figure Test, followed by the identification of the level of mathematical spatial abilities, the level of intelligence. To anticipate a decline in maths learning confidence, poor performance, and loss of interest in the relevant area of achievement, we pre-reported individual scores to students, emphasising that they did well on tests and that their spatial ability was sufficient for maths learning.

4.4.3 Raven's Progressive Matrices

Standard Progressive Matrices (RSPM) a classic study using this test contains numerous motors used for various purposes. RPM is a non-verbal test typically used to measure general human intelligence and abstract reasoning and is regarded as a non-verbal estimate (Raven, 2020). The Raven Progressive Matrices test is one of the non-verbal intelligence tests and is based on two theories developed by Gestalt psychology: the theory of form perception and the so-called "neogenesis theory" by Charles Spearman (Lovie, 1983). Raven's matrices can be applied to subjects with any linguistic composition and sociocultural background, with any level of speech development. We used several algorithms for the psychological interpretation of the results obtained: the definition of intelligence according to the percentage scale; the translation of the obtained results into an IQ-indicator (Raven, 2020).

4.4.4 Gottschaldt's Hidden Figure Test (GHFT)

This test measures figure-ground discrimination abilities. A participant is asked to look at 30 masked figures to find one of the 5 reference figures. Masked figures are presented in turn, it is necessary to record the total time of the task by the subjects. An example was given before starting the technique performing the exercise with the correct answer for children with hearing impairments to be sure that they understand the text of instruction. Calculation of results obtained by respondents according to the method "Figures of Gottschaldt" was carried out according to the formula:

$$I = \frac{N}{T},$$

where I – index of field dependence or field independence; N – the total number of points (correctly completed tasks); T – time to complete all tasks in minutes.

4.4.5 Rey-Osterriet Composite Figures Test (ROCF)

Rey-Osterriet Composite Figures Test (ROCF) is a neuropsychological technique, in which a participant is asked to paint an image (subtest 1), and then paint it from memory (subtest 2). The test figure itself (shown in the figure) is made up of 18 elements, which can be divided into three groups: the head form, the outer elements, and the internal elements in the head form. The technique allows for the development of memory, deep-space functions, and deep-constructive habits. It is significant that this test is included in the international list of tools for assessing cognitive dysfunctions in neurology.

All tests have traditionally been used as psychometric methods to assess factors of intelligence and/or disturbances in spatial perception. Through their combined use, researchers were able to obtain an integrative assessment of using ICT for the study of maths that became a booster and helps for problem-solving tasks in maths for a child to predict and make observations based on the given information, which requires strong language skills and the ability to critically think. Thus, it becomes possible to effectively identify the problems and opportunities for using ICT.

4.4.6 Criteria for Assessing the Academic Performance

The results of the e-learning course were examined to make judgments on students' academic performance. In such a manner, in case of the absence of mistakes in Gottschaldt's Hidden Figure test, the child's performance was rated as high. If one or two mistakes were made, the performance was deemed moderate. More than two mistakes corresponded to low academic attainment. The analysis of Raven's test results used several algorithms for the psychological interpretation of the results obtained: the definition of intelligence according to the percentage scale; translation of the obtained results into an IQ. When conducting Rey-Osterriet Composite Figures Test (ROCF), the level of student's visual and spatial thinking was determined high if the head form, the outer elements, and the internal elements in the head form without errors; average if the child was unable to copy form and details without mistakes; and low if no tasks were completed successfully.

4.5 Intervention Methods

The intervention lasted for each grade selected by the researchers (8th and 9th grade of high school) for two academic years (October to May) of online learning under quarantine restrictions during the COVID-19 pandemic. The intervention was carried out by integrating the ICT programs described in the article into the methodology of teaching mathematics by teachers and modifying the curriculum by the general school support team (teacher's assistants, psychologists, and parents).

An example of adapted and modified planimetry curricula for students with hearing impairments (Geometry, grade 8-9):

- Topic 1 (28 hours). Quadrilaterals. Quadrilateral, its elements. The sum of the angles of a quadrilateral. Parallelogram, its properties and signs. Rectangle, rhombus, square and their properties. Trapeze. Inscribed and circumscribed quadrilaterals. Inscribed and central corners. Thales' theorem. The middle line of a triangle, its properties The middle line of a trapezoid, its properties.
- Topic 2 (14 hours). Similarity of triangles. Generalized theorem of Thales. Similar triangles. Signs of similarity of triangles.
- Topic 3 (22 hours). Polygons. Areas of polygons. Polygon and its elements. Convex and non-convex polygons. The sum of the angles of a convex polygon. Inscribed and circumscribed polygons. The concept of the area of a polygon. Main properties of areas. Area of a rectangle, parallelogram, triangle. The area of the trapezium.
- Topic 4 (20 hours). Solving right triangles. Sine, cosine, tangent of an acute angle of a right triangle. Theorem of Pythagoras. Perpendicular and inclined, their properties. The ratio between the sides and angles of a right triangle. The value of sine, cosine, tangent of some angles. Solving right triangles.
- Topic 5 (4 hours). Solving triangles. Sine, cosine, tangent of angles from 0° to 180°. Basic trigonometric identity, reduction formulas.
- Topic 6 (16 hours). Cartesian coordinates on the plane. Coordinates of the middle of the segment. Distance between two points with given coordinates. The equation of a circle and a straight line.
- Topic 7 (20 hours). Vectors on the plane. Vector. Modulus and direction of the vector. Equality of vectors. Coordinates of the vector. Adding and subtracting vectors. Multiplication of a vector by a number. Collinear vectors. Scalar product of vectors.

4.5.1 Online Service LearningApps Usage for Teaching the Students with HI

Based on the conducted research the authors developed the teaching aid (Kramarenko, 2019). The first part covers general guidelines for teaching pupils with special educational needs using ICT and means of remote technologies. The second section focuses on the usage of LearningApps online training. The teaching aid provides both references on worked out exercises and QR codes which are generated through the service. The use of a variety of online resources, including online services and learning environments, is becoming increasingly popular. One of the prime examples of such environments is the LearningApps multimedia didactic exercising service (https://learningapps.org/). It is intended for the development, storage, and usage of interactive exercises in the educational process. Such exercises can be applied not only on a lesson with an interactive whiteboard but also as individual tasks for students with special needs (figure 1). A significant advantage of this service is the ability of task integration into Moodle LMS.

The educational aim of using interactive exercises of the LearningApps service in the study of Mathematics and in particular stochastics is to achieve strong mastering of knowledge, the formation of practical skills to solve problems on the basics of combinatorics, probability theory, and mathematical statistics, to show the connection between stochastics and real life and to teach students to carry out non-typical tasks.

4.5.2 Using GeoGebra in Mathematics Teaching

For the use of GeoGebra Maths Apps (Kramarenko, 2019) mathematics teachers are offered several visuals for visualisation of geometric constructions, the hypothesis concerning the properties of geometric figures, and the proof of theorems. GeoGebra Dynamic Mathematics (https://www.geogebra.org/) visuals include the usage of mobile phone applications such as Geometry, 3D-Calculator, Graphing Calculator, and the visuals demonstrating stochastic experiments in the teaching of probability theory and mathematical statistics.

It is extremely positive that using both of the above-mentioned services allows students to collaborate in the offered virtual classes (Google Classroom). These features have recently appeared. And they can play a significant role in socialisation, especially for deaf and hard-of-hearing learners. As our research has shown, Mathematics teachers practically do not use them in their work. Partly because of a lack of competence in this matter.

GeoGebra has become the leading provider of dynamic mathematics software, supporting science, technology, engineering, and mathematics (STEM) education and innovations in teaching and learning worldwide. We consider it reasonable to use the GeoGebra Maths Apps in teaching deaf and hard-of-hearing learners. The authors offered a mathematics teacher a teaching guide and tasks for students to use GeoGebra in teaching Planimetry and Stochastics. In particular, the use of built-in functions for calculating the values of combinatorial compounds, testing using GeoGebra and examining electronic visuals that simulate accidental events by Sada (Sada, 2021).

To present an experiment demonstration, a teacher can use the GeoGebra dynamic Maths program. In an exercise developed by a teacher in advance, a student will be able to simulate a large number of bone tosses and monitor their results. In developing visuals that model accidental events, we used the ideas of Sada (Sada, 2021).

5 RESULTS

Data obtained before and after the intervention from groups were analysed using descriptive and inferential statistics (t test, and repeated measures ANOVA), by SPSS software version 17 at $p < 0.05$ significance level. Kolmogorov-Smirnov test determined whether the data were normally distributed ($p = 0.9$) and also homogeneity of variances with $p = 0.21$ was determined. Nonparametric statistics were used to describe qualitative sociodemographic characteristics of participants. T-tests were used to compute the mean scores and compare the maths performance before and after the intervention. This quasi-experimental intervention study aimed to evaluate the effect of using ICT in maths courses.

The results of this study are based on the data of 80 students with hearing impairments participating in the research. The mean and standard deviation of their age was 12.5 ± 1.06. In this study, deaf students' performance in relation to the subjects (geometry, algebra) was examined before and after the training using ICT in the maths course.

To reduce the repetitive experience of stereotype threat in teaching mathematics using ICT, we used a preliminary diagnosis of the Rey-Osterriet Composite Figures Test, the Raven's Progressive Matrices and the Gottschaldt's Hidden Figure Test, followed by the identification of the level of mathematical spatial abilities, the level of intelligence (table 3). In addition, children with hearing impairments are more (63) related to the field-dependent style (1.9 ± 0.13) according to the results of the Gottschild Figures and trust visual impressions more and hardly overcome the visible field when it is necessary to detail and structure the situation (table 3).

A pretest of students' maths performance indicated that all children had a poor performance in advanced geometry such that the mean total performance score of students in the intervention group before the training was 6.3 ± 1.08; algebra (6.23 ± 1.04) (table 4). Therefore, based on the independent t-test results, there was no significant difference between the mean pretest scores in groups 2019-2021. The assumption of equality of variances was also met (Levene's test $p = .920$). Descriptive statistics are presented in table 4. The highest and the lowest mean scores, obtained in various dimensions of the performance checklist after the intervention, were on the topics how the position of the center of a circle (9.2 ± 1.01) and learning about the concept of an event, an impossible, accidental, and probable event (8.6 ± 1.04), respectively.

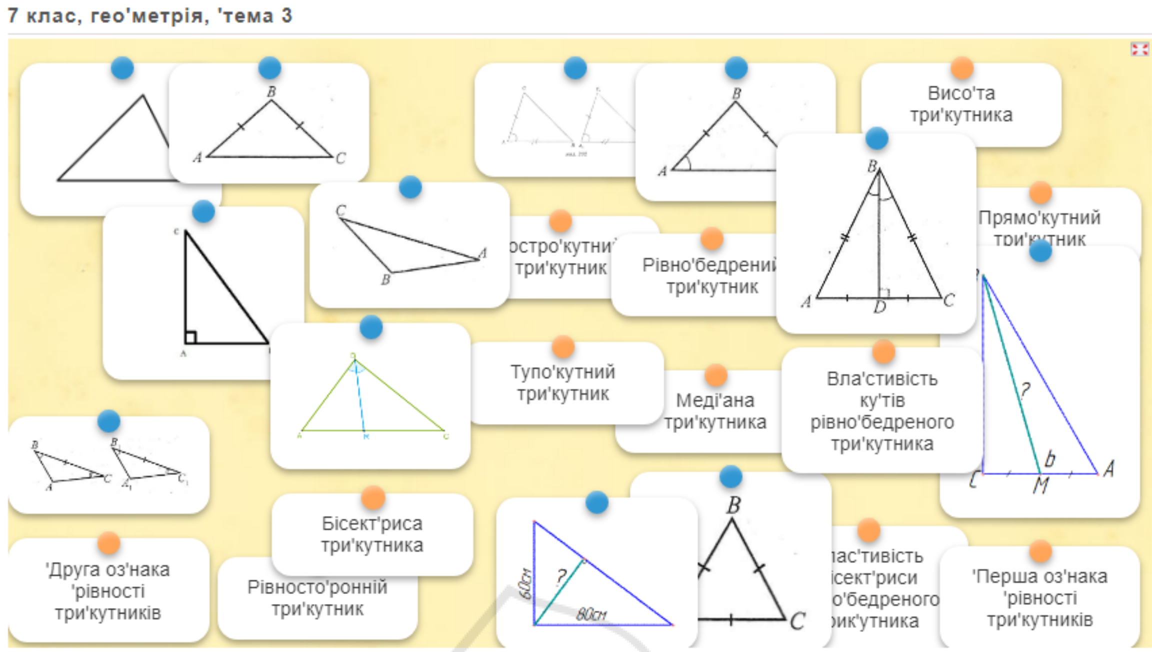

Figure 1: Geometry exercise for the topic “Triangles” (LearningApps software).

Table 3: Descriptive stats table of mean performance scores of students ($N = 80$).

Raven’s Progr. Matr.[ab]	Rey-Osterriet Comp. Figures Test[ac]	Figures of Gottschaldt[ad]
101.8 ± 6.43	8.1 ± 2.36	1.9 ± 0.13

*N*ote. [a] Data are presented as mean ± SD [b] IQ-index [c] Summary score of Copy Presence and Accuracy, Organization (According to BQSS (Le Brun, 2022)). [d] I index.

6 DISCUSSION

The research question investigated in this study was: does ICT boost the maths skills of hearing-impaired teenagers? The current research extended the work of previous research by investigating whether ICTs such as LearningApps, Geogebra can boost maths skills.

Previous research showed that most children with hearing impairment have a gap of approximately three years behind their hearing peers in mathematics (Rochester Institute of Technology, 2022b). Our participants before were known for their individual scores on Rey-Osterriet Composite Figures Test, the Raven’s Progressive Matrices, and the Gottschaldt’s Hidden Figure Test, emphasising that they did well on tests and that their spatial ability was sufficient for maths learning. This diagnostic was for the prediction of reducing the repetitive experience of stereotype threat in teaching mathematics using ICT.

According to the study results, there was a significant increase in the mean score of performance after the intervention than before the intervention. In other words, this increase represents the effectiveness of ICT educational methods. Furthermore, we highlighted some recommendations for using online service LearningApps, GeoGebra Dynamic Mathematics system.

6.1 Case Study – Example 1: Using Online Service LearningApps for Teaching the Children with HI

Let us demonstrate how LearningApps service interactive exercises can be applied at different stages of learning maths. For example, at the stage of learning about the concept of an event, an impossible, accidental, and probable event, it is reasonable to offer students an exercise to determine the type of event. The following events appear alternately in the exercise window. A student should determine which events are probable, which are impossible, and which are accidental.

Task 1. Determine “which” type is the event.

In this task, each word is stressed. It is reason-

Table 4: Comparison of mean performance score of students before and after intervention ($N = 80$).

Performance	Geometry	Algebra
Before intervention	6.3 ± 1.08	6.23 ± 1.04
After intervention	8.1 ± 1.9	8.2 ± 1.6
Paired t-test results (P, t)	0.001, 0.61	0.002, 0.21

able to introduce exercises to children with hearing impairment in such a way. In the following lessons, this exercise can be also used at the stage of refreshing students' basic knowledge on the topic.

Students with SEN may find it difficult to understand and memorise theoretical material, so it is best first to demonstrate examples of learned concepts and then return to the theory when necessary. For this purpose, it is reasonable to offer the students with special educational needs the opportunity to find a pair in the LearningApps online service during the initial consolidation stage. In the process of studying events operations, one should use as many examples as possible, reflecting not only the essence of these operations but also the differences between them.

Children with hearing impairment can easily find both the sum and value of events using definitions. So solving applied problems is important in this process. After students have mastered the theorems of adding incompatible events and multiplying independent events, they use them to calculate the probability of events, solving the corresponding problems.

Here are some other examples of tasks that can be conveniently created in LearningApps templates and used in Stochastics teaching.

Task 2. "Classification" exercise. The essence of this exercise is that the screen on the student's computer or mobile phone is divided into two fields: a right triangle and an isosceles triangle. Next, students are given definitions, properties, constituents, or examples of triangles to be referred to as a right triangle or an isosceles one. After completing the exercise, the student can "push" the button to the right from the bottom to check if the tasks are done correctly.

Task 3. "Classification" exercise. In figure 1 a screenshot of the 7th grade geometry exercise on the topic "Triangles" is presented (https://learningapps.org/display?v=p1gk6f39a22). The exercise is intended for students to repeat the types of triangles and consolidate knowledge on the signs of equality of triangles. A small number of words are used in the exercise. Stress is placed before the corresponding stressed syllables. Students must match concepts, names of theorems with corresponding pictures.

Task 4. "Match" Exercise. The essence of this exercise is that a student should connect the notion with its definition or example. For instance, the term "bisector" refers to the definition of a bisector of a triangle, to a certain notion corresponding to a picture that illustrates it, to calculate the perimeter of a triangle, if the lengths of its sides are given, etc.

The use of similar tests allows a teacher to determine the level of success of a child with hearing impairment and to identify gaps in his/her knowledge. It will help to correct his learning and to plan further work. For example, the possibility of repeated repetition of the exercises created with LearningApps will give students confidence. It will also contribute to better learning.

6.2 Case Study – Example 2: GeoGebra Dynamic Mathematics System

We have upgraded the set of visuals offered by Sada (Sada, 2021) to adapt it to students' learning in Ukrainian. For example, one of the exercises allows us to see changes and patterns in the process of any number of the tests carried out. The student can observe whether there is any tendency as the number of falls in a single number increases, and compare it with the number of falls in another number. Such activity in the lesson should be structured for a student with special needs in the form of clearly formulated actions, and algorithms for completing the task. Instructions should be brief and clear, repeated several times. It may be difficult for a student with disabilities to concentrate, so he or she has to be repeatedly urged to carry out, to control this process until its completion. The task should be adapted so the student has time to work at the pace of the whole class.

The task is complicated when the student is offered the following exercise: modelling and counting the results when throwing two, three or more dice and calculating the sum of the falling numbers, etc. By practising research on the tossing of two and three coins, it may be easier for the student to imagine the situation of tossing 4 coins and others. It gives a good result and use of the lessons of planimetry, the library of electronic visibility (Sada, 2021).

Task 5: How the position of the centre of a circle described around a triangle is related to the view of a triangle (figure 2).

It should be taken into consideration that the GeoGebra Dynamic Mathematics system can be installed on smartphones. So the children with hearing

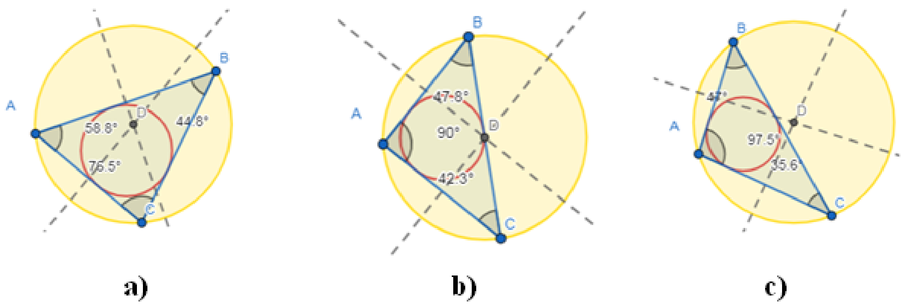

Figure 2: Investigation of the position of the centre described around a triangle of a circle (GeoGebra Geometry): a) an acute-angled triangle, b) rectangular, c) obtuse.

impairment will be able to check the correctness of their tasks during the lesson, especially when working independently or in groups. One can also start the exercise by using the link or QR code for the exercise. It is enough for the student to install a code scanner on his/her smartphone. One of these is the free Qrafter application, which allows you instantly to read QR codes using only your smartphone's camera and Internet access.

The use of GeoGebra in preparation for admission to higher education institutions provides ample opportunities for students with special educational needs. Using GeoGebra 3D Calculator, they will be able to develop spatial imagination, master the techniques of constructing spatial figures. A number of illustrations for solving problems of open type of external independent evaluation (EIE) are given by us in the manual (Kramarenko, 2019). Here are some of them in this article. These are two open-ended tasks with a detailed answer, which are evaluated by examiners according to special rules (EIE-2018).

Task 6. In a regular quadrangular pyramid SABCD, the side of the base ABCD is equal to c, and the side edge SA forms an angle a with the plane of the base. A plane c is drawn through the base of the height of the pyramid parallel to the plane ASD. Construct a section of the pyramid SABCD plane in, justify the type of section and determine its perimeter (figure 3).

By studying the function line, students will be able to use the GeoGebra Graphing Calculator to determine all possible solutions to an equation or inequality. This will provide visualization, help students better understand the process of solving such complex problems.

Task 7 (GeoGebra Geometry, grade 8-9). Construct an arbitrary convex quadrilateral. Investigate: a) the quadrilateral formed by the successive connection of the midpoints of this quadrilateral is a parallelogram; b) the area of the resulting parallelogram is half the area of the original quadrilateral (figure 4). Using the same visualization, it would be possible to investigate that the quadrilateral formed as a result of mapping an arbitrary point relative to the midpoints of the sides of the original quadrilateral is also a parallelogram. And therefore its area does not depend on the choice of a point inside. However, the substantiation of such a hypothesis goes beyond the mathematics curriculum for deaf children.

7 CONCLUSION

1. The conducted research proved the relevance of the problem of modifying the strategy of teaching mathematics to deaf and hard-of-hearing students based on the implementation of distance learning technologies. Studying the problems of teaching mathematics to deaf and hard-of-hearing students made it possible to draw the following conclusions: the most important task of a teacher and teacher's assistant is to encourage deaf and hard-of-hearing students to study; one of the effective ways of teaching mathematics to students of the specified categories is the use of remote technologies; in the text messages of visual aids offered to students with hearing impairments, it is advisable to emphasize each word so that they know how to read the words correctly.

2. We found that the LearningApps educational environment can be used at different stages of the lesson: during the organization of independent, individual activities, in joint research activities. Thanks to interactive exercises, deaf and hard of hearing students should become active participants in the educational process. The toolkit of the service allows you to create training classes, inviting them to your students by hyperlink. Since deaf and hard-of-hearing students put much more effort into the task, the system for evaluating the educational achievements of such students can be stimulating. After each student has completed

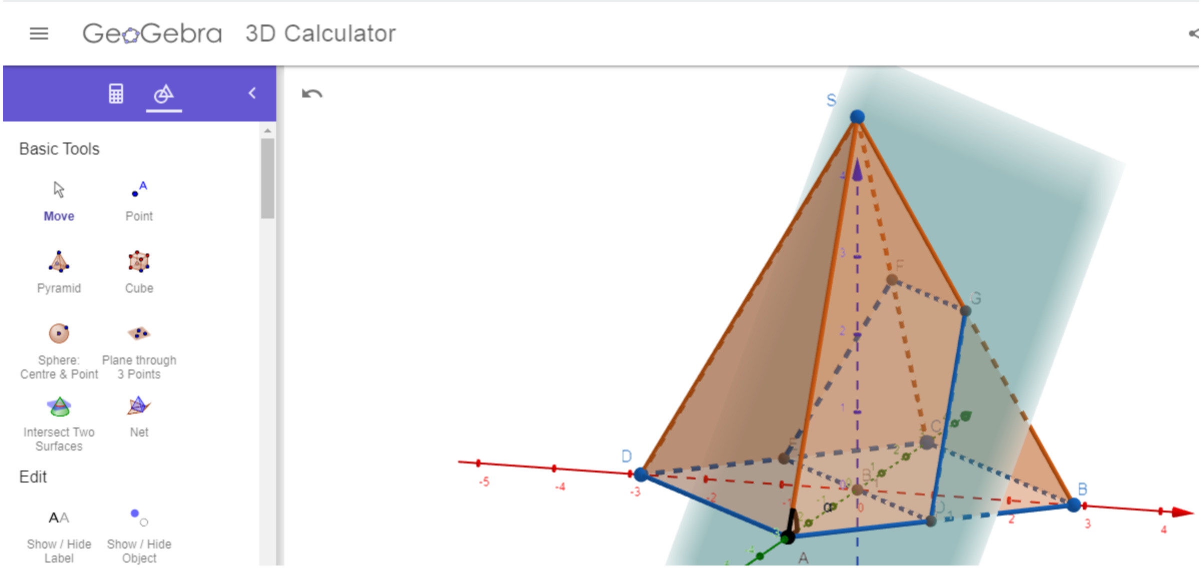

Figure 3: Examples of open-ended tasks (task 32 from EIE-2018 (https://zno.osvita.ua/mathematics/298/), GeoGebra 3D Calculator).

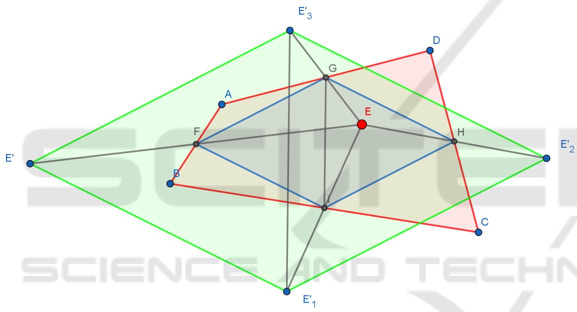

Figure 4: Studying the shape of a quadrilateral using GeoGebra.

each exercise, the teacher should analyze and compare the expected results with the actual performance of the students. A mandatory condition for teaching students with special educational needs in mathematics is feedback: to find out whether students are satisfied with their work and the knowledge they have acquired, whether they understand the importance of this knowledge for further study of the subject.

3. Using the proposed clarifications will help a student with hearing impairments to better understand mathematical material. Therefore, the student receives complete information if it is supported by visual perception of the text, tables, diagrams.

4. In order to investigate progressive shifts in the learning of mathematics by deaf and hard of hearing students using ICT, it is appropriate to compare the shifts in the scores of the diagnostic test and the test. Statistical groups can be analyzed by two G-tests and Wilcoxon tests. These algorithms involve the use of small sample sizes. So we used it and tested it for individual academic groups. We observed a trend of increasing values of the characteristic (scored points) from the initial training exercises to the control of the achieved level of knowledge and skills.

The prospects of the research are related to the expediency of using the GeoGebra dynamic mathematics system for the development of spatial imagination and spatial thinking, etc., in children with hearing impairments.

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